International Conference on Hydrology and Climate Change in Mountainous Areas

November 15-17, 2008

PROCEEDINGS

Society of Hydrologists and Meteorologists - Nepal
Department of Hydrology and Meteorology
United Nations Educational, Scientific and Cultural Organization

International Conference on Hydrology and Climate Change in Mountainous Areas

November 15-17, 2008, Kathmandu, Nepal

Organized by

Society of Hydrologists and Meteorologists
(SOHAM-Nepal),
Department of Hydrology and Meteorology
(DHM-Nepal),
and
United Nations Educational, Scientific and Cultural Organization
(UNESCO)

Society of Hydrologists and Meteorologists – Nepal

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PREFACE

Changes in the environment have been worrying issues to the scientific communities and planners. In order to open forum in these topics, Society of Hydrologists and Meteorologists–Nepal. (SOHAM-Nepal), Department of Hydrology and Meteorology (DHM–Nepal), and UNESCO with support from several organizations like IHP-Nepal National Committee, Real Time Solutions Pvt. Ltd., RECHAM Consult (Pvt) Ltd., The Small Earth Nepal, and National Trust for Nature Conservation jointly organized an International Conference on **"Hydrology and Climate Change in the Mountainous Areas"** on 15-17 November 2008 in Kathmandu, Nepal.

With an aim to address on reviewing the available technology in the field related to climate change and its impact on snow, glaciers and hydro-meteorological processes, assessment of the impact of sediment on water resources, environment, biodiversity and socio-economy and to look for a mechanism for research and capacity building on understanding of hydrological system of mountainous areas, the conference focused on the main themes of (1) climate change impacts and adaptations, (2) sedimentation and mass wasting, (3) snow and glacier hydrology, (4) floods in Nepal, (5) water induced disaster management, (6) hydrological extremes and early warning systems, (7) hydrological modeling, and (8) climate change & biodiversity. The conference was held in the Everest Hotel, Baneshwar in Kathmandu, the Capital city of Nepal.

There were eight technical sessions along with another special presentation on Planning Urban River Conservation in the Himalaya: Learning from Bagmati River Action Plan. Nine papers were presented on 15 November 2008, fifteen on 16 November, and twelve on 17 November. An abstract volume was published and circulated in the conference.

The Organizing Committee consisted of SOHAM-Nepal Chairman Mr. Kiran Shankar Yogacharya as the Conference Convener, and Director General Mr. Nirmal Hari Rajbhandari of DHM as the Co-Chairman, with another 19 members. Mr. Jagat K. Bhusal of DHM was the Member-Secretary of the Organizing Committee. Among the members were Mr. Dhiraj Pradhananga, the General Secretary, SOHAM-Nepal and the Chairman of the Small Earth Nepal. Scientific Committee was headed by Prof. Dr. Suresh Raj Chalise with Academician Dr. Madan L. Shrestha and Prof. Dr. Bidur Prasad Upadhyay as the Co-Chair persons with additional eight persons as the members of the committee and seven international members. The Advisory Committee consisted of Mr. Adarsha P. Pokhrel as the Chairman and Prof. Dr. P. K. Jha as the Co-Chairman along with other eight members of this committee.

The inaugural session was held on 15 November 2008. The Chief Guest was the Hon. Minister Bishnu Prasad Paudel, Ministry of the Water Resources, GoN. In his inaugural address, he expressed his concerns on the global warming impacts on the fresh water resources of Nepal that are creating challenges for economic development, emphasized the importance of the conference on hydrology and climate change on mountainous areas, and also pointed out the need for making the public aware of the climate change issues including adaptation measures.

The Keynote Address was delivered by Dr. Siegfried Demuth, UNESCO. The session was chaired by the SOHAM-Nepal Chairman Mr. Kiran Shankar Yogacharya. The welcome address was given by Mr. Adarsha P. Pokhrel, Chairman, Nepal National Committee for International Hydrological Programme (IHP), and the vote of thanks by Mr. Nirmal Hari Rajbhandari, Director General, Department of Hydrology And Meteorology, Government of Nepal.

The closing session was on 17 November 2008, and was chaired by the SOHAM-Nepal Chairman Mr. Kiran Shankar Yogacharya. The Chief Guest was Hon. Minister Ganesh Shah, Ministry of Environment, Science and Technology, GoN. In his closing address, he expressed that the management of water resources is becoming increasingly complex in the changing global climatic

situation, emphasized the importance of the scientific knowledge of interactions between climate and hydrological processes for effective design and implementation of adaptation strategies, and expressed his ministry's commitment to work with the international community to better understand the climatic processes and adapt to increasing uncertainties. He appreciated the initiation taken to strengthen the mass balance measurements in key glaciers in Nepal, and expressed his sincere thanks to UNESCO's team, who has been collaborating with the Government of Nepal.

The Conference Summary was presented by Mr. Dhiraj Pradhananga, General Secreatary, SOHAM – Nepal. Remarks from participation were made by Prof. Dr. M. Shoshany, Geo-Information Engineering, Faculty of Civil & Environmental Engineering, Israel Institute of Technology, Israel, and Dr. P. C. Jha, Institute of Engineering, Tribhuvan University, Nepal. **Kathmandu Declaration 2008** was presented by Mr. A. P. Pokhrel, Chairman, IHP-Nepal National Committee, and was well adopted by the session. The Closing Remarks were given by the Chairperson Mr. Kiran Shankar Yogacharya, Chairman, SOHAM-Nepal. The Vote of Thanks was given by Mr. Jagat Kumar Bhusal, Member Secretary, Organizing Committee, and Vice-Chairman, SOHAM-Nepal.

We, hereby, express our thankfulness to all the organizers, sponsors, volunteers, presenters, session chairpersons, rapporteurs, and other active individuals and organizations for their best efforts and practical supports to make the international conference on hydrology and climate change in the mountainous areas successful.

We would like especially to express our cordial thanks to Dr. Siegfried Demuth, Dr. Georg Kaser, and Dr. Bhanu R. Neupane, from UNESCO, for their invaluable contributions in giving keynote addresses and assuming the roles of chairpersons in some important technical sessions, and also in providing their most helpful guidance and suggestions for the smooth and successful conduction of the conference.

Mr. Nirmal Rajbhandari, the Director General of the Department of Hydrology and Meteorology, GoN, and Mr. Adarsha Prasad Pokhrel, the Chairman of the IHP Nepal National Committee, deserve our cordial appreciation for their active roles for the purposes of the success of the conference.

I would like to especially thank my publication team and its members that include Mr. Jagat Kumar Bhusal, Dr. Laxmi Prasad Devkota, Mr. Suresh Marahatta, and Mr. Dhiraj Pradhananga for their untiring efforts to bring out the present volume on the proceedings of the International Conference on Hydrology and Climate Change in the Mountainous Areas.

On behalf of the organizers, I would like to express my whole hearted gratitude to the UNSECO for kindly supporting the conference to its successful conclusion.

Kiran Shankar Yogacharya
Chairman, SOHAM-Nepal
Conference Convener

The Kathmandu Declaration and the Recommendations of the Conference

The participants of the International Conference on "Hydrology and Climate Change in Mountainous area", held during the period 15 to 17 November 2008 in Kathmandu, Nepal, unanimously adopted the "**The Kathmandu Declaration on Hydrology and Climate Change in the Mountainous Areas"** and **the "Recommendations of the Conference"** presented below.

"**The Kathmandu Declaration on Hydrology and Climate Change in the Mountainous Areas"**

We, the Participants of the International Conference on "Hydrology and Climate Change in Mountainous Area" <u>reaffirming</u> the right of every citizen living in the mountainous areas of the World in general and of HKH region in particular for a prosperous future in consistent with the principles of food security, sustainable development, economic prosperity and a healthy rural livelihood,

<u>Recalling</u> the critical role that water plays for sustainable development, and the role of water resource management in mountainous region the light of increasing uncertainties due to changing climate and global phenomena,

<u>Noting</u> that creating, sustaining, improving and transferring knowledge and knowledge base on hydrology and climate change are indispensable to deal with the uncertain future that looms in the mountainous areas, and

<u>Recognizing</u> poorly understood hydro-meteorological processes of mountainous areas in the micro level and highland-lowland contexts during the International Conference on "Hydrology and Climate Change in Mountainous Area" which confirms that a comprehensive approach to improve the hydrological and climate change sciences is essential to achieve a sustainable development of the Himalayas,

<u>Resolve</u> that sound scientific knowledge base educational institutions and dedicated teams of scientists plays a key role in meeting the present and future challenges of water resource management in the Himalayas, especially that emanates from increasing uncertainty.

We, therefore, call for the following:

Hold an International conference to advance the science of hydrology and climate change in the mountainous areas, once in every two years, technically and financially supported by a group of dedicated international and national donors and hosted in rotation by the sponsors of the 2008 Kathmandu International Conference on Hydrology and Climate Change in Mountainous Areas;

Reenergize the existing networks of hydrologists, meteorologists, and other interdisciplinary scientists and institutions, such as SOHAM-Nepal, IHP-National Committees, HKH-FRIEND, etc. with the goal of promoting information and knowledge exchange, enhancing public awareness, influencing enabling policies and contributing to capacity building in hydrology and climate change;

Suggest modalities for formulating short-term and medium-term perspective plans on hydrology and climate change in the Himalaya, taking into consideration the ongoing Regional, National and State-level programmes, recognizing the institutional and human resources capacity in the countries, and in full conformity with the regional, national and state-level policies with regard to water resource management and development.

Formulate pilot projects, on the basis of the short-term and medium-term perspective plans mentioned on (c) above, in collaboration with appropriate regional, national and state-level institutions to promote institutional capacity building, training facilities, knowledge sharing, researches.

Establish Regional Center of Excellence on Climate Change and Cryospheric Research in Himalayan Region in Kathmandu.

We call upon, with a sense of urgency, on all international and national institutions, including NGOs and the private sector, who are committed to and have mandate for sustainable mountain development in general, and sustainable development of Himalayas in particular, to contribute to and participate in implementing the Kathmandu Declaration on Hydrology and Climate Change in Mountainous Area;

We urge the key sponsors of the 2008 Hydrology and Climate Change in Mountainous Area, in particular,

Ministry of Environment Science & Technology, Government of Nepal,

Ministry of Water Resources, Government of Nepal,

United Nations Educational, Scientific and Cultural Organization (UNESCO),

Society of Hydrologists and Meteorologists - Nepal,

International Hydrological Programme (IHP) of the UNESCO,

Nepal National Committee on IHP,

Department of Hydrology and Meteorology, GON

Central Department of Hydrology and Meteorology, Tribhuvan University, and

National Trust for Nature Conservation to initiate joint action for implementing the Kathmandu Declaration on Hydrology and Climate Change in Mountainous Area,

We congratulate the organizers of the 2008 Conference on Hydrology and Climate Change in Mountainous Area, particularly SOHAM-Nepal, the Department of Hydrology and Meteorology, MoEST; UNESCO for bringing together technical experts on a wide range of subjects on hydrology and climate change in the mountainous areas and the constructive discussions that have taken place, and

We **express our gratitude** to Honourable Minister for Water Resources, and Honourable Minister for Environment, Science and Technology, Government of Nepal; for providing their patronage to the conference and office bearers of SOHAM for its gracious hospitality.

(b) General Recommendations

Establish a Regional Centre of Excellence on Climate Change and Cryospheric Research in Himalayan Region in Kathmandu.

Strengthen the hydrological and meteorological institutions such as the Department of Hydrology and Meteorology, in providing comprehensive climate change data to understand the climatic process in the mountainous region. Expand the hydrological and meteorological observation network with real time data acquisition system.

Enhance the capacities of the relevant institutions and their staff at both the governmental and non-governmental levels. Provide academic courses and trainings surface and subsurface hydrology on snow/glacier mass balance estimation, .

Raise public awareness on climate change, disa ster management, and adaptive and mitigative measures.

Develop early warning system for floods, medium and long-range weather forecast and flood forecasting (real time facility).

Identify the impacts of climate change particularly on water resources sector through participatory research on agriculture and livestock, health, biodiversity, livelihoods, knowledge and data gap on hydro-meteorological processes need to be identified at the micro level linking highland and lowland.

Regional (International) and national **climate centre** – government supported and recognized (addressing both government and non-governmental organization – 1) **capacity building**, 2) **public awareness** on climate change and disaster, 3) **participatory** research on climate change impacts (**Agriculture**, Health, biodiversity, livelihoods, disaster) and climatic processes in Himalayas and cryosphere 4) **early warning system** and flood forecasting (telemetric facility), preparedness, prevention and mitigation 5) hydro-meteorological network strengthen and expansion (mainly automatic weather station with real time data acquisition, community weather station) – Center for Excellency – Himalayan Center for Climate

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Spatial distribution of water resources in the Tatra Mountains and their foreland, Western Carpathian Mts (Central Europe)

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ABSTRACT

The Tatra Mountains represent a high-mountain massif in the Western Carpathians (Central Europe) reaching the altitude of 2655 m a.s.l., and relative height of almost 2000 m above the surrounding intermountain basins. The main ridge of the mountains reaching the length of 55 km and running from the west to the east, represents an orographic barrier for humid air masses coming mainly from the NW sector. The mountain massif is built of crystalline, metamorphic and sedimentary rocks, including karstic rocks. Glacial morphology and locally karst morphology predominate in the relief of the mountains. This paper discusses the influence of different elements of natural environment on spatial differentiation of water resources of Tatra massive, with special reference to climatic asymmetry of the southern and northern slopes of the main ridge. Water resources of the Tatra Mountains massive show spatial differentiation conditioned by screening influence of main mountain ridge, geological and geomorphological zoning, horizontal zoning of relief and karst circulation of waters. The northern slope of the Tatras receives more precipitation than the southern slope, which is located in rain shadow, and, at the same time, evaporation in the northern slope is smaller than in the southern slope. The runoff in the northern slope increases with altitude from 650 to 1600 mm, whereas in the southern slope from 300 to 1320 mm. Also lake retention influences larger water resources of the northern slope of the Tatra Mountains. The index of lake retention is however in the northern slope of the Tatras 19 times smaller than the discharge index, whereas in the southern slope it is 41 times smaller. The volume of water retained in the lakes in the whole area of the Tatra Mountains represents only 5% of the annual runoff from these mountains. Water resources in Tatra Mountains related to river runoff are not larger than in other high mountains in the zone of temperate climates. However, as compared to mountains located closer to the sea or ocean coasts also in the way of humid air masses inflow, water resources of the Tatra Mountains, are at least 10 times smaller.

Key words : water resources, water balance, runoff coefficient, lake retention, Tatra Mountains, Western Carpathians

INTRODUCTION

In the analyses of water resources of mountain areas and their forelands, we should take into account the amounts of water permanently or periodically retained on the ground surface (lakes, snow cover, glaciers, swamps) and also amounts of water discharging in river channels. From the practical point of view, the notion of water resources of mountains may be limited to a total mean discharge of all rivers in the place where they flow out to the mountain foreland. Water resources in the mountains may be also analysed using contour lines of mean specific discharge, q [$l\,s^{-1}\,km^{-2}$] or runoff index, H [mm]. According to Lvovich (1978) spatial distribution of mountain water resources should be considered: (1) in zonal pattern, because in case of large territorial range of the mountains, the climate influence is essential, whereas in smaller scale, the influence of ground morphology and geology is essential, (2) in horizon pattern, when influence of climate, ground morphology and geology occur, (3) as a result of karst water circulation, which is not consistent with ground topography, when one of the neighbouring rivers shows a decreased discharge and the other shows an increased discharge. In a local or even regional scales, a screening role of orographic barrier of mountain ridges and side ridges is assumed as a dominating factor in differentiating water resources of mountains (Lvovich, 1978, Atlas …, 1983, Lajczak, 1996, 2006)

(Figure 1). These barriers constrain larger water resources on windward slopes and water shortage on leeward slopes, which results from differentiation of precipitation totals, and, in case of S-W slope exposition, also evaporation differentiation

The aim of this paper is a quantitative analysis of spatial differentiation of water resource in the high mountain massif of Tatras in Carpathian Mountains (Central Europe). Different factors (orographic, climatic, geological and morphological) differentiating water resources were analysed. It was shown that the course of the main high ridge of the mountains, which limits the flow of humid air masses predominantly influences the differentiation of water resources in this massive.

INVESTIGATION AREA

The Tatra Mountains represent a high-mountain massif, the highest (2655 m a.s.l.) one in the area of the alpine orogen of the Carpathian Mountains. Taking into account considerable differences in relative height in relation to the surrounding basins reaching 1500-2000 m, and also a W-E course of the main ridge which is 55 km long, the northern slope plays a role of a precipitation screen for humid air masses coming from the NW sector. Most of the massif is built from crystalline and metamorphic rocks, and in the northern part also sedimentary rocks including karstic carbonate rocks. In the massif, glacial morphology predominates, and locally in the northern slope karst morphology occurs. The massif is drained by numerous tributaries of the Dunajec and Poprad rivers which flow to the Baltic Sea, and also by tributaries of the Wag and Orawa rivers, which belong to the drainage area of the Black Sea (Figure 2). The Tatra Mountains are located in the central part of the Western Carpathians. Along the main ridge of the mountains, a Polish-Slovakian border is located.

Despite the fact that investigations on the Tatras' hydrology were carried out for many years, only a few works pay attention to spatial differentiation of water resources of this massif, usually in Polish part of the mountains (Dobija, 1981, Lajczak, 1996). Water resources of the whole Tatra massif were analysed by Lajczak (2006). Basing on the maps from Atlas … (1983) and maps from Lvovich (1978) a runoff index from the Tatra Mountains may be compared with other areas.

MATERIALS AND CALCULATION METHODS

This work is based on information from the following papers: Ziemońska (1966, 1973), Chomicz, Šamaj (1974), Wit-Jóźwik (1974), Lvovich (1978), Atlas … (1983), Lajczak (1996, 2006). In case of the Polish part of the Tatra Mountains, additional analyses included multi-annual measurement data of the Institute of Meteorology and Water Management from water-gauging stations located at eight rivers near the borders of these mountains or in a close distance from them, and at three lakes, which makes it possible to evaluated in details water resources of the northern slope of the Tatra Mountains (Figure 3). Parameters describing water resources of the Tatra Mountains were calculated according to valid procedures. The elements of a total runoff, i.e. underground total runoff, underground base runoff, underground variable runoff, and surface runoff were calculated using Wundt's method, assuming that a basic period is a decade (Lajczak, 1996).

WATER BALANCE OF THE TATRA MOUNTAINS

Table 1 shows a mean value of precipitation index, P [mm], runoff index, H [mm], and losses in runoff, RL [mm], for the whole area of the Tatra Mountains and additionally for the northern and southern slopes of these mountains from the line of the main ridge to the northern and southern limits of these mountains. These values were taken from the maps included in the work by Chomicz and Šamaj (1974) and data included in Atlas … (1983). The northern slope of the Tatras shows more intensive watering, where mean precipitation totals are larger by14% than the totals in the southern slope, and a mean runoff is larger by 22%. This results from a screening role of the orographic barrier, which is the main ridge of the Tatras, in conditions of the most frequent north-western flow of humid air masses, and also because of larger evaporation on the southern slope.

The difference between the watering of the both slopes of the Tatra massif is even more distinctive in case of precipitation totals in summer months (June – August), when the northern slope receives on average about 600 mm of precipitation, and the southern slope only 450 mm (Chomicz, Šamaj, 1974). The difference in the runoff value from both slopes of the Tatras is larger than the precipitation totals which these areas receive. The size of evaporation in the Tatras decreases with the altitude: at the foot of the northern slope it reaches 410 mm, whereas at the high areas of the mountains it is 200-300 m (Lajczak, 2006).

Hydrogeological investigations and balancing the runoff from a selected catchment areas show larger losses in water runoff from the Tatra massive, in relation to the size of evaporation (Gieysztor, 1961, Ziemońska, 1966, 1973, Wit-Jóźwik, 1974, Małecka, 1981, Lajczak, 1996, 2006). It may be assumed therefore, that the values of the basic elements of water balance of the Tatras, resulting from standard measurements of meteorological and hydrological services in Poland and Slovakia are lowered. The settled mean precipitation index concerns only measured precipitation, i.e. the so called vertical precipitation, and does not include horizontal precipitation. The totals of horizontal precipitation (both in solid and liquid states), in contrary to vertical precipitation, systematically increase with altitude, e.g. at Łomnica, one of the highest peaks of the Tatras, horizontal precipitation represents 67% of the annual totals of measured precipitation (Orlicz, 1962). Because of the lack of suitable data, it is not possible to evaluate real precipitation totals in the Tatra Mountains. The runoff index showed in Table 1 concerns only this part of the waters which flows in river channels and is recorded in water-gauging stations. In fact, mean runoff of the rivers at the Tatras limit is decreased as a result of water "escape" from the channels. The escaping water recharges the underground (artesian) aquifers at the foreland of the Tatra Mountains (Gieysztor, 1961, Małecka, 1981, Lajczak, 1996, 2006). Real values of the losses in water balance are therefore larger than these shown in Table. 1. In the northern slope of the karstic Tatras, a deep water escape from river channels occurs. This results in a decreased river discharge or periodical decay of rivers. The size of this escape is difficult to evaluate. Only part of the "losing" water flows to the artesian aquifer at the Tatras foreland, and the rest flows to shallow water aquifers in fluvioglacial sediments. Water infiltrating in gravels comes back to the river in its further course, in place where a rock channel occurs. In the southern slope of the Tatra massif and its foreland, where larger area is covered by Quaternary sediments, the decrease of the discharge may occur along longer sections of the rivers.

Assuming a mean value of evaporation at the northern slope of the Tatras equal 300 mm, and excluding a deep water escape from river channels, the index of effective precipitation in this area accounts to at least 1720 mm and may probably exceed this value. At the southern slope of the Tatra Mountains, a mean value of evaporation is undoubtedly larger than 300 mm, therefore the index of effective precipitation in this area considerably exceeds 1460 mm.

Basing on the assumed values of water balance elements of the Tatras, the runoff coefficient, RC [-], expressing the ratio of the runoff index to precipitation index, $H P^{-1}$, accounts to 0.86 in the whole area of Tatra Mountains. At the northern slope of the massif it accounts to 0.89, and at the southern slope to 0.83 (Table 2). These values are typical for mountains with high precipitation (from 0.70 to over 0.80) and slightly smaller than in mountains with glaciers and large intensity of snow avalanches (over 0.90) (Lvovich, 1978). Large value of runoff coefficient in the Tatras, especially at their northern slope, results from small evaporation caused by low temperature, large air humidity, frequent precipitation, rapid flow of waters on the crystalline substratum and its deep circulation in the screes, moraines and especially in karstic rocks. Taking into account the suggested larger totals of effective precipitation in the Tatras, the runoff coefficient in this area may reach the value below 0.86. At the northern slope this coefficient probably accounts on average to not more than 0.83, including the areas built of crystalline rocks accounting to not more than 0.86, the areas built of carbonate rocks below 0.81, and at the Tatras foreland built of flysch sediment below 0.61 (Table 3). Taking into account the suggested above larger totals of effective precipitation, the runoff coefficient at the southern slope of the Tatras is probably smaller than 0.79.

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The runoff coefficient of some Tatras' rivers shows anomalies caused by karstic circulation which is not consistent with the area topography. Rivers discharged from karstic springs show higher values of this coefficient. For example, the runoff coefficient of the Kościeliski Stream at the northern slope of the Tatras according to Ziemońska (1966) accounts to 0.87, whereas in the neighbouring Chochołowski Stream, it accounts to 0.78.

The shown above informations concerning only the Tatra massif confirm the opinions of many authors about large vertical and horizontal differentiation of the elements of water balance and water resources of mountains.

FEATURES OF SPATIAL DIFFERENTIATION OF WATER RESOURCES IN THE TATRAS

In spatial differentiation of water resources in the Tatras, there are similar features as in other high mountains. The analysis of each of the features of water resources differentiation in the Tatras cannot be carried out separately but it has to include all other features, which illustrate a complex system of water circulation in the mountains (Lajczak, 2006).

THE EFFECT OF SCREENING ROLE OF MOUNTAIN RIDGES (RUNOFF ASYMMETRY)

The first feature of spatial differentiation of water resources of Tatra Mountains is larger amount of water draining the northern slope than southern slope. This phenomena is caused by a screening role of the main ridge of the Tatras in relation to the most frequent inflow of humid air masses from the north-western direction. It is reflected in annual precipitation totals and annual runoff and even more distinctively it is shown in precipitation totals and runoff value from summer months. Precipitation totals increase with altitude at the northern slope from 1200 mm to over 2000 mm. In summer season, precipitation totals at this slope increase from 550 mm to over 700 mm. The southern slope of the Tatra Mountains, which is located in a rain shadow receives smaller precipitation totals – from 800 mm to over 2000 mm, and each isohyet is located higher at this slope, than at the northern slope (e.g. an isohyet 1200 mm is located 400 m higher at the southern slope than at the northern one). Precipitation totals in summer season at the southern slope of the Tatra Mountains account to 300-600 mm, and they are almost twice as small as they are at the northern slope. At both slopes of the massif, above the altitude 2000 m a.s.l., a precipitation inversion occurs, but it includes only a small area of the mountains. The screening role of the main ridge of the Tatras is shown on the map by Chomicz and Šamaj (1974), with the location of areas with surpluses and shortages of precipitation within the Tatra Mountains and their foreland. At the northern slope, the surplus of precipitation exceeds locally 250 mm, whereas in the zone of a deep rain shadow, precipitation shortage locally accounts to 450 mm. Mean annual precipitation totals at the northern slope of the Tatra Mountains are higher by about 200 mm than they are at the southern slope. Also an average thickness of a snow cover in March in the altitude section of 1700-2000 m a.s.l. at the northern slope is higher by over 0.5 m than it is at the southern slope (Lajczak, 2006).

The runoff index at the northern slope of the Tatra Mountains is in the range from 650 mm to almost 1600 mm and reaches a mean value of 1420 mm. At the southern slope it is in the range from 300 mm to over 1320 mm with a mean value of 1160 mm (Figure 3). In the whole Tatra massif together with its foreland, the largest difference in precipitation and runoff values occurs along the line running NW-SE across the highest Tatras' peaks. The runoff index at the north-western foreland of the Tatra Mountains is even 4 times larger than at the mountains foot at their south-eastern side, where it accounts to 150-300 mm. In that transect, the contour line of the runoff index – e.g. 650 mm, runs at the northern slope of the massif about 400 m lower than in case of the southern slope, and the contour line 1320 mm, at least 700 m lower (Atlas ..., 1983).

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The runoff index in the Polish sector of the Tatras and their foreland reaches higher values by over 15% than those shown on the maps from Atlas ... (1983), and shows similar relative spatial differentiation (Figure 5, Figure 6). The main reason of this difference is probably connected with the fact that the Author included data from larger number of water-gauging stations, located not only at large rivers discharging from the Tatras, but also at their tributaries. At the Tatras' foreland, the runoff index is estimated to about 650-1000 mm, and at the northern slope to over 1600 mm.

Also side ridges of the Tatra Mountains of the course SW-NE have a screening influence on the size of precipitation and runoff. At their eastern side a decreased runoff occurs (Chomicz, Šamaj, 1974, Lajczak, 1996, 2006). Hydrological effect of local rain shadows in the Tatras and their foreland is shown more distinctively taking into account multi-annual results of measurements of Polish hydrological service.

The asymmetry of the runoff size from the Tatra Mountains conditioned by a screening role of the main mountain ridge and expressed by contour lines of the runoff index is, due to a small size of the Tatra massif, less visible than in other high mountains which are located on the way of humid air masses movement (Figure 7, Figure 8). A relative surplus of the runoff from the windward slope of the Tatras is rather small as compared to the Southern Andes or New Zeeland Alps, where a runoff index may locally exceed 6000 mm. Also the shortage of the runoff from the leeward slope of the Tatras is not as clearly visible as it is at the eastern part of the mentioned above mountains, where the runoff index is at the level typical for deserts (even less than 50 mm) and where transit mountain rivers are the only source of water.

Figure 9 shows estimated mean discharge, Q [$m^3 s^{-1}$] of individual rivers and streams at the Tatras border. Only ten rivers and streams show a mean discharge at the mountain border larger than 1 $m^3 s^{-1}$, and six of them drains the northern slope. The Białka river, draining the northern slope of the highest part of the Tatras has the largest mean discharge – over 2 $m^3 s^{-1}$. A total mean discharge of rivers and streams draining the northern slope of the Tatras accounts to 12,8 $m^3 s^{-1}$, and the southern slope – 10,8 $m^3 s^{-1}$. The runoff from the northern slope of the Tatras is larger by 19% than the runoff from the southern slope.

ZONALITY

Water resources in the mountains of large territorial range refer to zonaly differentiated climatic conditions occurring in latitudinal or longitudinal profile and also to the height above the sea level, ground morphology and geology. Because of a small territorial range of the Tatra Mountains, this form of spatial differentiation of water resources is poorly expressed and it is decreased by the influence of other factors. It is possible however to distinguish in the Tatra massif three zones of different systems of water circulation, which is connected with different water resources in this area (Ziemońska, 1966, 1973, Wit-Jóźwik, 1974, Lajczak, 1996, 2006). Three zones are distinguished at the northern slope of the Tatras: (1) lowest located zone built of carbonate sediments with shallow water circulation and their small resources; (2) higher located zone – carbonate, with deep and long-lasting karst water circulation and its large resources; (3) the highest located zone built of crystalline rocks where precipitation and water resources increase towards the main ridge. Above the horizon of rain inversion, in the area of steep rock slopes, water resources decrease with height. Water resources in these zones account to: (1) 20 – 30 $l s^{-1} km^{-2}$, (2) 30 – over 40 $l s^{-1} km^{-2}$, (3) over 40 $l s^{-1} km^{-2}$. The southern slope of the Tatra massif totally built of crystalline rocks, despite considerably differentiated water resources from 12 to over 40 $l s^{-1} km^{-2}$, should be considered together with the third zone within the northern slope.

At the foot of the northern and southern slopes of the Tatra Mountains, where fluvioglacial sediments occur which retain part of the water flowing out from the valleys to the mountain foreland, other zones should be distinguished. They play the role of the aquifers of waters "escaping" from the river channels.

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At the northern slope an attention is paid to the zone (1) and (2), which import part of waters from the crystalline zone and export water to the deep artesian aquifer at the mountain foreland. At the same time, along the northern border of the Tatra massif, an ascensic springs occur, which recharge shallow ground waters. This kind of water migration is assumed as insignificant in the scale of the whole Tatra Mountains. The crystalline zone in the Tatras, as contrary to other zones, plays only the role of a water exporter – water flows out on the surface in rivers, and in much smaller scale under the surface in karst systems.

VERTICAL ZONALITY

Apart from the influence of geological and morphological conditions, the differentiation of water resources in height profile of the Tatra massif is influenced by climatic conditions. In the part of the Tatra Mountains built of crystalline rocks, three height zones are distinguished which show differences in water resources (Ziemońska, 1966, 1973, Wit-Jóźwik, 1974) (Figure 10):

a) the highest located zone which includes rocky slopes and steep slopes covered by thin weathering mantel, showing rapid surface flow and small water resources,

b) the zone with slopes covered by thick weathering mantel (including moraines) with numerous post-glacial lakes, with highest precipitation and largest accumulation of avalanche snow. Water circulation in weathering mantel is slow down and in the lakes it is retained. This is the zone of the highest water resources in the Tatra Mountains,

c) the zone including valley floors, where rivers are recharged by water circulating in weathering mantels and water flowing out from the lakes. This is a zone of large and stable water resources.

In the karstic area of the Tatras, two height zones are distinguished with different water circulation and water resources:

a) the zone embracing high located parts of ridges with deep water circulation and developed karst processes. Water flows to the surface in valley floors as efficient karst springs,

b) the zone embracing valley floors with large water resources where rivers are recharged by karstic springs in their whole course and also by uncontrolled flow of ground waters.

EFFECT OF KARSTIC WATER CIRCULATION

Spatial differentiation of water resources in the Tatra Mountains caused by karstic circulation of waters is limited to their northern slope. In the distinguished higher located zone of the Tatra massif built of karstic rocks, the western or north-western direction of deep water circulation predominates, which is transversal to topographic watersheds (Lajczak, 1996). Locally, the flow of karstic water to rivers from the eastern direction occurs. As a result of such circulation of karstic waters, some rivers and streams have water shortages, and this shortage is even recorded at the mountain foreland. On the other hand, the rivers and streams located on the western side of the above mentioned water courses have water surpluses, because they are alimented by karst springs. The Bystra Stream has a privileged position, as it is alimented by karstic waters from the west and the east. At the lower located part of the northern slope of the Tatra massif, a deep runoff of karstic waters to the artesian basin at the mountain foreland occurs. In this area, transit rivers "lose" some of their waters near their discharge from the Tatras to the mountain foreland.

In case of some rivers in the northern slope of the Tatras, where underground escape of water to neighbouring water courses occurs on the largest scale, it is possible to evaluate the decrease of its mean discharge at the mountains' border. The water shortage represents a result between a mean discharge determined basing on the maps of contour lines of runoff index (see – Figure 5) and an effective discharge in the area of its outflow from the mountains to the their foreland. The estimated mean discharge of the Sucha Woda Stream, which is the largest Tatras' water course sometimes totally loses its waters, accounts in a hypothetical situation of the lack of water loses to

about 1.30 m³ s⁻¹. An effective mean discharge of this stream, at the border of Tatra Mountains does not exceed 0.5 m³ s⁻¹. In other smaller water courses which also lose some of their waters the difference between a hypothetical and effective discharge is not so considerable.

Similar estimation was carried out for water flowing out from three rivers in the northern slope of the Tatra Mountains, which are most considerably recharged by karstic waters. This water surplus in the rivers represents a result between their mean effective discharge at the mountains border and the discharge determined basing on the maps of contour lines of runoff index (see – Figure 5). Mean discharge of the Kościeliski Stream from the data included in the map is about 1.50 m³·s⁻¹, whereas in fact, it counts to 1.62 m³ s⁻¹. Even larger increase of the mean discharge as a result of transit recharge of karstic waters was determined in case of the Bystra Stream, where a mean discharge from the map is 0,77 m³ s⁻¹ whereas in fact it is 1.21 m³ s⁻¹. The largest anomalies were determined in the Olczyski Stream, which is recharged by one of the largest karstic springs in the Tatras (Olczyskie spring – yield about 500 dcm³ s⁻¹). A mean discharge of this stream is about 2.5 times increased by the recharge of karstic waters and accounts to 0.58 m³ s⁻¹., whereas on the map the discharge is 0.22 m³ s⁻¹.

It may be assumed, that a total value of the decrease of a mean discharge of these water courses and the increase of discharge in other described water courses balance each other as a result of karstic circulation of water.

Another effect of karstic circulation is large differentiation of the share of runoff elements, especially underground recharge, in total runoff of rivers and streams at the northern slope of the Tatra Mountains (Figure 11). These elements of runoff include: (a) the most stable form of underground runoff, called a base runoff, which influences river discharge in long-lasting dry periods, especially during frosty winter, (b) more dynamic element of underground runoff which develops in periods of renewal of ground water resources, (c) total ground water runoff which represents the total of the described above runoff elements, (d) the most dynamic element of the runoff, i.e. a surface runoff which reaches the largest values during spring thawing periods and summer precipitation. Also absolute value of the recharge of the rivers [l s⁻¹ km⁻²] by the runoff elements is differentiated. The rivers recharged by karstic springs are more frequently recharged by waters comprising underground runoff, than any other rivers. The alimentation of these rivers by a base runoff has different size, which results probably from different intensity of loses in a discharge caused by water escape from the river channel to a groundwater aquifer, which is especially visible in periods of low water stages (Lajczak, 1996). It is worth to mention exceptional large values of two elements of underground runoff in the Olczyski Stream, which is recharged by a karstic spring, which mean yield accounts to as much as 86% of the mean discharge of this stream in a water-gauging station. An opposite situation is represented by a neighbouring Sucha Woda Stream, where underground recharge periodically disappears which means that a basic runoff in this area of the Tatra Mountains does not occur on the ground surface.

Drainage basins of the rivers recharged by karstic springs show larger retention of ground water than the drainage basins which do not have karstic springs. This is illustrated by relations between a retention of ground water related to a topographic drainage basin of the river and expressed in the thickness of water layer [mm], and the size of river discharge in a water-gauging profile [m³ s⁻¹] in successive days of a dry period (Figure 12). Curves representing rivers where "discordances" of discharge size caused by karstic processes were not determined, occupy a narrow zone in the central part of the diagram. The area below this zone in the diagram is represented by drainage areas where ground retention and runoff is reduced due to underground runoff of water to neighbouring drainage basins. The area on the upper part of the diagram represents drainage areas where rivers have increased discharge. For example, with a mean river discharge of 0.50 m³ s⁻¹, ground retention is included in a wide range from about 0.2 mm in a drainage basin losing most of its water, to 20 mm in a drainage basin significantly recharged by transit karstic waters.

LAKE RETENTION

Lake retention represents the most important element of surface resources of waters in the Tatra Mountains. Among other forms of surface retention of waters in this area, a snow cover becomes almost totally melted in summer period, and the amount of water accumulated in permanent snow patches may be assumed as insignificant. Also swamps contain little amount of water.

Total capacity of all lakes in the Tatra Mountains is about 53 mln m^3, including 42 mln m^3 at the northern slope and 11 mln m^3 at the southern slope. After calculating these values into index values (lake retention index, LR [mm]), it is visible that the northern slope of the Tatras contains the layer of 107 mm of lake waters, and the southern slope contains the layer of 28 mm of these waters (mean value for the whole Tatras is 67.5 mm). These values are much smaller than the runoff index in this area – by19 times for the whole Tatras, by 41 times at their southern slope, and by 13 times in their northern slope.

The volume of water retained in all Tatras' lakes equals 7.1% of the annual runoff from these mountains. In case of the northern slope of the Tatras the volume of the lake waters represents 10.4% of the annual runoff from this area, and in case of the southern slope 3.2%. In fact, only a small part of waters retained in lakes takes part in the runoff. The largest recharge of streams by lakes occurs during the highest water stages: in periods of snow cover melting in a drainage basin, during ice float melting, and on smaller scale after long-lasting and intensive rains in summer (Lajczak, 1996). A characteristic feature of Tatras' lakes is rapid increase of their water stages in spring and then long-lasting decrease of water stages in summer and autumn. In winter, the decrease of water stage is the slowest. Only part of water may flow out from lakes, especially from their subsurface layer between a maximum and minimum water stages. The rest of water is permanently accumulated in lake basins. Only shallow lakes may periodically dry out. If there is more than one lake in the valley, the size of recharge is influenced by the lowest located lake, especially if it has a large capacity. The estimated total volume of water in the two largest Tatras' lakes, determined by the difference between the mean upper and the mean lower water stage represents a small part of the annual runoff of the Białka River which drains the drainage basin of these two lakes (see – Figure 3). This part of the volume of these two lakes together represents an equivalent of a mean discharge of this river at the water-gauging station located at the Tatars' border, from only 18 hours. A total volume of waters in other lakes in the Tatra Mountains determined from the range of oscillations of mean water stages, is considerably smaller than the volume of water in the two largest lakes of this massif. During extreme hydrometeorological events the recharge of Tatras' rivers by lake waters is more intensive and shows longer duration (Lajczak, 2006).

CONCLUSIONS

Water resources of the Tatra Mountains consist of waters retained in lakes and waters discharging in river channels. The amount of waters retained in lakes represents an equivalent of 5% of annual runoff from the Tatras, but only their small part takes part in the runoff, the rest in permanently kept in lakes.

Water resources of the Tatras related exclusively to river runoff are not larger than in other high mountains in the zone of temperate climates. In relation to high mountains located in the way of humid air masses flow, the water resources of the Tatras are at least ten times smaller.

Water resources in the Tatra Mountains show spatial differentiation, especially between their northern and southern slopes. Spatial differentiation of water resources in this massif is larger in relation to lake waters than to waters which take part in the runoff. In each of these situations, larger amount of waters is accumulated in the northern slope of the mountains than in the southern slope, in case of lakes even four times. The screening role of the main ridge of the Tatra Mountains in relation to the most frequent inflow of humid air masses represents the most significant factor influencing spatial differentiation of water resources in these mountains.

The Tatras' sector in the Polish territory has a privileged position concerning water resources, more in relation to total capacity of lakes than to the runoff size. In the Białka drainage basin within the Tatras (which is the largest river draining the northern slope of the mountains), the index of lake retention reaches extremely high values in the scale of the whole massif, accounting to 600 mm, which represents almost a half of the value of the runoff index at the northern slope of these mountains. Anomalies of river drainage caused by transit circulation of karstic water occur only in the Polish part of the Tatra Mountains.
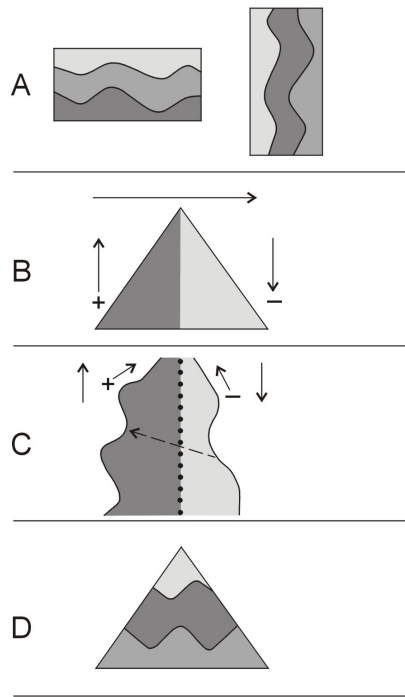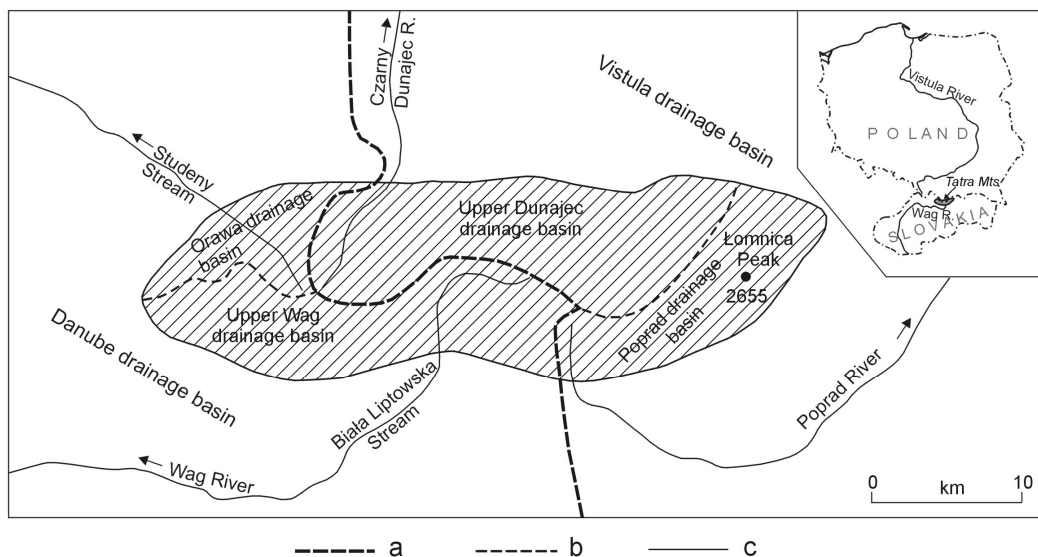
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Figure 2
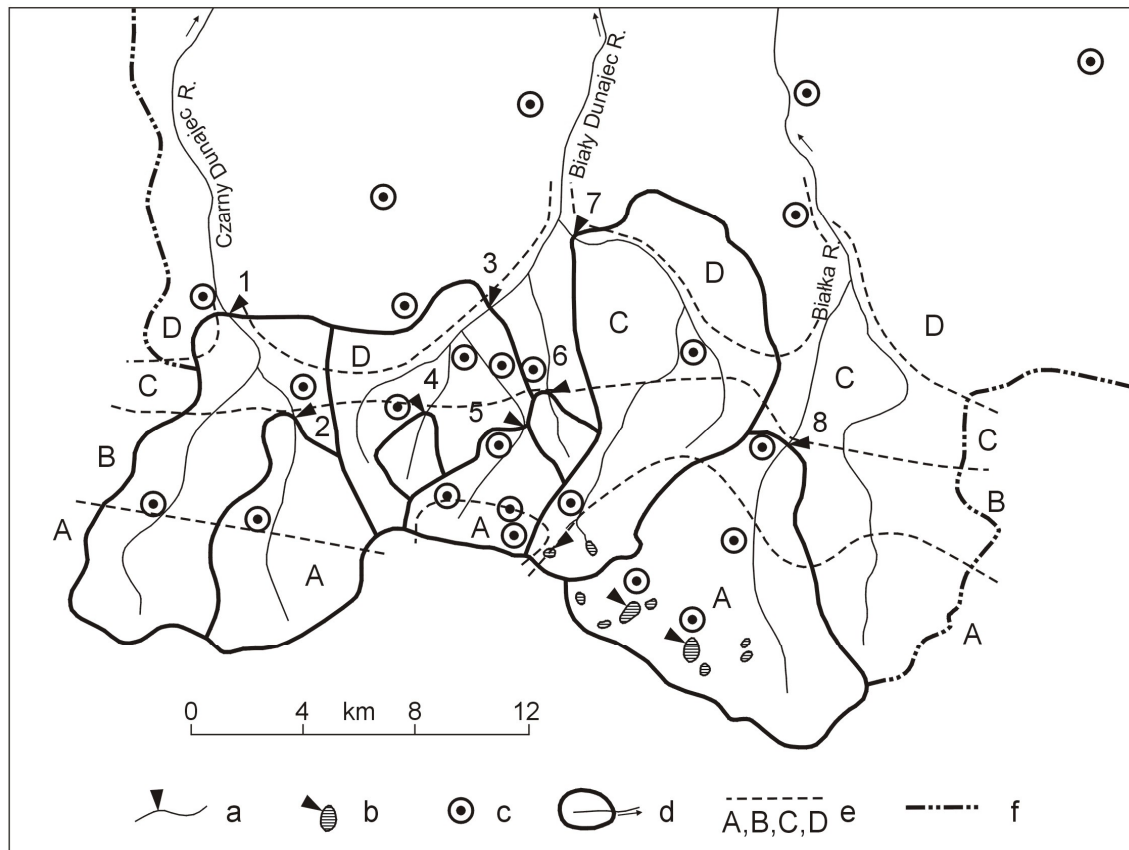
Figure 3

Figure 4

Figure 5

Tatra Mts
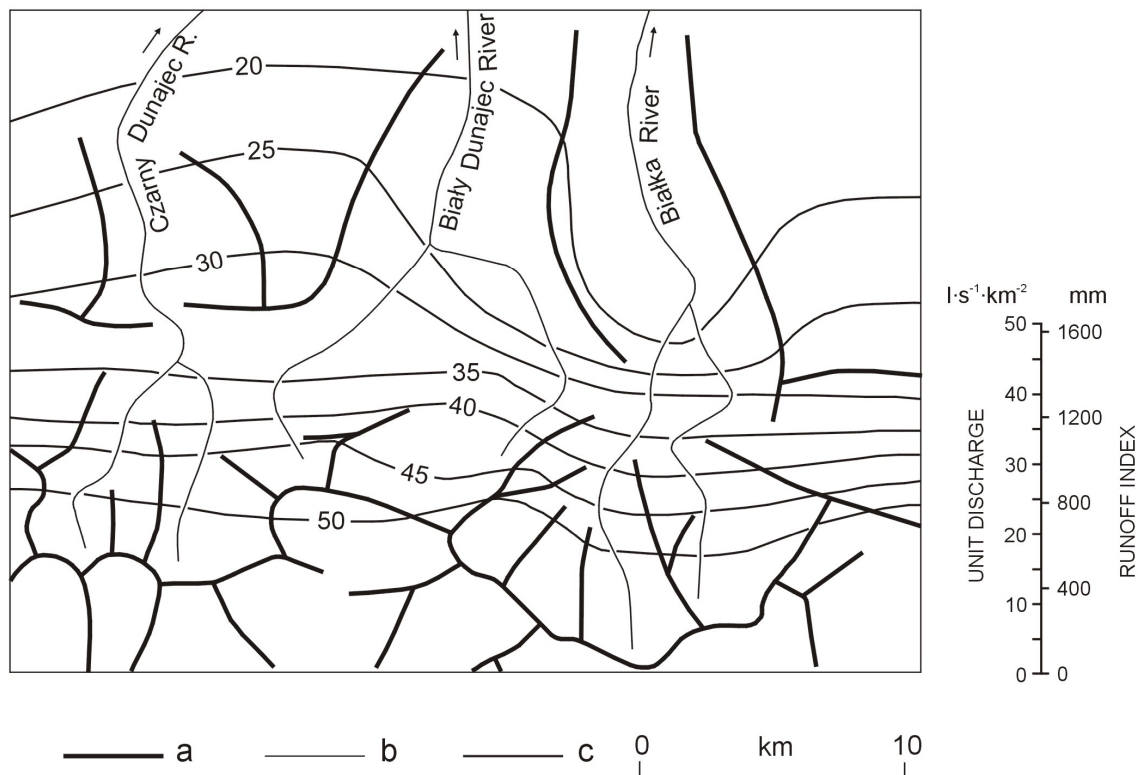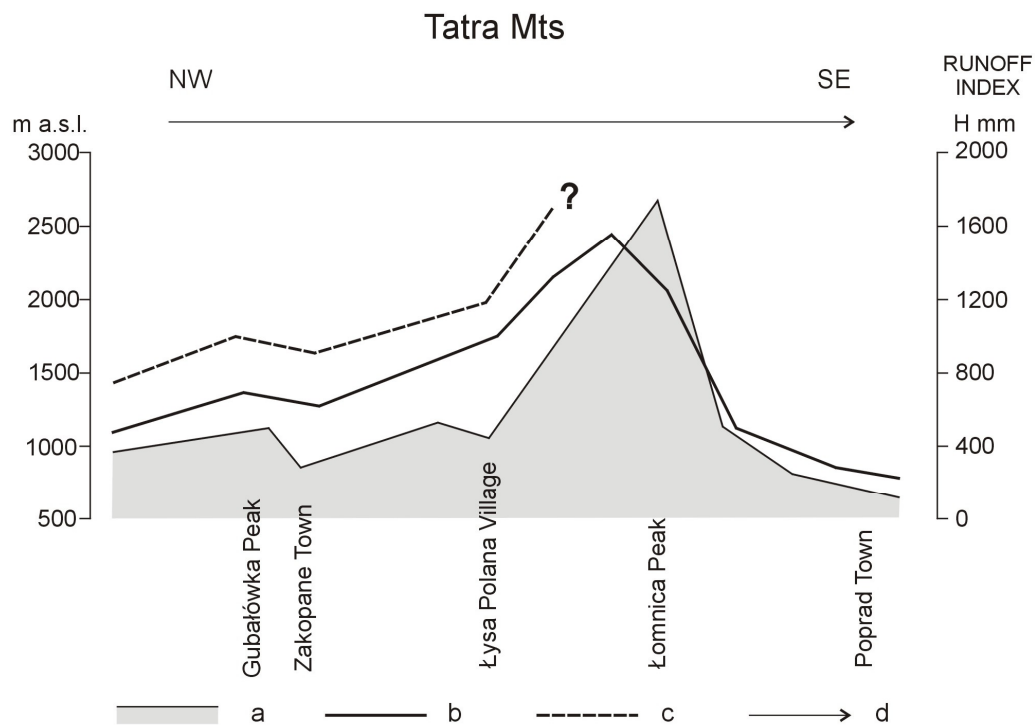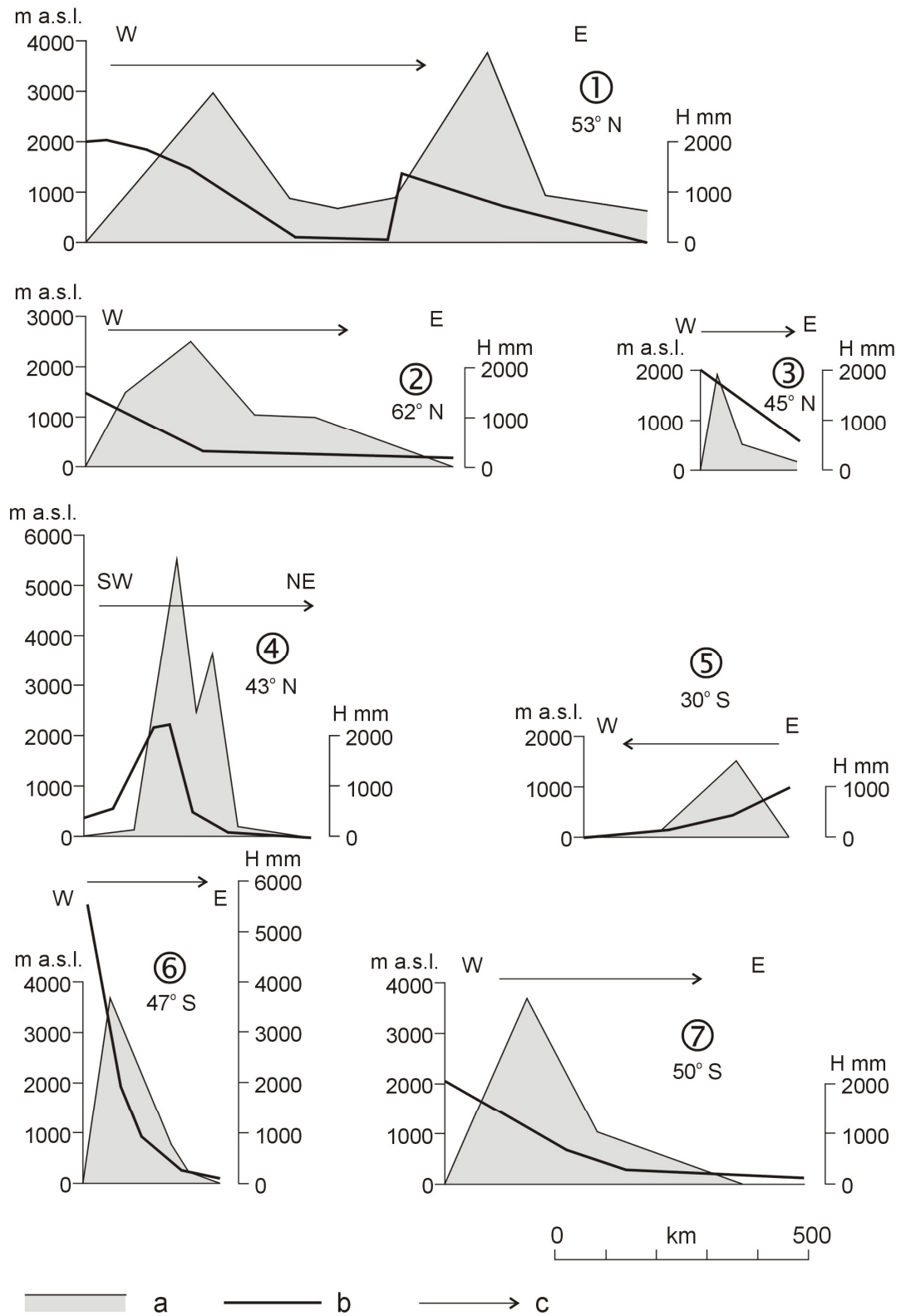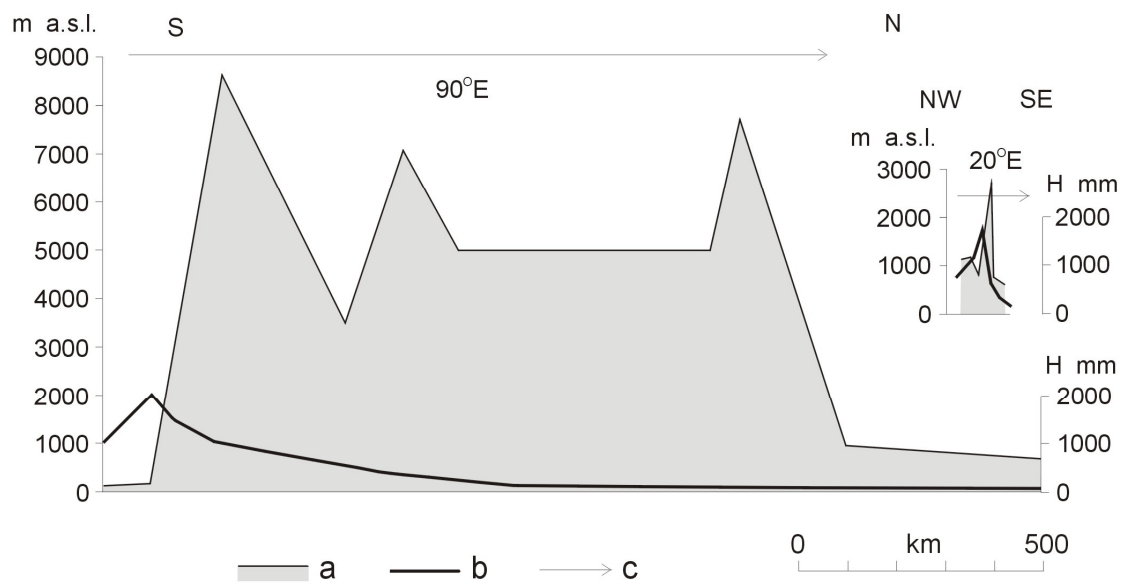
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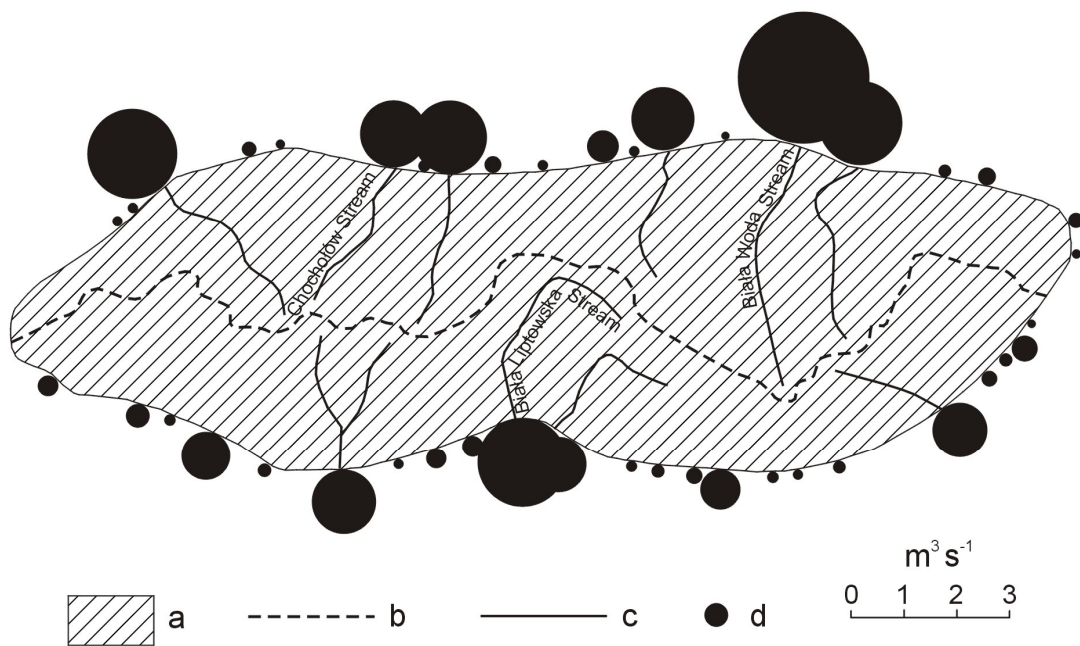
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Figure 8

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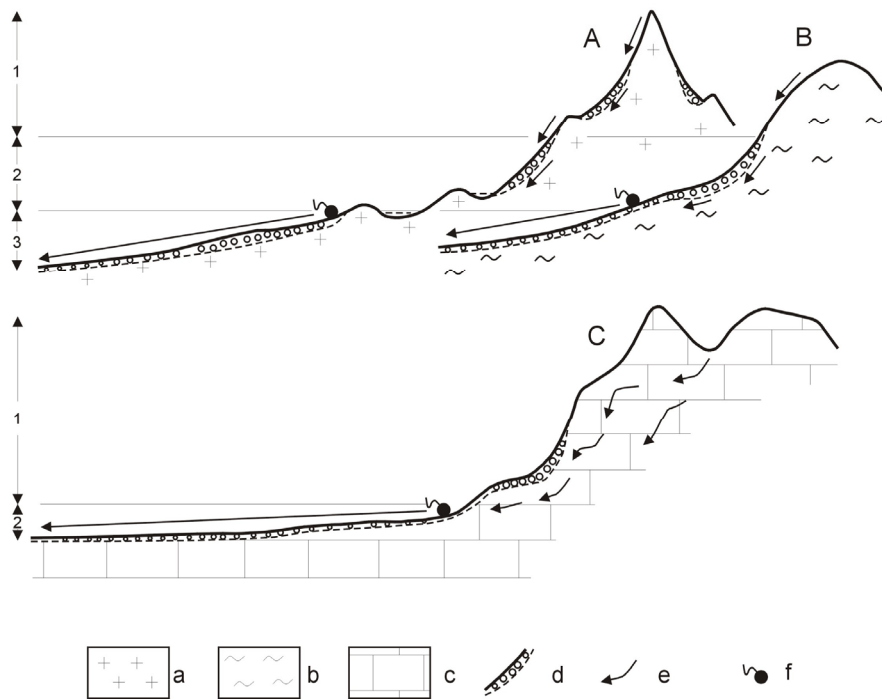
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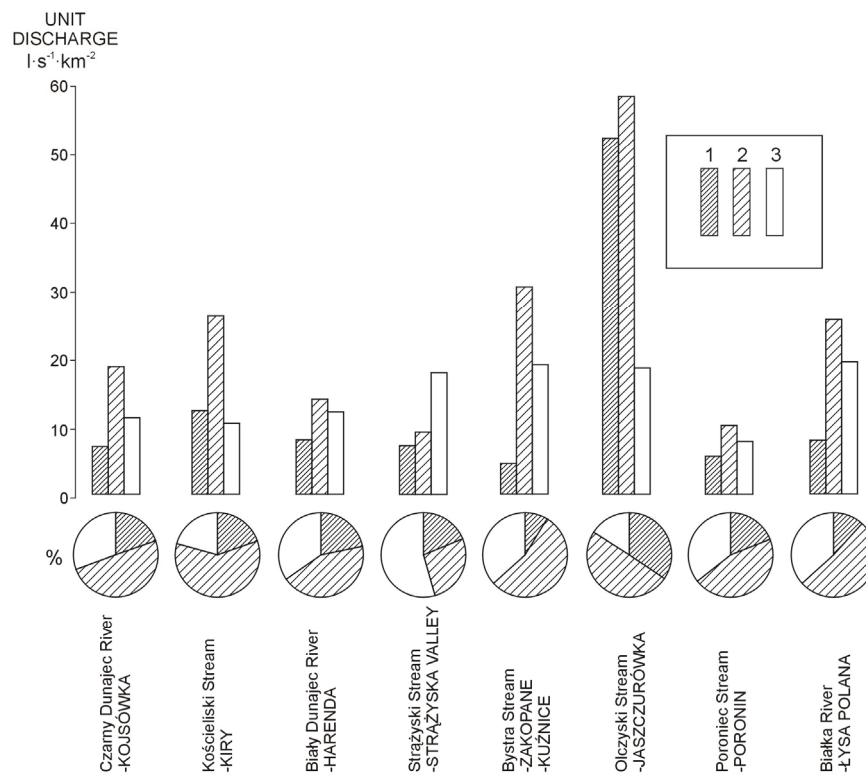
Figure 11
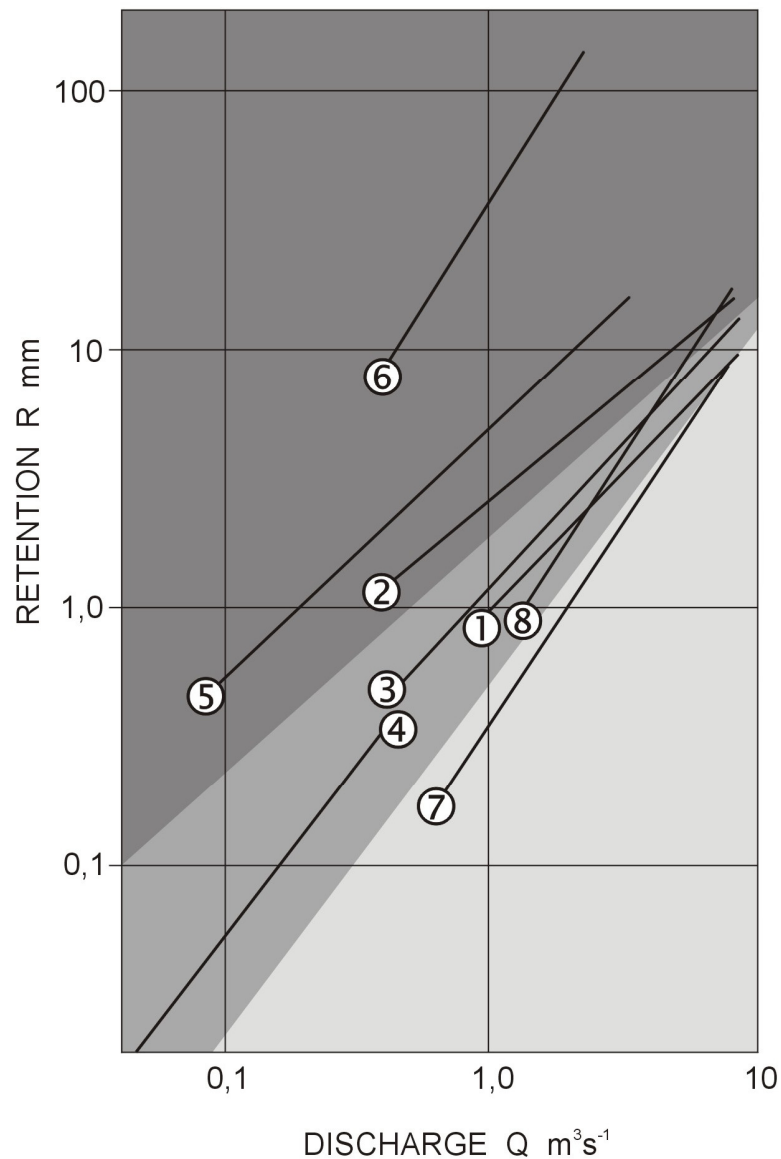
Figure 12

ACKNOWLEDGEMENTS

APPENDIX

P   – precipitation index [mm]
H   – runoff index [mm]
RL   – losses in runoff [mm]
RC   – runoff coefficient, $H\,P^{-1}$ [-]
LR   – lake retention index [mm]

Q   – river discharge [$m^3 s^{-1}$]

q   – specific discharge [$l s^{-1} km^{-2}$]

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FIGURE CAPTIONS

Figure 1. Forms of spatial differentiation of water resources in mountains: A – zonality, B – screening influence of mountain ridges (runoff asymmetry), C – runoff anomalies in karst areas, D – vertical zonality. Arrows pointing up – increase of water resources, down – decrease of water resources, horizontal arrows – predominant direction of air masses movement over mountains.

Figure 2. The Tatra massif as a source area of large Carpathian rivers. a – European Watershed, b – main ridge of the Tatra Mountains apart from European Watershed, c – main rivers.

Figure 3. Location of water and meteorological gauging stations of the Institute of Meteorology and Water Management in Polish Tatras and their foreland. a – gauging stations at streams and rivers (1- Czarny Dunajec river, 2- Kościeliski Stream, 3- Biały Dunajec river, 4- Strążyski Stream, 5- Bystra Stream, 6- Olczyski Stream, 7- Sucha Woda – Poroniec Stream, 8- Białka river), b – gauging stations at lakes, c – precipitation stations, d – limit of stream and river catchments down to gauging stations, e – boundaries of hydrographic regions (A- area built of crystalline rocks – crystalline Tatras, B- of carbonate rocks, C- of flysch rocks overlaid by fluvioglacial deposits – Sub-Tatra Graben, D- of flysch rocks), f – limit of the upper Dunajec catchment apart from the sections of the streams mentioned above which delimit the boundaries of the catchment.

Figure 4. Isolines of specific runoff, q [l s^{-1} km^{-2}] in the Tatra Mountains and their foreland according to Atlas … (1983). a – main mountain ridges, b – main water courses, c – isolines of specific runoff values may be recalculated into runoff index, H.

Figure 5. Isolines of specific runoff, q [l s^{-1} km^{-2}] in the Polish Tatra Mountains according to Lajczak (2006). The isolines are based of multi-annual measurement data received from the Polish Hydrological Survey. a – main mountain ridges, b – main water courses, c – isolines of specific runoff may be recalculated into runoff index, H.

Figure 6. Value of runoff index, H, in the transversal profile of the Tatra Mountains. a – schematic orographic profile, b – runoff index, H, according to Atlas … (1983), c – according to Lajczak (2006), d – predominating direction of air masses movement over the Tatra Mountains. Location of chosen towns, villages and peaks is marked.

Figure 7. Asymmetry of runoff index, H, in transversal profile of the selected mountains (1- Rocky Mts, 2- Scandinavian Mts, 3- Welebit Mts, 4- Caucasus Mts, 5- Great Watersheed Mts, 6- New Zealand Alps, 7- Southern Andes). a – schematic orographic profile, b – runoff index, H, according to Lvovich (1978), c – predominating direction of wet air masses inflow.

Figure 8. Asymmetry of runoff index, H, in transversal profile of the Himalayas and Tibet Plateau. For comparison the High Tatras are shown at the same scale. a – schematic orographic profile, b – runoff index, H, according to Lvovich (1978) and Atlas … (1983), c – predominating direction of wet air masses inflow.

Figure 9. Mean discharge, Q [m^3 s^{-1}], of streams and rivers in the place where they flow out from the Tatra Mountains to their foreland, according to Lajczak (2006). a – the Tatra massif, b – boundary between the northern and southern slopes of the Tatras, c – main water courses (only these with a mean discharge over 1 m^3 s^{-1}), d – value of mean discharge (the measure is the diameter of circle diagram).

Figure 10. Vertical zonality of water resources in the Tatra Mountains. A – the High Tatras built of crystalline rocks, B – the Western Tatras built of crystalline or metamorphic rocks, C – area built of carbonate rocks. In areas A and B three vertical zones are distinguished, whereas in the area C two vertical zones are distinguished (described in the text). a – granite rocks, b – crystalline and metamorphic rocks, c – carbonate rocks, d – thick covers of weathering mantel (including moraines), e – water circulation (surface and subsurface runoff), f – location of the most efficient springs. Height zones: 1-3 for areas A and B and 1-2 for area C, described in the text.

Figure 11. The value of runoff components [l s^{-1} km^{-2}] of rivers and streams in the Polish Tatras and their share in total runoff of these water courses [%]. Runoff components: 1 – base runoff, 2 – dynamic element of underground runoff, 3 – surface runoff. Names of water courses and gauging stations are marked.

Figure 12. The relation between the retention of groundwater in topographic catchment of streams or rivers in the Polish Tatras and their foreland expressed in [mm], and the size of a discharge [m^3 s^{-1}] in the succeeding days of low-water flow. Gauging stations are numbered as in Figure 3.

Tables

Table 1 : Elements of water balance of the Tatra Mountains.

elements of water balance	all area of the Tatra Mts	northern slope	southern slope
precipitation index, P	1500 mm	1600 mm	1400 mm
runoff index, H	1290 mm	1420 mm	1160 mm
losses in runoff, RL	210 mm	180 mm	240 mm

Table 2 : Runoff coefficient in the Tatra Mountains based on data presented in Table 1.

all area of the Tatra Mts	northern slope	southern slope
0.86	0.89	0.83

Table 3 : Runoff coefficient in the Polish Tatra Mountains and their foreland based on probable real sum of precipitation.

all area of the Polish Tatra Mts and their foreland	area built of crystalline rocks	area built of carbonate rocks	area built of flysch rocks partially covered by fluvioglacial deposits
0.83	0.86	0.81	0.61

Impact of Climate, Climate Change and Modern Technology on Wheat Production in Nepal 1970/71-2006/2007

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ABSTRACT

The relation between climate and wheat production in Nepal was studied for the period 1970/71-2006/07. Due to the topographical differences within short north-south span of the country, Nepal has wide variety of climatic condition. About 70 to 90% of the rainfall occurs during the summer monsoon months (June to September) in Nepal and the rest of the months are almost dry. Wheat is cultivated during the dry winter period; and therefore, the supplementary irrigation plays a vital role in its cultivation. Varieties of wheat have been developed to suit the local climatic conditions. Due to the availability of improved seeds, modern cultivation practice and a supplementary irrigation; the wheat cultivation has increased substantially throughout Nepal. The national area and production of wheat has remarkably increased from 228,000 ha to 702,664 ha and 193,360 mt to 1,515,139 mt during 1970/71 to 2006/07 respectively. Though modern facilities such as irrigation, improved seeds and fertilizers are available to some extent, weather and climate still plays an important role in the increase of area and production of wheat in Nepal. Future planning to increase the wheat production in Nepal should give due consideration to the effect of global warming also.

Key words: Climate, weather, wheat production, irrigation, improved seeds.

INTRODUCTION

In Nepal wheat is grown in the temperate climate and subtropics. For higher yields, water requirements are 350-500 mm depending on climate and length of growing period in Nepal. There should be adequate water during the establishment period. Water deficit during the filling period results in reduced grain weight. However, during the ripening and drying–off period, rainfall or irrigation have negative impact on the yield.

It is desirable that the minimum and maximum temperature during the wheat growing period should be 3° C to 32° C and the mean daily temperature for optimum growth is between 20^oC and 25^oC (Briggle, 1980). Knowledge of genetic characteristics and particularly growth and development pattern of wheat varieties is essential for meeting the combination of various climatic requirements for growth development and yield formation. It is known that the upper limit of crop production is set by the climatic condition specially temperature regimes and the genetic potential of the variety grown. The extent to which this limit can be reached will always depend on how finely the engineering aspects of water supply are in tune with the biological needs for water in crop production (FAO, 1979). The area under wheat cultivation in different regions of Nepal is shown in Figure 1.
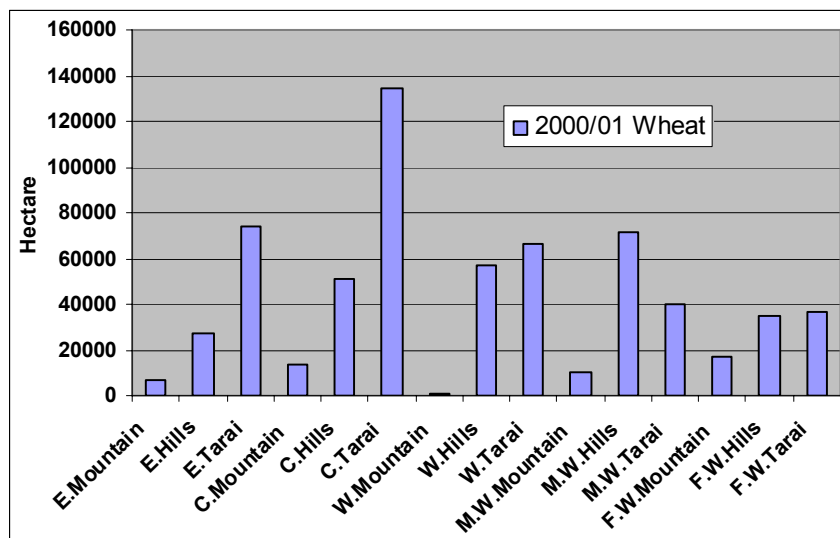
Figure 1 : Wheat cultivation in the different regions in Nepal

DATA

This study has used thirty six years (1970/71 – 2006/07) of crop data in Nepal. Weather data were made available by the Department of Hydrology and Meteorology (DHM). Source of the wheat data is the then Department of Food and Agricultural Marketing Services (DFAMS), Nepal Planning Commission (NPC), Central Bureau of Statistics (CBS) and Ministry of Agriculture and Cooperatives (MoAC).

Taking into consideration the winter rainfall and the growing season of wheat, this study attempts to cover whole of Nepal and three ecological belts.

ANALYSIS

i. National Level

While observing the wheat yield and their production in Nepal, during 1970/71 to 2006/07, the area was about 228,400 (two hundred twenty eight thousands and four hundred) hectare during 1970/71 and in 2006/07, the area has increased to 702,664 (seven hundred and two thousand six hundred sixty four) hectare. There is clear indication that the area under wheat cultivation has increased more than three folds in 2007 during the study period. The wheat production was 193,360 (one hundred ninety three thousand and three hundred sixty) mt in 1970/71 and now the production is 1,515,139 (on average 1.5 million) mt in 2006/07. The wheat production during the study period of 1970/71-2006/07 has increased almost seven fold. During 2006/2007, the total production of wheat was 1.5 million mt. At present rate, Nepal produced wheat worth of more than US$ 400 million (NRs.27272.5 million).

National Agriculture Research Council (NARC, 1997) mentioned that performance in wheat production in Nepal has increased remarkable due to wide spread cultivation of high yielding varieties since 1972. Although attempts on variety development were initiated since late fifties, the systematic breeding works began only after the establishment of National Wheat Development Program in 1972. In fact Department of Agriculture had launched a "Grow More Wheat Campaign" in 1965/66 with the introduction of Mexican wheat varieties introduced via India. The new varieties of seed were launched since then and now occupy 96% in 2006/2007(MOAC, 2006). There are altogether 30 varieties developed for different environment in Nepal (NARC, 2007). The national wheat area and production from 1970/71 to 2006/07 are shown in Figure 2. Initially during the first decade, the yield was almost constant and in the later part the yield increased to

more than 2 mt per hectare as shown in Figure 2. This is clearly due to improved modern technology and adoption of high yielding varieties as well as supplementary irrigation.
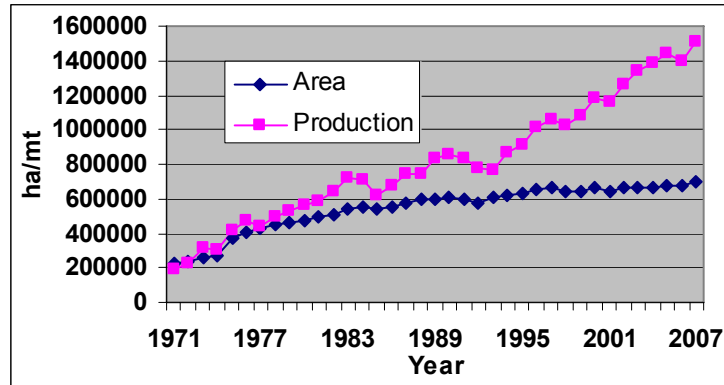
Figure 2 : The National wheat area and production

ii. Ecological belts

The wheat area and production in three ecological belts are as follows:

MOUNTAIN

In course of studying wheat cultivation in three ecological belts, the Mountain region showed that the increase of area has almost doubled and the yield increased to the little above 50% during the last 36 years. The gap of the area and production showed a change after 1995 in the Mountain (Figure 3). This can be attributed to the improvement of technology of wheat farming as shown in Figure 3. The production of wheat in the Mountain region increased from 28,900 mt to 81,004 mt during the last 36 years from 1970/71 to 2006/07. During the wheat growing season (November to May) in the Mountain region, the rainfall is about 150 t0 250 mm, but the nature of rainfall was very erratic. The average annual temperature during the growing season in Mountain was 6°C to 18°C. In fact Mountain region as defined include only 7.5% of the total wheat area and contributes 5.7% of the total wheat production in the country.
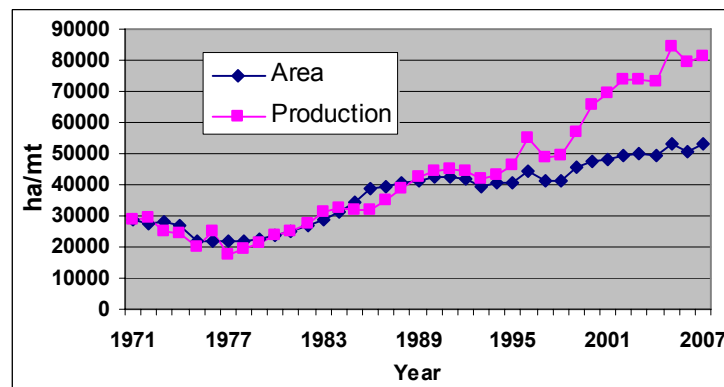
Figure 3 : The wheat area and production in Mountain

HILLS

During the wheat growing season (November/December to April/May) in the Hills Region, the rainfall is about 100 to 200 mm with higher distributions in the Western Hills than the Eastern Hills. Therefore, the cultivation of wheat area is more in the Western Hills than the Eastern Hills as

shown in Figure 2. Mean annual temperature during the growing period in the Hills ranged from 9°C to 24°C. The Hills region showed nearly three fold increase of area and the yield showed 100% increase during the same period from 1970/71 to 2006/07. The gap of the area and production showed a change after 1988 in the Hills (Figure 4). The production of wheat in the Hills region increased from 82,800 mt to 436,852 mt during the study period. In fact Hills region as defined include only 35.6% of the total wheat area and contributes 32.5% of the total wheat production in the country.
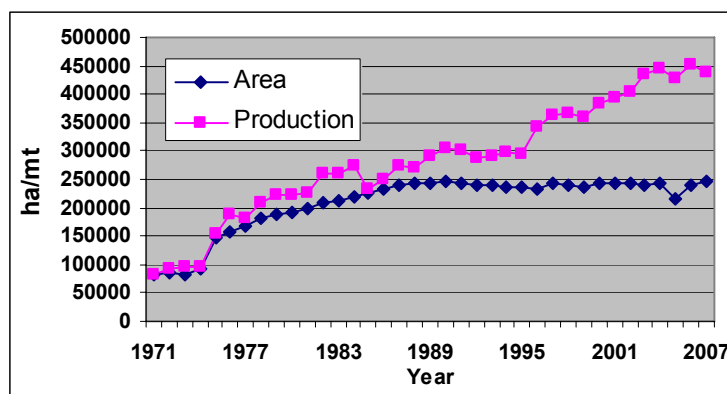
Figure 4 : The wheat area and production in Hills

TARAI

The wheat is grown during winter (November/December to March/April) in Tarai. During this period about 2 to 5 percent (less than 100 mm, more precisely 30-90 mm) of seasonal rainfall occur in the Tarai. These winter rains are very irregular and erratic in nature. In Nepal, 70 to 90% of rainfall occurs in the summer monsoon and the rest of the months are almost dry. Distribution of winter rainfall is more in the Western Tarai than in the Eastern Tarai. The winter rain caused by westerly disturbances originates from the Mediterranean Sea. Annual mean temperature during the growing period of wheat in Tarai is 15°C to 30°C. In fact Tarai region as defined include only 56.9% of the total wheat area and contributes 61.8% of the total wheat production in the country.

During the last 36 years period from 1970/71 to 2006/07 (Figure 5), the production of wheat in the Tarai region increased from 81,600 mt to 997,283 mt. It is interesting to note that the wheat yield in Tarai was initially lower. After the introduction of high yield varieties and irrigation facilities, the yield increased more than those of the Hills and Mountain. In Tarai alone area under wheat increased by 350% and its yield increased three fold. The harvesting of wheat is about a week earlier in Western Tarai than in the Eastern Tarai due to the temperature differences.
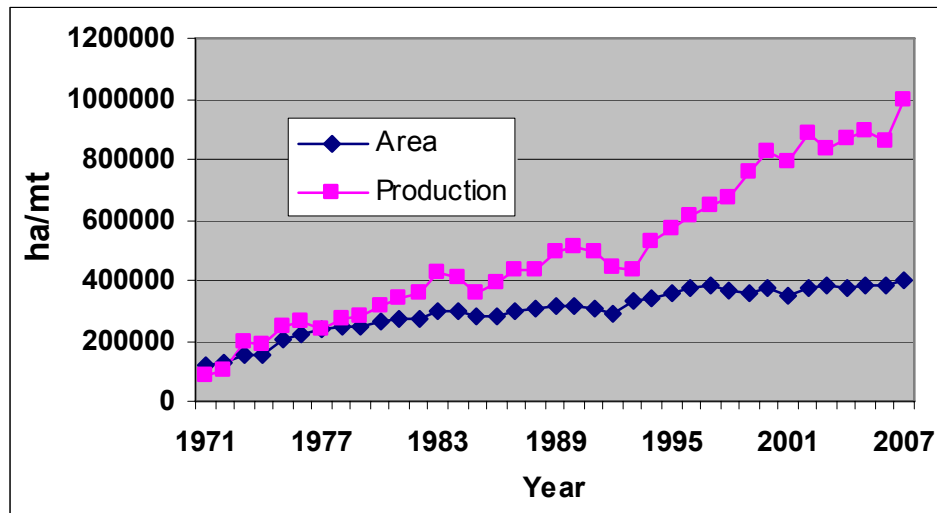
Figure 5 : The wheat area and production in Tarai

In terms of development of wheat at three different ecological belts, the productivity is measured by yield and therefore the yield at three ecological belts are presented in Figure 6, which shows that the yield is much higher in Tarai than in the Hills and the Mountain region.
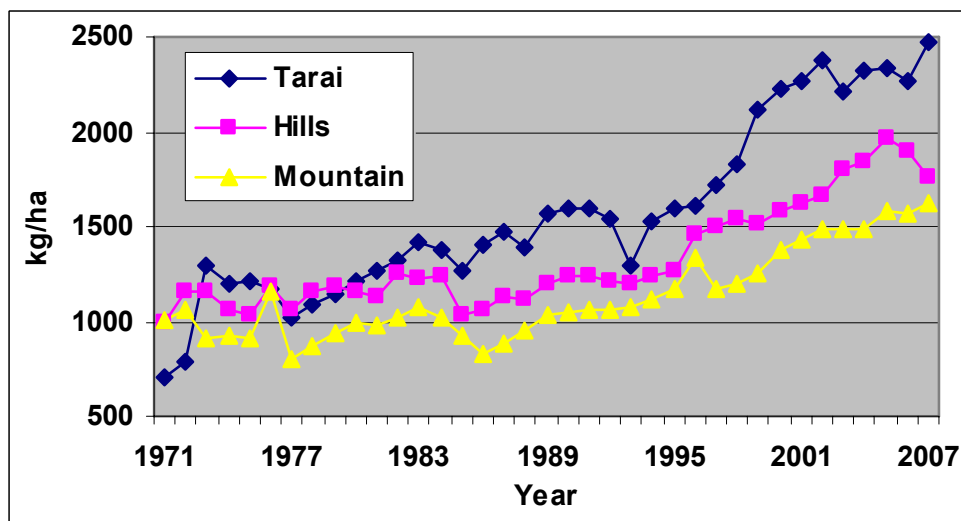
Figure 6 : The wheat yield at three ecological belts

But it is interesting to note that after peak area of wheat achievement in 1983, the decrease of wheat cultivation was noted up to 1998 and latter the area of wheat has been increasing trend. Another puzzling factor, the yield showed sharp up and down in different years. A similar study was attempted on variations of rice yield with rainfall in Nepal and a crucial relationship between rainfall and rice yield was noted even in national as well as regional scale (Nayava, 2008). The relationship between rainfall and wheat yield is very complex due to non availability of data on irrigation applications. It is certain that rainfall distribution in February and March had a very good impact on yield. There seemed that the most of the up and down cultivation of wheat area was a result of October rainfall and it helped as residual moisture during planting time. Therefore, it is certain that weather and climate still plays an important role in the increase of area and production of wheat in Nepal.

CLIMATE CHANGE AND THEIR EFFECTS ON WHEAT

During 1977-2006, the annual warming in the three different climatic region, namely, Jumla, Surkhet and Bhairhawa) have observed 0.03^0 C, 0.03^0 C and 0.003^0C. Similarly maximum and minimum temperature trend during the wheat growing season were also analyzed. The wheat growing season covers two seasons and therefore the analysis of trend analysis was done for two periods during November to February as winter season and March to May as Pre –monsoon season. There was a little higher trend of maximum temperature in higher altitude than the lower altitude. The lower region showed negative trend in maximum temperature, which is very small. Due to frequent cold waves in the Tarai as mentioned before, the temperature were dropped considerably during winter months. Cold waves had occurred during late December and January. But for wheat yield and production is concerned, temperature regimes from November to whole of March are very important especially for the Tarai region. But in the Hills, yields are more affected by drought rather than temperature regimes (Bhatta, 2008).

The trends of maximum and minimum temperature during March to May were also not so significant .The temporal variation of rainfall in Nepal during 1971- 2000 was also studied by Nayava, 2004.The study showed that there seemed no fixed trend of annual rainfall in Nepal, but the author further remarked that the rainy days seemed to decrease and the intensity of rainfall appeared to increase.

Recently the effect of climate change to agriculture in Nepal was also studied by different researchers. The latest report shows that the there is positive role in percentage change in wheat yield in all the agro-ecological zones. With doubling of carbon dioxide, wheat production is likely to increase with adoption of more heat tolerant varieties (Sharma, 2007). The study of present variation of climatic parameters such as rainfall and temperature in the crop yield should be regularly studied and discussed. The diurnal variation as well as short term temperature such as weekly and ten days mean with reference to daily temperature are needed to see the relation between climatic parameters with crop cycle. Recently the trend of minimum temperature was observed to have increased during February and March in 2006 and the rainfall was nil during November to February, 2006. This resulted poor wheat yield in Bhairhawa (Bhatta, 2008). Similar study should attempt in different places of Nepal to verify those cases.

DISCUSSION AND SUGGESTIONS

The area of wheat cultivation in Nepal has increased drastically, by three folds, especially at the Tarai region as described earlier. Previously area of cultivation was very limited and the yield was less than 1 mt/hectare in Tarai. Now, with availability of the high yielding varieties as well as improved irrigation facilities in Tarai, wheat yield has increased more than three times in the Tarai. However, during the same period wheat yield showed 100% increase in the Hills and only 50% increase in the mountains.

It seemed that the first irrigation used to provide during the crown root stage, but how much water had been provided, the records were not available. If that was the case, the fluctuation of the cultivation of wheat may not have happened. As a second application, during the grain filling stage of the wheat, it seems that very few farmers used to apply, but this is the critical period for water deficits in wheat. At this time the weather is very dry and the rain-fed rivers are almost dry. Therefore the occurrence of rainfall during that period seemed to be very important for the wheat production in Nepal. But due to the non availability of when and how much water had been added by the irrigation and at the same time the wheat yield and production data were just aggregated at district level. In that circumstance, how much rainfall affected in wheat production was a complex issue. Therefore, It is very necessary to stress that it is very important to have the data, when, where and how much water had been added. Collecting those kinds of information by field observation, one can make the possible suggestions, how much more water is demanding due to global warming. Thus a necessary recommendation can be laid down for the future planning and crop development.

CONCLUSION

Nepal started preparing the 'National Adaptation Program of Action' (NAPA) on climate change about six years ago. However, nothing substantial has been accomplished so far. The Nepal's NAPA seems to be focusing more on the effects on tourism, biodiversity, abnormal rain, storm, rapid melting of snow and glacier formation. Though these aspects are important too, the most important effect of climate change would be on agriculture (food production). Therefore, the country should be more concerned on the negative impact of climate change on the agriculture. Shortening of winter season, summer season getting hotter and erratic rainfall patterns as a result of climate change could have serious adverse impact on agriculture.

The Ministry of Agriculture and Cooperatives in the Government of Nepal should be very serious and immediately establish a working committee on climate change impact on agriculture. A country can not wait until the last minute and they have to fully prepare before any catastrophic consequences. Nepal has very few studies on weather, climate and crop relation studies. It is high time to know the variation and trend during the past climate data and their relation to crop in detail. Any extreme occurrence of weather and climate event may damage the crop. Now it is known only that the global warming has been taking place since 1970's and may increased 3 to 6^0 C during this century. This message is not enough for agriculture and therefore you have to know, what is going on at the different places in the country and what can be done. Specially Nepal is such a unique country in the world and has a diverse climate within a short distance and its biodiversity are so rich. Therefore a bird's eye view or close watch is very necessary through studies.

ACKNOWLEDGEMENTS

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Correlations Between Mass Transport Processes and Ion Concentration Distributions in Loei River and Mekong River, Thailand

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ABSTRACT

Major ion concentrations and trace metals in natural water of two rivers were analyzed with the aim of correlating mass transport processes and ion concentration distributions. Study areas were located in ten sampling sites of Loei River where covered approximately 160 km long in Loei province. Analytical results in Loei River were compared to the results in Mekong River during summer time in April. The distance of both Rivers was totally 388.3 km long and 21 sampling sites. Water sampling locations were mostly closed to local community. Major cation (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anion (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-) were compared to accumulative distances along Loei River and Mekong River. Concentrations of major ions in Loei River were more variable than Mekong River. Water type of water samples in Loei River initially was Ca-HCO_3 and changed to Ca-SO_4-HCO_3 and finally became Ca-SO_4. Along this River, ion exchange occurrence from upstream to downstream area was HCO_3^- to SO_4^{2-}. On the other hand, all cations nearby the estuary were suddenly varying when reached to Mekong River. Even though, Mekong River showed more consistency of ion concentration than Loei River, ion exchange processes were even strong appearance and reflected by the variety of ions in the water type, such as Ca-Mg-HCO_3-SO_4, Ca-HCO_3-SO_4 and Ca-Mg-Na-HCO_3-NO_3, excluding Cl^-. Ion concentrations suggested a distribution of anthropogenic effect. Ten trace metals in water samples including Fe, Mn, Ni, Zn, Cd, Co, Cr, Cu, Hg and Pb were determined; however, only four of them (Fe, Mn, Ni and Zn) could be detected by Atomic Absorption Spectrophotometry. Amount of SO_4^{2-} was an important present of high concentration of trace metals. The present of SO_4^{2-} produced the higher trace metals. Phase mole transfers of calcite and dolomite were selected for this study. Additionally, redox mole transfer of Fe^{3+} was also chosen. They were analyzed by PHREEQC computer program. Upstream area of Loei River should have limestone (or calcite) as of a host rock. Also, the recharge area was lack of Fe^{3+}. Several ions transported to the Rivers and Fe^{3+} was still sustain and not transformed to other ions. Both mole transfers could explain significantly well the variation of mass transport processes.

Key words: Mass Transport, Water Type, Trace Metals, Loei River, Mekong River

INTRODUCTION

Chemical mass transport model is very useful to predict trace metals and heavy metal distribution through the surface water or ground water. Several models are created for these predictions, such as MINTEQA2, OTIS, PHREEQC [1, 2]. Chemistry of masses when they changes to variation of surroundings or environments is mainly affected by physical, chemical and biological factors. Ion prediction is one of the crucial methods for selection of the risk assessment of pollutants or toxic materials to water sources. This work aims to integrate chemical data, particularly water quality, to understand the chemical processes which regulate the ion transport in Loei River and compare to Mekong River. The AquaChem computer program and PHREEQC model are tooled to overcome the chemical transport analysis. However, the particular water qualities in each area depend on the geological characteristics and the effect of human activities.

Loei River is a short river in Loei province, around 120 km long, and interconnected to Mekong River to the north direction. Loei province is located in the upper north of the Northeast of

Thailand. The tectonic effect of Himalayan Orogeny during the late Cretaceous caused the land more complexity. Thus, it is one of the most mineral complications in Thailand. The important mineral ores, such as gold, iron, copper, manganese, zinc were found in Loei province. Impact of mineral deposits on water quality of Loei River is not well understood especially trace metals and heavy metals. Major ion and trace metal distributions were examined to compare each of them transporting from place to place. In addition, the hydrodynamics is the important factors for this study. Moreover, there are many parameters affected the chemical mass transport of the river which is hardly revealed anything.

STUDY AREAS

Loei River is sited only in the Loei province. Upstream of this River occur in Phu Kradung and flow upward to the North (Figure 1). Water source of the River is mainly provided for agriculture use. Principally large flood plain is located in Amphoe (or District) Wang Sa Phung. Many fish ponds, for example, tilapia, cat fish can be seen along the River. Moreover, this area is still embarked with several small to medium industrials nearby the River. Mining industrials are highly active within these catchments. Base metal sulphides are generally found in Loei province, for example iron, manganese and copper. In addition, the gold mines "Phu Tup Fah" is located in this region. Depending on geology, heavy metals from mineral deposits may transport into the Rivers.

Loei catchments have approximately 1,200 km^2. Water current from Loei drainage basin flows to Mekong River with an average of 555 m^3/year [3]. Sampling sites (Figure 2) base on topographic map (1:50,000) covers to Mekong River (Table 1). Sampling locations were managed entirely Loei River and some part of Mekong River from an estuary (Loei River) to Nong Khai province. Sample number 1-10 and 11-21 (Table 2) were the sampling sites in Loei River and Mekong River, respectively. Water samples were collected during summer time in April (2005). Typically, the lowest water level of the River occurs in summer especially in March. However, water level depends on the season.
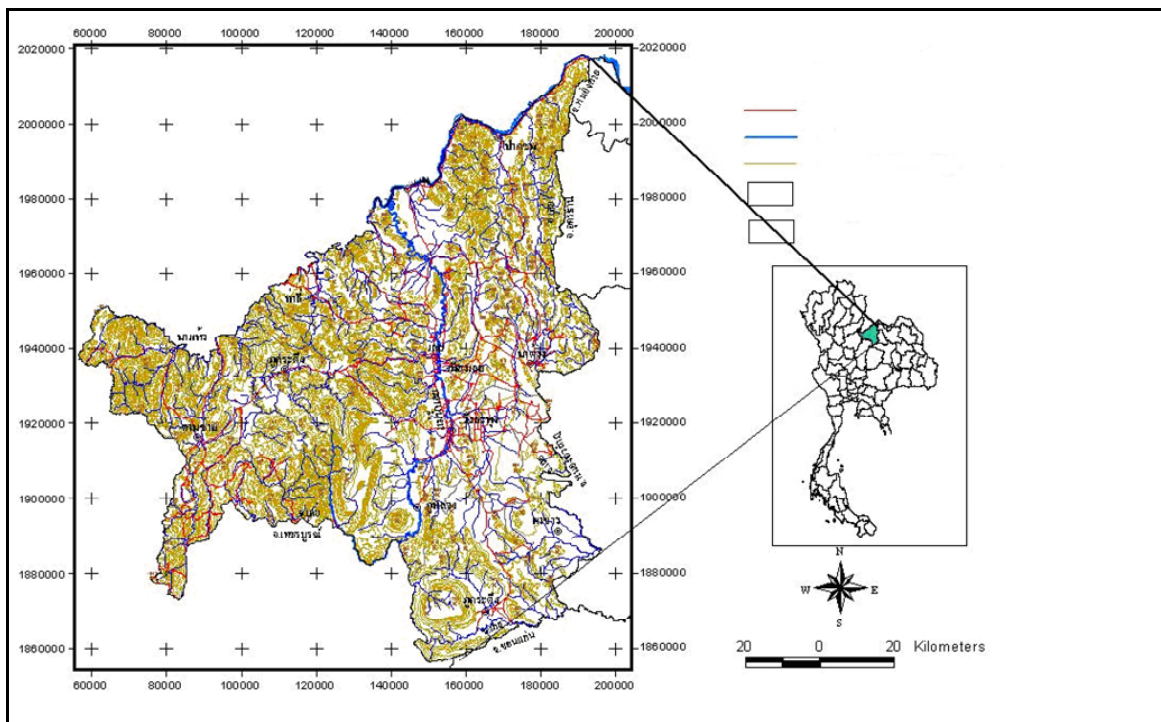
Figure 1 : Topographic map of Loei province displaying Loei River interconnected to Mekong River in Chiang Khan, Loei province, Thailand

Table 1 : Map sheet (scale 1:50,000) of the study areas where covered entirely Loei catchment areas

Name of Map Region	Map Sheet
Amphoe Wang Sa Pung	5343 I
Amphoe Phu Luang	5343 III
Loei Province	5343 IV
Ban That	5344 III
Ban Sup	5344 II
Amphoe Chiang Khan	5344 IV
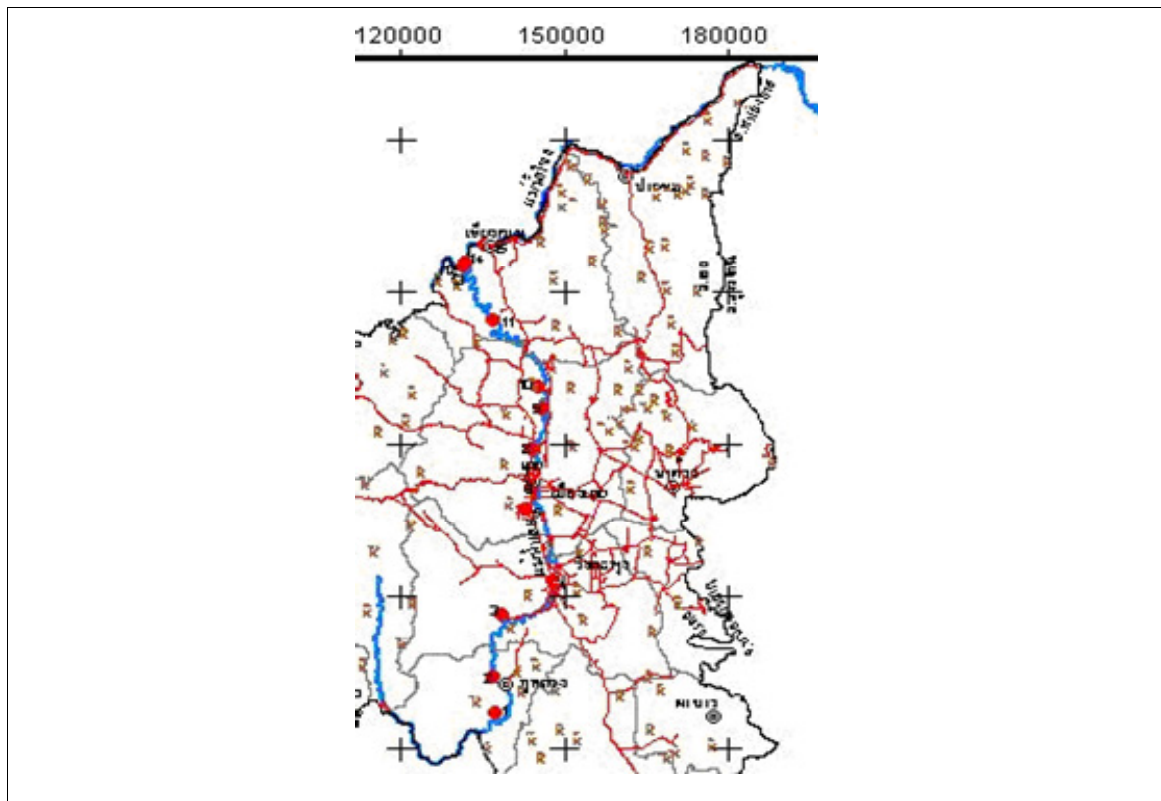
Figure 2 : Sampling sites of study areas along Loei River and some part of Mekong River (Loei to Nong Khai province)

EXPERIMENTAL DESIGN AND PROCEDURES

Some parameters, pH, temperature and electrical conductivity (EC) were determined on sites in the river at the sampling locations, as indicated in Table 3. Water samples were collected from interested locations on the River. For example, selected sites were closed to agricultural areas or communities where the River flows through. Water samples were preserved and analyzed major cations (Na^+, K^+, Mg^{2+}, Ca^{2+}), major anions (Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-) and also trace metals. All major cations and trace metals were examined by Atomic Absorption Spectrophotometry (AAS). Major anions, SO_4^{2-}, NO_3^- and Cl^- were determined by Flow Injection Analysis System (FIAS). However, HCO_3^- was analyzed by titration. Ten trace metals in water samples including Fe, Mn, Ni, Zn, Cd, Co, Cr, Cu, Hg and Pb were determined at the Department of Geotechnology, Faculty of Technology, Khon Kaen University, but only four of them (Fe, Mn, Ni and Zn) could be detected. Other trace metals presented concentrations below the detection limit by AAS. Total dissolved solids (TDS) were determined by drying method at 105-110 ^{0}C.

Two computer programs, AquaChem and PHREEQC, were used for analyzing all data. The AquaChem basically simulated the water type whereas the PHREEQC principally simulated the mole transfer of chemical mass transport. Analytical results of major cations and anions were plotted as shown in Figures 3-6. Concentrations of trace metals and mole transfers of both Loei and Mekong River were explicated in Figures 7-8.

Table 2 : Sampling locations with grid references and accumulative distances

Sample ID	Grid References	Location	Distance (km)
1	47785444/1895718	Phu Luang, Loei	0
2	47785151/1904640	Wang Sa Phung, Loei	19.85
3	47794510/1913131	Wang Sa Phung, Loei	34.90
4	47794861/1915872	Wang Sa Phung, Loei	40.55
5	47790188/1928054	Muang, Loei	59.55
6	47792414/1928696	Muang, Loei	64.25
7	47790900/1933100	Muang, Loei	70.50
8	47790614/1935099	Muang, Loei	73.20
9	47787918/1959728	Muang, Loei	116.95
10	47777291/1926547	Chiang Khan, Loei	159.45
11	47776437/1975716	Chiang Khan, Loei	188.95
12	47781350/1980159	Chiang Khan, Loei	197.00
13	47788973/1981896	Chiang Khan, Loei	205.75
14	47812474/2001855	Pak Chom, Loei	252.50
15	47211804/1999249	Sang Khom, Nong Khai	296.75
16	48243877/1987095	Sri Chiang Mai, Nong Khai	320.30
17	48255227/1973217	Muang, Nong Khai	337.65
18	48244671/1974893	Tha Bo, Nong Khai	356.65
19	48257775/1977606	Muang, Nong Khai	363.25
20	48271606/1986084	Muang, Nong Khai	380.35
21	48278749/1989125	Muang, Nong Khai	388.30

Table 3 : Some parameters (pH, temperature and electrical conductivity, EC) determined at the sampling sites and water type from AquaChem computer program

Sample ID	pH	T (^{o}C)	EC (μS/cm)	TDS (mg/L)	Water Type
1	7.45	26.78	269	232.0	Ca-HCO3
2	7.17	28.25	183	136.9	Ca-HCO3
3	6.88	25.29	556	328.6	Ca-SO4-HCO3
4	7.01	28.31	599	294.2	Ca-SO4-HCO3
5	6.99	23.73	304	203.8	Ca-Mg-HCO3
6	7.15	28.03	515	246.6	Ca-Na-Mg-SO4
7	6.83	29.32	558	286.4	Ca-SO4
8	6.83	28.48	604	290.8	Ca-SO4
9	7.34	26.34	536	286.7	Ca-SO4-HCO3
10	7.81	25.95	452	229.0	Ca-Mg-Na-SO4-HCO3
11	7.72	23.81	281	197.8	Ca-Mg-HCO3-SO4
12	6.83	24.02	282	193.6	Ca-Mg-HCO3-SO4
13	7.01	23.68	278	200.7	Ca-Mg-HCO3-SO4
14	7.23	23.42	276	219.1	Ca-HCO3-SO4
15	7.39	24.36	229	217.7	Ca-HCO3-SO4
16	7.12	24.23	280	199.4	Ca-Mg-HCO3-SO4
17	7.61	24.16	281	179.9	Ca-Mg-HCO3
18	7.16	23.85	283	195.9	Ca-Mg-HCO3-SO4
19	7.52	25.29	286	208.5	Ca-HCO3
20	7.17	25.19	287	196.5	Ca-Mg-HCO3-SO4
21	7.52	25.75	290	171.0	Ca-Mg-Na-HCO3-NO3

CHEMICAL DATA CHARACTERISTICS

Major Ions

Major ion concentrations both cations and anions were compared to accumulative distances along Loei River and Mekong River (Figure 3). Concentrations of major ions in Loei River were more different than Mekong River. Water type of water samples in Loei River was initially Ca-HCO$_3$ and then transformed to Ca-SO$_4$-HCO$_3$. During this alternation, other cations, such as Mg and Na exchanged and shared together. The end of the water type changing was Ca-SO$_4$. Ion exchange from upstream to downstream area was HCO$_3^-$ to SO$_4^{2-}$ along Loei River. Thus, Ca^{2+} and HCO$_3^-$ were majority among other ions. However, nearby the estuary (sample #10), all cations were suddenly varying when reached to Mekong River. Water type was complicated and showed all ions of Ca-Mg-Na-SO$_4$-HCO$_3$, except Cl$^-$. In Mekong River, major ion concentrations of Na$^+$, K$^+$ and Cl$^-$ were less alteration and more steady than the others.
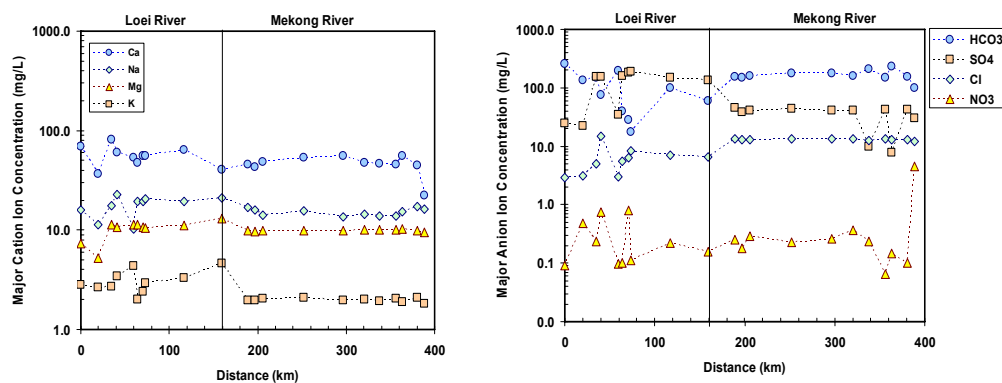
Figure 3 : Concentrations of major cations and anions with the sampling distance in Loei and Mekong River

A straight line of 1:1 ratio drawn between sodium ion and chloride ion concentrations at Loei River and Mekong River provided a theoretical balance combination line (Figure 4). Concentrations of sodium and chloride ions of Loei River were more diverge than 1:1 ratio when related to concentrations in Mekong River. The difference came from the analytical results of sodium ions (not chloride ions), which were greater than chloride ions of Loei River. When comparing to other ions-sulphate and calcium ions in Figure 5, sulphate ions presented highly distribution than chloride and calcium ions. Moreover, concentrations of all ions in Loei River were obviously more dispersed concentrations than the analytical results in Mekong River (Figure 6).
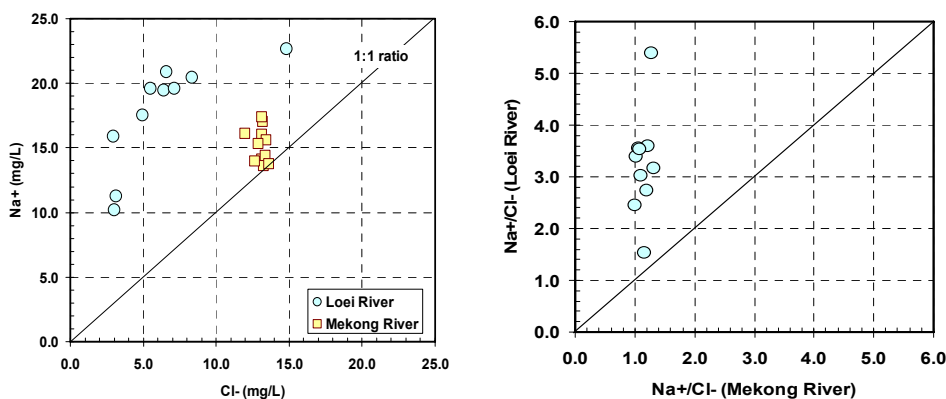
Figure 4 : Concentrations of sodium and chloride ions with the straight line of 1:1 ratio and sodium/chloride ratio between Loei River and Mekong River

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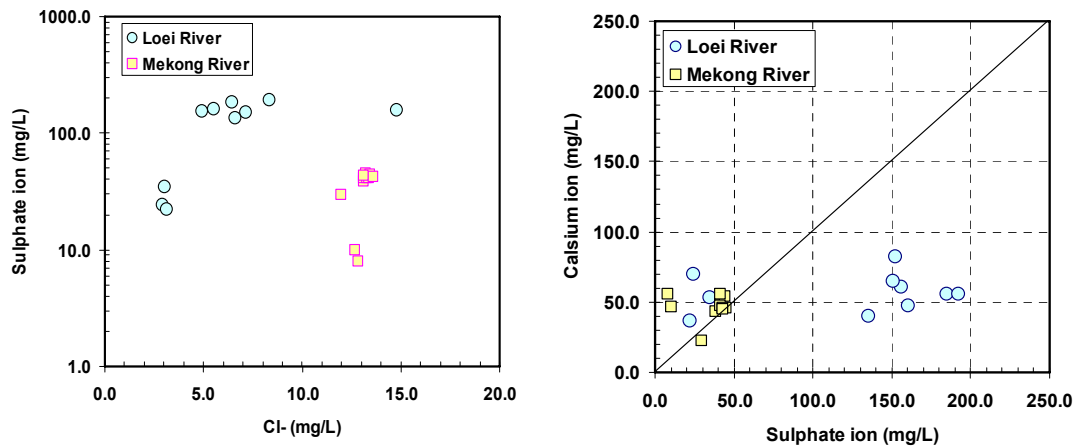
Figure 5 : Relationship of two couple ions of SO_4^{2-}- Cl^- and Ca^{2+}-SO_4^{2-}
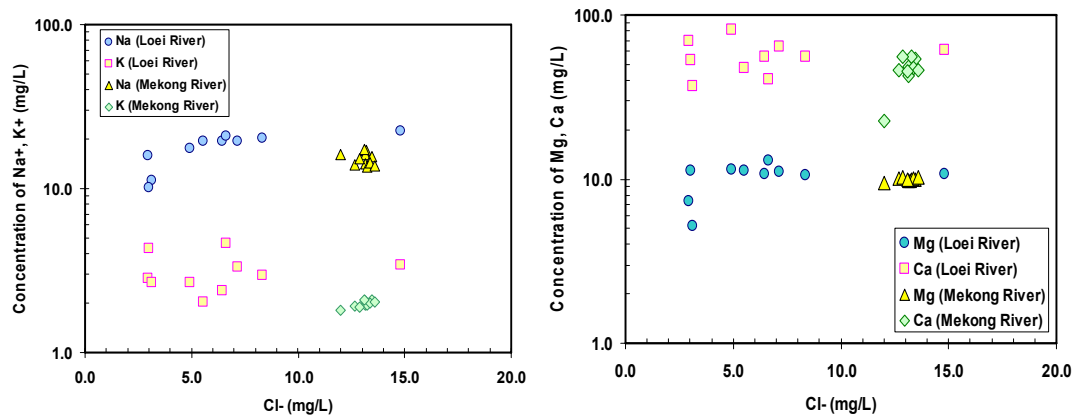
Figure 6 : Concentrations of Na^+, K^+, Mg^{2+} and Ca^{2+} as a function of Cl^- compare to Loei River and Mekong River

Source of the ions originated from host rocks which were chemically weather and transport by water or flood to streams and rivers. Calcium and bicarbonate ions were dominant at the beginning. Among other cations, calcium ions were always the main cations both in Loei and Mekong River. Bicarbonate ions were coordinated by a multiplicity of processes. Upstream area has basically bicarbonate resource. Thus, concentration of bicarbonate ions indicated considerably recharge areas. Nature of mineralization was reflected by Ca^{2+} and HCO_3^-. These ions may be reflected carbonate mineral weathering. The relatively high concentrations of HCO_3^- and SO_4^{2-} substituted each other by ion exchange during transportation processes along the River. An estuary at Loei River (Sample ID # 10) presented variations in mixing ions.

Trace metals

Analysis of 10 elements, Fe, Mn, Ni, Zn, Cd, Co, Cr, Cu, Hg and Pb, was determined in water samples from Loei and Mekong River. The analytical results indicated that samples contained only Fe, Mn, Ni and Zn. Other trace metals were presently less concentration than the detection limit by Atomic Absorption Spectrophotometry. In natural water, the ions of Fe, Mn, Ni and Zn were rather common species (Figure 7). Trace metals at an estuary of Loei River presented concentrations of Mn and Fe below their average concentrations, around 10 times for Mn and 2 times for Fe. Also, comparison to Loei and Mekong River, the intensities of Mn and Fe for Loei River were greater than Mekong River roughly 10 times for Mn and 2 times for Fe, respectively. Furthermore, concentration of Zn was slightly increased in Loei River than Mekong River, but concentration of

Ni did not change among both Rivers. Ions of Mn and Fe remained predominantly dissolved in the River. Trace metal concentrations in Loei River were considerably greater than those Mekong River due to a higher ratio of surface water to ore deposits of base metal sources.
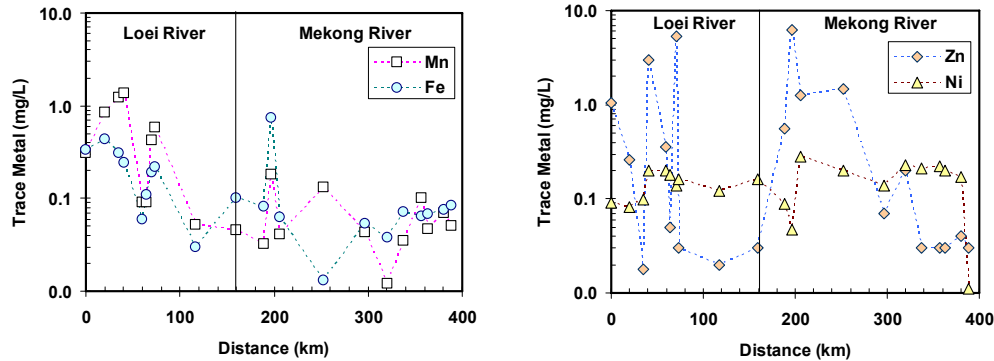
Figure 7 : Concentrations of Mn, Fe, Zn and Ni of both Loei and Mekong River

Mole Transfer

Phase mole transfers (as of calcite and dolomite) and redox mole transfer (as of Fe^{3+}) were analyzed by PHREEQC software program [4]. Among major cation, Ca^{2+} and Mg^{2+} were dominant in natural stream water. Chemical weathering of calcite and dolomite has influenced to upstream of Loei River. Thus, high calcite and dolomite mole transfers were found in upstream area more than downstream area (Figure 8). Mole transfer of calcite did not present every area of sampling locations. Ion exchange from Ca^{2+} and CO_3^{2-} to other ions was highly happened during movement. The pH value was an important factor for this criterion. However, redox mole transfer of Fe^{3+} was exhibited opposite appearance of phase mole transfers of calcite and dolomite. Ion of Fe^{3+} was less transferring electron in upstream area of Loei River. The lowest value of redox mole transfer of Fe^{3+} was located in the estuary (~ 160 km). The plot of redox mole transfer of Fe^{3+} and distance in Figure 8 displayed about zero or no Fe^{3+} redox mole transfer in natural stream water.
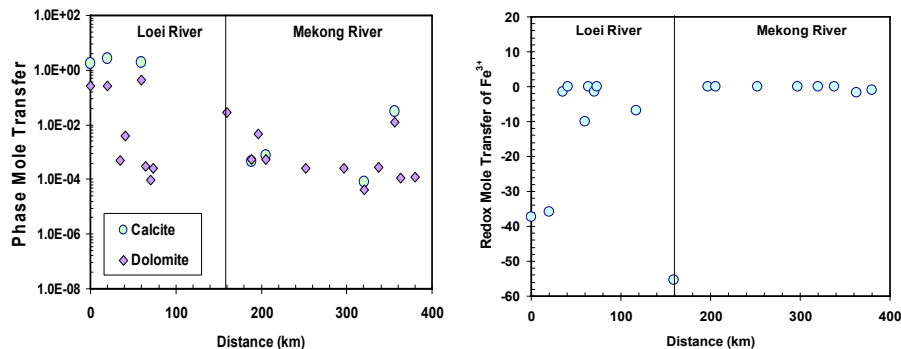
Figure 8 : Mole transfers as a function of distance compare to Loei and Mekong River

DISCUSSIONS AND CONCLUSION

The chemistry of water in Loei River was varying higher than Mekong River. Stream water in Loei River during summer was slowly flow and not as much of water. Depth of water level at upstream was high only 20-30 cm and increasing along downstream area to an estuary. Agricultural activities were relatively less in summer. However, anthropogenic activities were still consistent. These activities and geological characteristics of the study areas may drive transport processes of mass or ions in water. Length and size of Loei River are reasonably short and small compare to Mekong River. The analytical results indicated that, in general, the distance on both Rivers had not clearly

effect on ion concentrations in natural water. High and low ion concentrations suggest a dispersal of anthropogenic effect.

At the beginning, the Ca^{2+} and HCO_3^- in Loei River likely related to the dominant recharge area. Processes of ion exchange between Ca^{2+}-HCO_3^- and Mg^{2+}-SO_4^{2-} were directly influence by transferring through the River. Major ions on the water type of Ca-Mg-Na-SO_4-HCO_3 presented more complicated at the Loei estuary. Although, Mekong River showed more consistency of ion concentrations than Loei River, ion exchange processes were even strong appearance and reflected by the variety of ions in the water type, such as Ca-Mg-HCO_3-SO_4, Ca-HCO_3-SO_4 and Ca-Mg-Na-HCO_3-NO_3. Stream sediments in Mekong River were more substantial than Loei River. Adsorption and desorption processes were an important cause of trace metals ions to precipitate or dissolve within the Rivers. Concentrations of some trace metals, Fe, Mn, Ni and Zn, can determine from the natural Rivers. Mining activities of limestone, copper, iron, manganese and gold mines may activate the major sources of mineralization which leached trace metals to stream. The quantity of SO_4^{2-} was an important supply of high concentration of trace ions of the Rivers. The greater SO_4^{2-} produced the higher trace metals, especially Ni and Zn.

Because of principally Ca^{2+} and HCO_3^- at first, phase mole transfers of calcite (and dolomite) were selected for study. Moreover, redox mole transfer of Fe^{3+} was also chosen. Turbulent flow of water in rivers can maintain Fe (III) better than Mn, Ni and Zn. These phase mole transfers (calcite and dolomite) and redox mole transfer of Fe^{3+} can significantly well explain the variation of mass transport processes. Upstream area of Loei River should have limestone (or calcite) as of a host rock and recharge area was lack of Fe^{3+}. Several ions transport to the Rivers and Fe^{3+} was still sustain and no transfer to other ions. Naturally, Fe^{3+} should not change form which indicates no electron transfer in redox reactions.

Dissolved concentrations of ions or trace metals lead to monitor water quality. These studies are very useful to assess contaminant sources and evaluate coverage for risk analysis which impacts potentials of particular water quality in the future. Ion transport processes are not simple to understand. Sometimes, computer simulations can be used to evaluate the complex chemical reactions for the best solution of ion concentration distribution. Many complicated factors should be further studies and compare to other rivers and estuaries. Finally, ion compositions could indicate the different sources of contamination.

Acknowledgements

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Contemporary flood frequency, fluctuations and trends of changes in water discharge in the piedmont course of the Vistula River, Southern Poland (Central Europe)

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ABSTRACT

Regular measurements of river discharge in the piedmont course of the Vistula River at the foreland of the Carpathian Mountains (Southern Poland) were started after 1930. The first conclusions concerning the trends of changes of river discharge in this area related to long-term precipitation changes and human impact became formulated in the 1960s and 1970s. There were even contradictory opinions indicated the increase or decrease of water discharge. Not earlier than in the 1990s, having long enough series of measurement results, was it possible to notice true changes in trends of water discharge. Until now and since 1930 there has been one full 40-year- long cycle in water discharge, with a maximum in about 1970 and minimums in about 1950 and 1990. These fluctuations of water discharge are shown by the changes of average annual river discharges and by variable in time frequency of large high water stages. The frequency of large high-water stages increased again in the mid 1990s. There are also visible ca. 10-year fluctuations of rivers discharge caused by clustering of large high-water stages in several-year long periods. The distinguished cycles of the piedmont Vistula's discharges refer to fluctuations of the lower course of the Vistula discharge known from the literature, which are approximately 24,0–36,5 years long or 53,0–57,0 years long, as well as to the cycles 12,5–14,0 years long. They refer also to the discharge cycles recorded in other European rivers. The fluctuations are still noticeable, despite the increasing number of large dams. Increasing or decreasing trends in water discharge of the river indicated in earlier papers, referred to the time period before and after 1970, and therefore were assumed as not representative for a long term period. The present data series, even longer than 70 years, are more credible, but still not suitable enough for the prognosis of the changes of water discharge of the river in the period longer than at least half of a 40 year- long cycle.

Key words : discharge fluctuations, flood frequency, floodplain inundation, upper Vistula River, foreland of the Western Carpathian Mountains

INTRODUCTION

The results of regular at least several-decade-long measurements of river discharge make it possible to determine not only the trend of changes in a runoff, including multi-annual changes in water resources of the drainage basin, especially mountain once, but also runoff fluctuations of different period. The investigations of the frequency of floods, not necessarily synchronic with runoff fluctuations may comprise much longer periods than those determined by hydrological observations. The investigations concerning these problems have been carried out for over 20 years on some European rivers, including the largest river in Poland, the Vistula and its tributaries, mainly upper once (Jeż et al., 1987, Probst, 1989, Babiński, 1992, Gutry-Korycka, Boryczka, 1993, Bogdanowicz, Stachý, 1995, Stachý et al., 1996, Lajczak, 1999).

The aim of this paper is to show some regularities in changes of mean annual discharge in selected water-gauging stations along the piedmont course of the Vistula at the Carpathians foreland in the period 1930s – 1995. The analysis is shown on the background of changeable in time frequency of large high water stages in this river and its mountain tributaries from the second part of the 18th century to the beginning of the 21st century.

INVESTIGATION AREA

The Vistula is the longest river in Poland (1047 km) and its drainage basin covers the area of 199813 km². The mean discharge at its mouth is 1100 m³ s⁻¹. The upper piedmont section of the river drains the northern slope of the Western Carpathians built mainly of flysch sediments, the southern slope of the upland area, and also the sub-Carpathians basins of lowland character. This section of the river, from the river outlet from the Carpathians to the lowland foreland, until the water-gauging station at Zawichost located directly below the outlet of the last mountain tributary, is 359 km long, and the Vistula's drainage basin until Zawichost covers an area of 50545 km² (Figure 1). The highest and lowest altitudes in the drainage basin account to 2655 and 135 m a.s.l. The Carparhians, the upland areas, and the lowland areas, make 45, 20 i 35% respectively of the drainage basin's area until Zawichost. Total percentage of rivers draining these areas in recharging of the piedmont section of the Vistula accounts to 80, 17 and 3% respectively (Lajczak, 1999). The precipitation in this area is from 600 to over 2000 mm with a maximum value in summer months. A mean discharge of the Vistula downstream the outlet of the last mountain tributary is 450 m³ s⁻¹ and maximum discharge is 7450 m³ s⁻¹. The location of the upper Vistula drainage basin in the transitional climate between the areas of oceanic and continental regime of water runoff results in occurring of large high water stages caused by rainfalls and early-spring thawing, which take place every couple of years. In the annual cycle, the largest discharge is recorded in summer, and in lower located areas in early spring. In these seasons, the largest high water stages occur, however summer high water stages reach the highest values.

The dynamics of water runoff in the Carpathian part of the Vistula drainage basin has been modified by human impact – until the half of the last century mainly by deforestation of the mountain part of the drainage basin and its agricultural colonisation, and then by forestation of this area and increasing number of water dams. The intensity of hydrological processes in rivers since the 19th century considerably depends on regulation works leading to straightening, narrowing and deepening of river channels (Lajczak, 1995a).

MATERIALS AND CALCULATION METHODS

The published results of hydrological measurements in the upper Vistula drainage basin including water stages and river discharges were analysed. The data concerns the period 1930s – 1995. The following hydrologic values were included in the analysis: mean annual and mean 5-year long discharges MQ, mean high discharges MHQ, annual values of the duration of overbankful water stages IN at selected measuring stations on the river. Basing on different source material, changes in the frequency of large water stages on the upper Vistula and its mountain tributaries since the second part of the 18th century were analysed. Only in this case the data series finish in 2008. The analysed hydrological parameters were calculating according to valid procedures (Lajczak, 1995a, 1995b, 1999).

FREQUENCY OF LARGE HIGH WATER STAGES DURING THE LAST 200 YEARS

The Vistula, and especially its piedmont section influenced by the Carpathians, shows large frequency of high water stages, together with periods of the increasing water stages. According to Streck (1953, after Lambor 1962), a mean number of such hydrological events in a year accounts to 2.7, which puts the Vistula on a second position, after Danube among the rivers of Central Europe. Among the mountain tributaries of the Vistula, the Dunajec (draining the northern slope of the Tatras – the highest massif of the Western Carpathians), shows the largest flood potential as well as the most western mountains tributary of the Vistula – the Soła. Large flood potential in the piedmont section of the Vistula is conditioned by large precipitation in summer at the northern slope of mountain ridges in Western Carpathians, which run across the most frequent inflow of

humid air masses from the NW. It is also influenced by small retention of flysch drainage basins in the Carpathians, which are still considerably deforested and used in agriculture. The maximum flood discharges in summer in the piedmont section of the Vistula are larger than discharges during spring thawing high water stages and show rapid increase along this section of the river (Soja, Mrozek, 1990).

The analysis of historical data since 1772 supplemented with the results of hydrological investigations in water-gauging stations carried out from the second half of the 19th century reveals that large high water stages in the piedmont section of the Vistula causing the flood in the floodplain and, after the river regulation, the flood within the narrow zone of inter-embankment, occurred in the period of the last 236 years on average every 2.5 years. In this period, until the end of the 19th century, a trend of decreasing frequency of high water stages to about one event in two years in the period 1772-1800 occurred, and to one event in about 3.3 years in the period 1860-1890. In the succeeding years until 2008, the frequency of high water stages increased again and reached about one event in 3.1 years (Figure 2). This process is also conditioned by human impact and represents the result of the deforestation of the mixed forest in the Carpathians which started in the 1850s, and introduction of spruce plantation. The mountain areas covered by spruce forests have a decreased conditions of the ground retention, and more often occurred there large high water stages. This situation has occurred until present times, despite the fact that after 1920 a reintroduction of the mixed forest in the mountainous part of the Vistula drainage basin started. Taking into account a criterion of large economic stages caused by floods, large high water stages in the studied section of the Vistula in the 19th century occurred once every 4.2 years, and in the 20th century (until 1972) once every 2.8 years (Punzet, 1973). The frequency of large high water stages in the mountain tributaries of the Vistula draining the eastern part of the area studied is almost twice as small as in case of mountain tributaries draining the western, more elevated part of the drainage basin. Therefore the flood risk in the piedmont section of the Vistula develops most of all under the influence of mountain tributaries of the river located in the western part of the drainage basin. Extremely large high water stages called catastrophic occurred in the piedmont section of the Vistula river in the period 1870-2008 on average once every 10 years, which confirms the earlier view of Punzet (1981). Over the half of these events occurred during the last 50 years.

Large high water stages in the piedmont section of the Vistula cluster in short 2-6-year periods. Such phenomena occurs also in case of catastrophic high water stages. In some periods, high water stages may occur every year, and catastrophic stages every two years. On the other hands, between these periods there are periods of over five years when such event may not occur at all. Since 1910, a distinctive clustering of large and catastrophic high water stages occurred on average every 10 years. In majority of such clustered high water stages the stages assumed as catastrophic occurred. The last clustering of high water stages in the studied section of the Vistula and its mountain tributaries occurred during six years in about 2000, after a 17-year period when only three large high water stages occurred. Years after 2003, represent a next period with not so frequent large high water stages occurrence.

RUNOFF FLUCTUATIONS OF DIFFERENT PERIODS

The results of discharge measurements from the period 1931-1995 from six water-gauging stations located on piedmont section of the Vistula show multi-annual synchronic fluctuations of similar time of occurrence of the highest and lowest values in the size range MQ and MHQ (Figure 3). In these years, there was only one complete cycle of runoff fluctuations about 40-years long, with runoff maximum in about 1970, and two minimum values in about 1950 and 1990. Babiński (1992) noticed a similar character of mean annual discharges in the lower Vistula, but only until the 1980s. These fluctuations of mean annual discharges in piedmont and lower sections of the Vistula correlate with discharge changes in the neighbouring large European rivers – the lower Oder and less intensively the Elbe (Probst, 1989). Such character of changes in the rivers' runoff is convergent

with 35-year geoclimatic cycle in Central Europe (Jeż et al., 1987). About 40- year cycle of the piedmont Vistula runoff in the values range MQ and MHQ may be correlated with the presented by Bogdanowicz and Stachý (1995) course of annual precipitation totals and the course of maximum 3-day precipitation in climatologic stations located at the mountain limit and in the mountain area in the drainage basin of the piedmont Vistula (Kraków, Rabka) in the period 1921-1992. There is also a convergence of multi-annual course of mean annual discharges of the piedmont Vistula with the described by Niedźwiedź (1995) character of annual precipitation totals in climatologic station in the neighbourhood of the Tatra massif, i.e. Zakopane in the period 1901-1990.

The smoothing of mean annual discharges from the succeeding years of the period 1931-1995 in the analysed water-gauging stations on the piedmont Vistula using a binomial 5-year filter (weights 0.06; 0.25; 0.38; 0.25; 0.06) revealed the occurrence of shorter, about 10-year discharge fluctuations (from 8 to 12 years), within the value range MQ and MHQ (Figure 4). These short-period fluctuations of the runoff overlap with more long-period changes of the Vistula runoff. The described hydrological situation in the piedmont Vistula is confirmed in its lower section (Babiński, 1992). About 10-year discharge fluctuations are more visible in case of mean high discharges MHQ than mean discharges MQ, which may be explained by the effect of clustering of high water stages in several-year periods of similar periodicity as changes of MQ and MHQ. Probst (1989) distinguished short-periods (about 10 years) of runoff fluctuations in the lower Vistula basing on measurement data since 1901, which are convergent with runoff fluctuations in the piedmont Vistula after 1931. They are also convergent with analogical fluctuations of the runoff of the Oder, Elbe and Danube in the 20th century (Probst, 1989). The obtained by the Author results of investigations are confirmed in the presented by Stachý et al. (1996) mean moved 5-year values of the quotient MHQ/MQ in 12 water-gauging stations at large and medium-sized rivers in Poland in the period 1921-1990. Also Jeż et al. (1987) indicate the occurrence of short-period cycles in the runoff of large European rivers of the duration 12-18 years with a dominant 12-14 years and also 12-18-year cycles in precipitation with maximum in the interval 14-16 years.

In the period 1931-1995, a convergence between the occurrence of clustering of years with large and catastrophic high water stages and the occurrence of about 10-year fluctuations of the piedmont Vistula runoff took place. Similar situation occurred in the period 1996-2008 (Figure 5). The following regularity is characteristic: the larger discharge in the range of MQ and MHQ in the distinguished 40-year runoff cycle, the runoff culmination is the most distinctively visible in about 10-year runoff cycle. Another words, about 10-year fluctuations of the piedmont Vistula runoff are the most clear in over 20-year periods marking the largest mean discharges in the 40-year cycle, and the least clear in the years with runoff shortage. Extrapolating this regularity to the past, it may be assumed that during the last ca. 140 years the succeeding large short-period increase of the piedmont Vistula runoff occurred in the 1920s and the beginning of the 1930s, and earlier – in the 1890s, when in the frame of a 40-year cycle, the Vistula runoff reached values similar to the values from the 1960s and 1970s (compare Figure 2). Assuming the distinguished time intervals of different-period runoff values, a prognosis of the next short-period increase of the piedmont Vistula runoff may be determined, which will take place in about 2010. In that time, in this section of the river as well as in the whole its run, the largest discharges in the range of MQ and MHQ will probably occur in the next 40–year cycle.

PROBLEM OF TRENDS OF RUNOFF CHANGES

The determination of the existence of decreasing or increasing trends in the size of the piedmont Vistula runoff since e.g. the beginning of the 20th century is difficult because of overlapping of different-period fluctuations of runoff and relatively short period (only over 70 years) of runoff measurement values. Having had the values of runoff measurements from the increasing measurement period it would give the base to distinguish even opposite trend of changes in the

Vistula runoff in different years of the 20th century (Figure 6). Therefore different evaluations of trend changes in the runoff of the investigated section of the Vistula published in different years should not be surprising (Punzet, 1973, 1981, Stachý, 1984, Gutry-Korycka, Boryczka, 1993, Bogdanowicz, Stachý, 1995, Stachý et al., 1996). Even at present, such evaluation of the hitherto and forecasting changes in the runoff of the investigated section of the Vistula is difficult, which results from estimated evaluation of runoff fluctuations before 1931 and also from the fact, that it is difficult to forecast the consequences of contemporary climate changes in the conditions of growing forestation of the mountain part of the Vistula drainage basin. Measurement values from the period 1931-1995 show decreasing in that period trend of changes in the size of the piedmont Vistula runoff. It is possible, that data from mean annual discharges in the succeeding years of the present 40-year runoff cycle will let to state that trend of changes in the runoff of this section o the Vistula does not show from at least 1931 either increasing or decreasing values.

FLOOD HAZARD IN THE CONDITIONS OF REGULATED RIVER

A hydrological consequence of regulation of the piedmont Vistula and its mountain tributaries is (1) a tendency of increasing of maximum water stages in the river, (2) tendency of shortening of flood wave duration and shortening the occurrence of overbankful water stages (floodplain inundation, IN) due to the increase of discharge velocity and increase of concentration of a flood wave. As a result, not all (even large) high water stages recorded in a given section of the river are recorded in its further course as overbankful water stages (Lajczak, 2007).

In the piedmont section of the Vistula, post-regulating changes in the river channel morphology reached different size (Lajczak, 1995a), therefore, despite a similar frequency of high water stages at mountain tributaries, the duration of overbankful water stages in the succeeding years of the period 1931-1995, are different in the analysed water-gauging stations (Figure 7). Despite a decreasing trend during the period of flooding the inter-embankment zone, caused by the channel deepening, still a clusterings of years may be distinguished with elongated inundation of this zone, which express about 10-year runoff fluctuations. A 40-year cycle of runoff fluctuations is visible during the inundation of inter-embankment zone only in water-gauging stations located on river sections with not advanced channel deepening.

FINAL REMARKS

In the whole course of the Vistula river, the following runoff cycles have been distinguished: 2.0-years, 3.0-3.5-years, 12.5-14.0-years, 24.0-36.5-years, 53-57-years and 159-163-years, which mainly represent the lower section of the river. The most regular are the following cycles: 3.0-3.5-years, 12.5-14.0-yeras and 24.0-36.5-years (Gutry-Korycka, Boryczka, 1993). The distinguished 10-year runoff cycles in the piedmont Vistula correspond with 12.5-14.0-year cycles distinguished by the cited above authors. It is difficult to compare the about 40-year cycle of the piedmont Vistula with 24.0-36.5-year or 53-57-year cycles typical for the lower course of the river. Because of the fact, that estimated duration of the two earlier cycles before 1950 basing on the frequency of large and catastrophic high water stages is only approximate, the answer to the question about the duration of the next cycle (the maximum of which is expected in 2010) may be possible after continuation of hydrological measurements.

The highest runoff in the period 1931-1995 occurred in the decade 1971-1980 (Stachý, 1984), when a mean discharge in the analysed water-gauging stations was even up to 50% larger than in the decades of smaller discharge, i.e. 1941-1950 and 1981-1990. In a 10-year cycle, the highest annual discharge of the piedmont section of the Vistula may exceed the smallest annual discharge only by 25%. The results of hydrological investigations from the period 1931-1995 reveal that the most dynamic changes of the mean annual discharge of the piedmont Vistula in the range of 10- and 40-year cycles occurred in the decades showing relative surplus of the runoff, and the smallest in the decades with runoff shortage.

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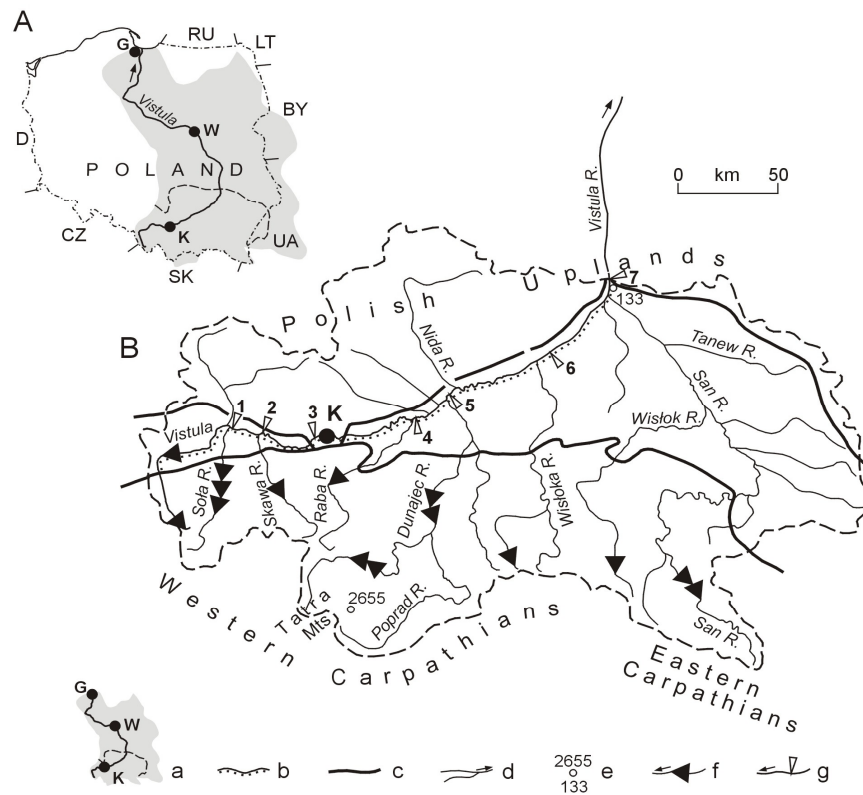
Figure 1 : The Vistula drainage basin on the background of Polish borders (A) and location of drainage basin of the upper course of the river with its piedmont section (B). a – drainage basin limit, b – the piedmont section of the Vistula, c – main geomorphological units (from north to south: Polish Uplands, Subcarpathian Basins, Carpathians), d – main rivers, e- the highest and the lowest points in the drainage basin, f – dam reservoirs (only at mountain tributaries of the Vistula), g- selected water-gauging stations, from which the results of multi-annual hydrological measurements were taken (1- Dwory, 2- Smolice, 3- Tyniec, 4- Popędzynka, 5- Karsy, 6- Koło, 7- Zawichost). K- Krakow, W- Warsaw, G- Gdansk.
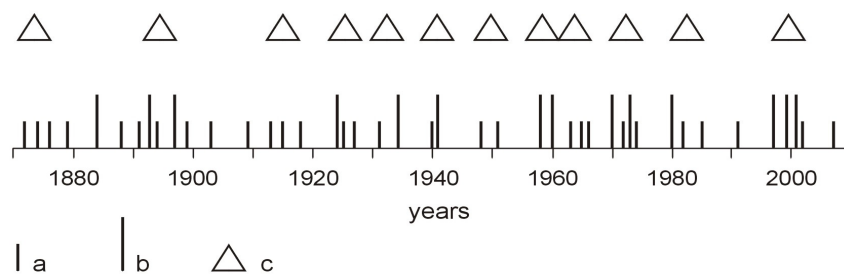
Figure 2 : Occurrence of the largest high water stages on the piedmont Vistula in the period 1870-2008. High water stages: a – large, b – catastrophic, c – main clusterings of high water stages in the periods 2-6-years.

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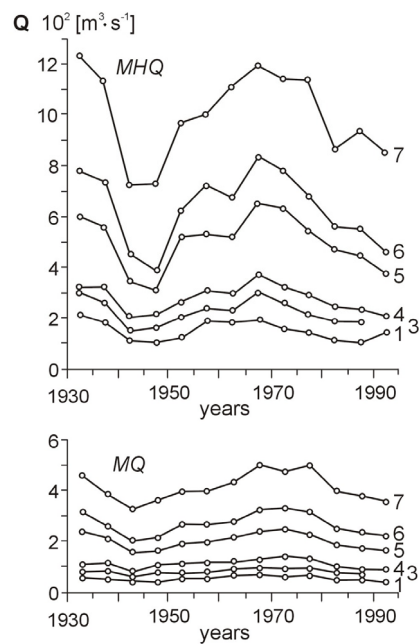
Figure 3 : Mean 5-year discharge values of the piedmont Vistula in the range MQ and MHQ in the period 1931-1995 in the selected water-gauging stations. The stations are numbered as in Figure 1.
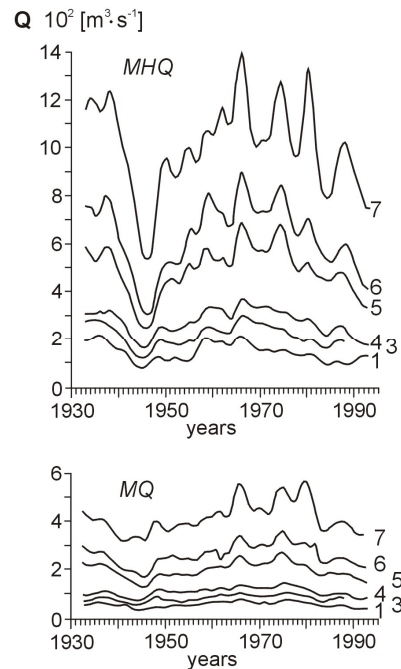
Figure 4 : Smoothed by binomial filter 5-year discharge values of the piedmont Vistula in the range MQ and MHQ in the period 1931-1995 in the selected water-gauging stations. The stations are numbered as in Figure 1.
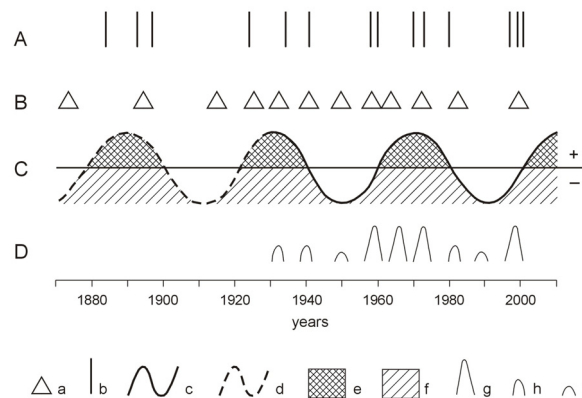
Figure 5 : A- occurrence of catastrophic high water stages, B- main clusterings of large and catastrophic high water stages, C- diagram of effective (after 1930) and probable (before 1930) about 40-year cycle of the runoff of the piedmont Vistula in the period 1870-2008, D- maximum of river runoff in a cycle close to 10 years (after 1930). a- main clusterings of large and catastrophic high water stages, b- occurrence of catastrophic high water stages, c- effective (after 1930) about 40-year cycle of the runoff of the piedmont Vistula, d- probable (before 1930) about 40-year cycle of the runoff of the piedmont Vistula, e- periods with increased runoff in a 40-year cycle, f- periods with decreased runoff in a 40-year cycle. Maximum of runoff in a 10-year period: g- the largest, h- medium, i- the smallest.
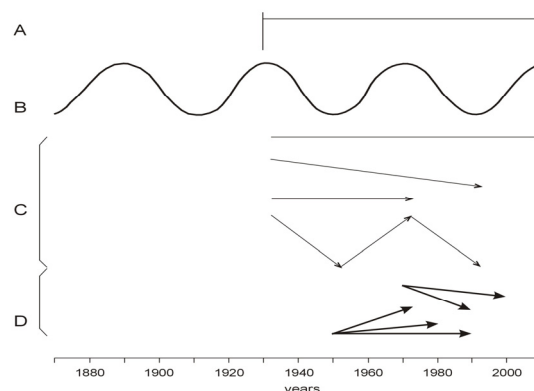
Figure 6. A- period of discharge measurements in the piedmont Vistula, B – a schematic 40-year cycle of the river runoff, C – a diagram showing trends of changes of the river runoff depending on the assumed period, D – example of trends of changes of the Vistula runoff described in literature and concerning different periods.
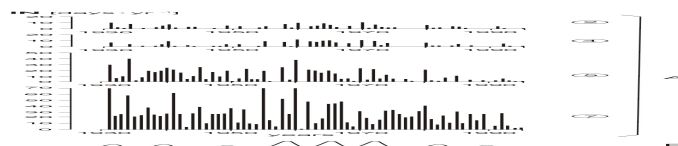
Figure 7 : A- duration of inundation, IN, of the piedmont Vistula inter-embankment zone in the succeeding years of the period 1931-1995 in the selected water-gauging stations, B-maximum of river runoff in a cycle close to 10 years (after 1930): the largest, medium and the smallest events. The stations are numbered as in Figure 1.

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Bed Roughness Estimation for High Gradient Rivers in Malaysia

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ABSTRACT

Mountain Rivers are classified as high gradient rivers typically consist of steep slope, cascading reach, torrent stream, large roughness elements, coarse and rough bed form as part of their physical characteristics. Basically, massive production of flow or discharge from the uppermost stream and flow towards the downstream are constantly affected by its flow resistance coefficient which directly influenced the velocity of flow. Thorough channel analysis is required when it comes to hydraulic computation and design in order to help reduce potential flooding caused by changes in water surface profiles. However, the ability to evaluate and select the bed roughness coefficient needs sound judgment and skill which should be developed primarily through experience. Continuous studies are still being carried out from time to time by various government agencies and private sectors in many countries to come out with approximate bed roughness coefficients for better estimation of river discharge. Apart from that, a number of researchers have also formulated empirical and semi-empirical equations in regards with various roughness characteristics of the channels such as Strickler (1923), Limerinos (1970), Hey (1979), Bray (1979), Griffiths (1981), Bathurst (1985) and many others. This paper reports the preliminary evaluations and preparation to be adopted in predicting the flow resistance coefficients (e.g. Manning, n and Darcy-Weisbach, f) for mountain areas which mainly involve surface sampling. Bed surface sediments will be sampled by using three (3) methods; Pebble Counts, Grid Counts and Areal Sampling. Basically, 100 surface sediments will be collected at high gradient rivers from different states in Malaysia and be analyzed. The sediment particles sizes namely d_{50}, d_{75}, d_{84} and d_{90} will be derived from the subsequent particle-size distributions curves. The prediction of bed roughness coefficients is to be achieved using existing equations as listed. Thus, the results will be verified and validated with field data obtain by the at-a-site approach. At the end of this research, the most suitable bed roughness prediction formula will be proposed.

Key words : High gradient rivers, Bed roughness equations, Bed roughness coefficients, Sediment size, Sampling methods.

INTRODUCTION

High Gradient River (HGR) is always associated with steep slope, entrenched confined stream with cascading reaches with deep pool and large bed material properties. Refer Figure 1 to Figure 3 that shows the typical morphological conditions of HGRs in Malaysia.

Quantification of flow velocity in high gradient river is important both for engineering problems (e.g., determination of flood hydrographs, water levels and sediment transport) and for ecological assessments (e.g., habitats, pollutant dispersion modeling). Apparently, this requires thorough flow resistance analysis which incorporates the estimation of bed roughness coefficients and should be developed primarily through experience. For over a century, various flow resistance equations have been developed although many such studies have been carried out using simplified flume modeling of the complex bed morphology that often characterizes steep channels (Comiti et. al,

2007; Peterson and Mohanty, 1960; Judd and Peterson, 1969). The uncertainty that arises from estimating the coefficients (e.g, Manning, n and Darcy-Weisbach, f) is one of the most important sources of error in the application of flow resistance equations in mountain rivers. Therefore, continuous studies are still being carried out by various government agencies and private sectors in many countries to develop verified bed roughness coefficients for better estimation of flow velocity.

ESTIMATION OF BED ROUGHNESS COEFFICIENTS IN HGR

The flow resistance relationship are a classical component of river hydraulic analysis and in mountain river, this is a complex phenomenon which are often poorly served by existing relationships and currently available formulae. There are three popular relationships linking velocity and flow resistance is the Darcy-Weisbach equation;

$$V = \left(\frac{8gRS}{f}\right)^{1/2}$$ ---(1)

The Chezy equation;

$$V = c(RS)^{1/2}$$ ---(2)

The Manning equation;

$$V = \frac{R^{2/3}S^{1/2}}{n}$$ ---(3)

Where V is the mean velocity, R, hydraulic radius, S, channel slope, g, acceleration due to gravity and f, c and n are resistance coefficients.

The main concern here is to evaluate the resistance coefficients. Several available equations can be categorized as; (1) equations that are based on Darcy-Weisbach; (2) equations that are based on Manning; and (3) equations that are based on Chezy.

Category 1: Equations that are based on Darcy-Weisbach

Manning-Strickler: $$\left(\frac{1}{f}\right)^{0.5} = 2.89\left(\frac{R}{d_{50}}\right)^{1/6}$$

Griffiths (1981) : $$\left(\frac{8}{f}\right)^{1/2} = 3.54\left(\frac{y_o}{d_{50}}\right)^{0.287}$$

Graf et al (1983): $$\left(\frac{8}{f}\right)^{1/2} = 5.62\,log\left(\frac{y_o}{d_{84}}\right) + 4$$

Jarrett (1987): $$\left(\frac{1}{f}\right)^{0.5} = 0.35R^{-0.33}S^{-0.38}$$

Bathurst (2002): $$\left(\frac{8}{f}\right)^{1/2} = 4.53\left(\frac{y_o}{d_{84}}\right)^{0.278}$$

Maxwell &

Papanicolaou (2001): $$\left(\frac{8}{f}\right)^{1/2} = -3.73\,log\left(\frac{H\cdot d_{84}}{L\cdot y_o}\right) \pm 0.80$$

Lee & Ferguson (2002) : $$\left(\frac{8}{f}\right)^{1/2} = 4.19\left(\frac{R}{d_{84}}\right)^{1.80}$$

Aberle & Smart (2003) : $$\left(\frac{8}{f}\right)^{1/2} = 0.91\left(\frac{y_o}{S}\right)$$

Where; f = Darcy-Weisbach friction coefficient
y_o= mean flow depth
d_i = particle size of the ith size class
S = channel slope
R = hydraulic radius
L = step length
H = step height

Category 2: Equations that are based on Manning.

Strickler (1923): $n = \dfrac{d_{50}^{1/6}}{21.1}$

Meyer Peter

& Muller (1948): $n = \dfrac{d_{90}^{1/6}}{26}$

Limerinos (1970): $n = \dfrac{0.113 R^{1/6}}{0.36 + 2.0 \, log\left(\frac{R}{d_{50}}\right)}$

Bray (1979): $n = 0.0593 d_{50}^{1/6}$

Brownlie (1983):

(Lower Regime Flow) $n = \left[1.6940 \left(\dfrac{R}{d_{50}}\right)^{0.1374} S^{0.1112} \sigma^{0.1605} \right] \dfrac{d_{50}^{0.467}}{29.3}$

(Upper Regime Flow) $n = \left[1.0.213 \left(\dfrac{R}{d_{50}}\right)^{0.0662} S^{0.0395} \sigma^{0.1282} \right] \dfrac{d_{50}^{0.467}}{29.3}$

Jarrett (1984): $n = 0.32 S^{0.38} R^{1/6}$

Bruschin (1985): $n = \left(\dfrac{d_{50}^{1/6}}{12.38}\right)\left(\dfrac{RS}{d_{50}}\right)^{1/7.3}$

Julien (2002): $n = 0.062 d_{50}^{1/6}$

$n = 0.046 d_{75}^{1/6}$

$n = 0.038 d_{90}^{1/6}$

Abdul Ghaffar (2004): $n = 2E - 08 \left(\dfrac{y_o}{d_{50}}\right)^2 - 3E - 05 \left(\dfrac{y_o}{d_{50}}\right) + 0.0511$

$n = 3E - 08 \left(\dfrac{R}{d_{50}}\right)^2 - 4E - 05 \left(\dfrac{R}{d_{50}}\right) + 0.0537$

Chang (2006): $n = 4E - 08 \left(\dfrac{y_o}{d_{50}}\right)^2 - 5E - 05 \left(\dfrac{y_o}{d_{50}}\right) + 0.0582$

$n = 5E - 08 \left(\dfrac{R}{d_{50}}\right)^2 - 7E - 05 \left(\dfrac{R}{d_{50}}\right) + 0.0622$

Where; n = Manning coefficient

y_o = mean flow depth

d_i = particle size of the ith size class

S = channel slope

R = hydraulic radius

σ = standard deviation of the sediment mixture

Category 3: Equations that are based on Chezy.

Van Rijn (1984): $c' = 18 log(12 h'/3 d_{90})$

Liu (2001): $c = \left(\dfrac{v}{u_*}\right) g^{1/2}$

Pacheco-Ceballos (1998): $c = 5.30 log\left(\dfrac{12h}{D_0}\right)/0.33$ (for plane-bed)

$c = 5.30 log\left(\dfrac{12h}{D_0}\right)/0.45$ (for transition)

Where; c = Chezy coefficient
h'=h= flow depth
v = flow velocity

$v_* =$ fiction velocity $= \sqrt{gRS_o}$

g = acceleration due to gravity

R = hydraulic radius

S_o = channel slope

$D_b = 3d_{90}$ (for plane bed)

METHODS OF SAMPLING IN HGR

The habitual procedures for estimating the resistance coefficients can be divided into the following groups;

a)   Ground survey which involves measurement of river cross section, channel slope, flow depth and flow velocity in the reach of interest which will be measured using equipments shown in Figure 4.

b)   Surface sampling by collecting bed-surface particles from the streambed. Three methods can be adopted that are Pebble Counting, Grid Sampling and Areal Sampling for bed conditions where majority of bed materials sizes are above 2 mm. Pebble counting can be performed along a selected transect by using "Heal to Toe" or "sampling in fixed interval along a measuring tape" methods as shown in Figure 5. A sample size of at least 100 bed material particles will be manually collected from the streambed (Wolman, 1954; Bunte and Abt, 2001; Fischenich and Little, 2007). These methods differ in terms of spacing between sampled particles, size of the sampling area, suitability for small and large particles sizes, field time vs. lab time and the comparability of sampling results. Besides surface sampling, volumetric sampling using Van Veen Grab sampler is also applicable for a reach with bed consisting of fine gravels or sand. The bed material sampling probes are shown in Figure 6.

c)   The particle-size distribution curves will be developed (Figure 7) and then are used in the assessment of flow resistance equations. Particle-size data are usually reported in terms of d_i, where i represents some percentile of the distribution and d_i the particle size, usually expressed in millimeters (Fischenich and Little, 2007).

The most important requirement in selecting the area of study is that the river reach must correspond to a single, approximately straight channel along which there is a steady and macroscopically uniform flow. Apart from that the reach should be free from vegetation and obstacles since these effects on flow are assumed to be minimal. In conclusion, to minimize complexity therefore flow resistance will be considered under ideal conditions of uniform flow with the resistance caused solely by the grain roughness of the bed material (Lopez *et al*, 2007 and Bathurst, 2002). Some of the selected reach morphology which is suitable for field sampling is shown in Figure 8.

FUTURE WORK

The methods proposed in this paper are currently being practiced in the field. The hydraulic and sediment database established in a predominantly step-pool streams in Malaysia will be used to test the applicability of the existing bed roughness equations. The calculated flow velocity or channel discharge will be compared with the measured velocity in order to propose the most suitable bed roughness prediction equation. Basically, the final aim of the ongoing research is to improve accuracy and applicability of flow resistance relationships for mountain rivers by assembling a range of datasets and following at-a-site approach.

CONCLUSION

The methodology proposed in this paper seeks to determine and identify the most suitable bed roughness equations for the High Gradient Rivers in Malaysia. In addition, a list of verified bed roughness coefficients could also be developed into a general engineering design chart to be used as a reference to assist engineers or authorities in their respected field.

ACKNOWLEDGEMENT

APPENDIX

Figure 1: Sungai Kibunut, Sabah

Figure 2: Lata Tembakah, Hulu Besut, Terengaganu

Figure 3: Sungai Langsat, Sarawak
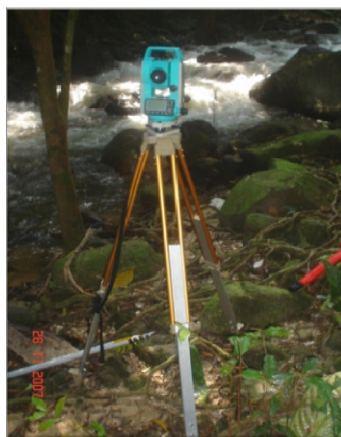
| a.   Measuring tape | b. Surveying equipment | c. Velocity meter |

Figure 4: Equipments used for Ground Surveying
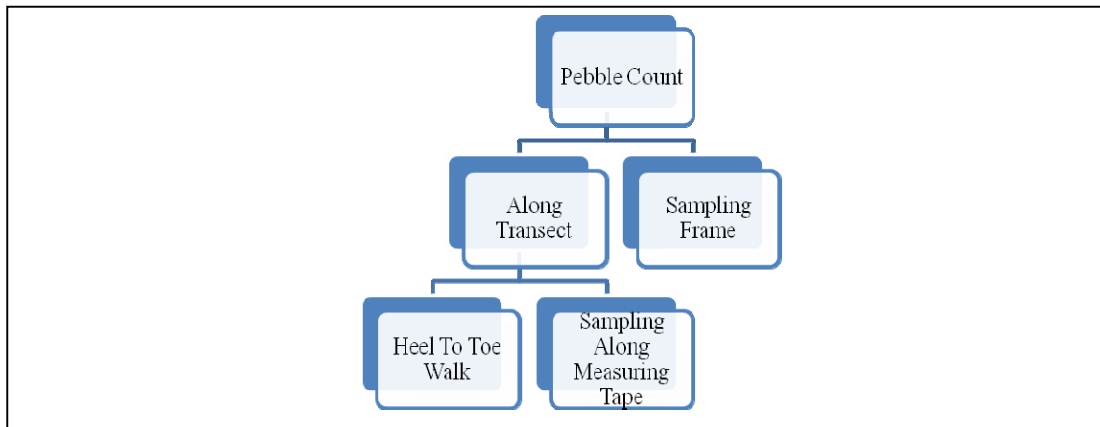
Figure 5: Pebble Counting Options (Bunte and Abt, 2002)

a. Gravelometer   b. Sampling frame   c. Van Veen Grab
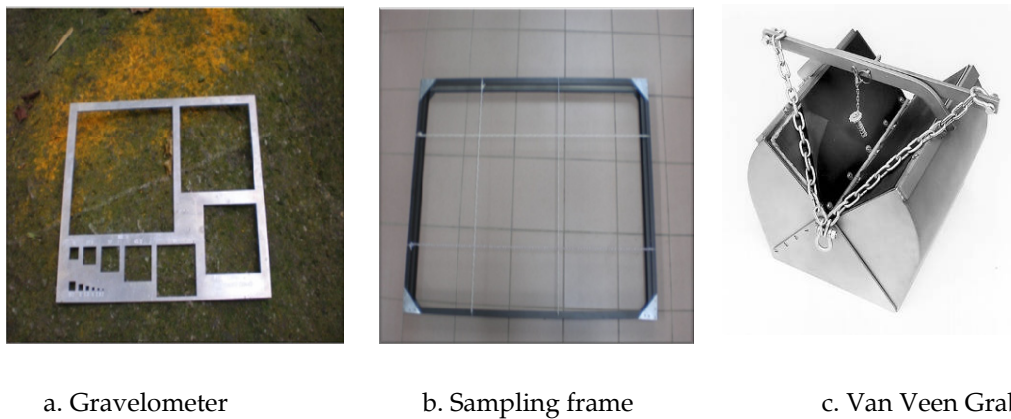
Figure 6: Equipments for Bed Material Sampling
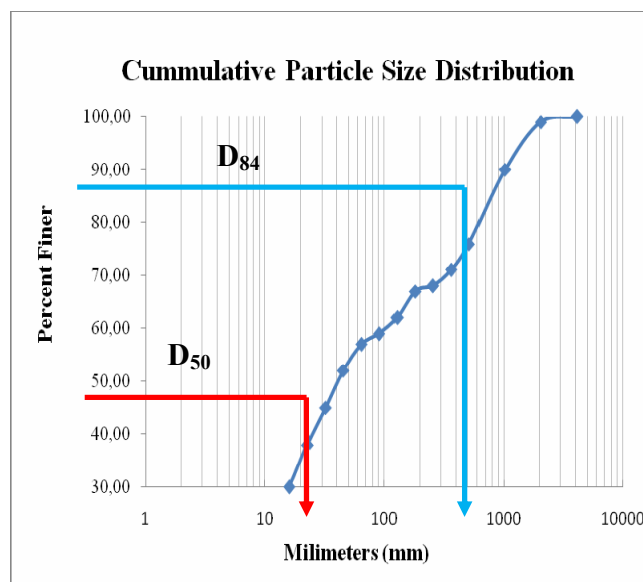
Figure 7: Particle-size Distribution Curve from a Wolman Pebble Count

| a. Approximately straight | b. Macroscopically uniform flow | c. Free from vegetation and obstacles |
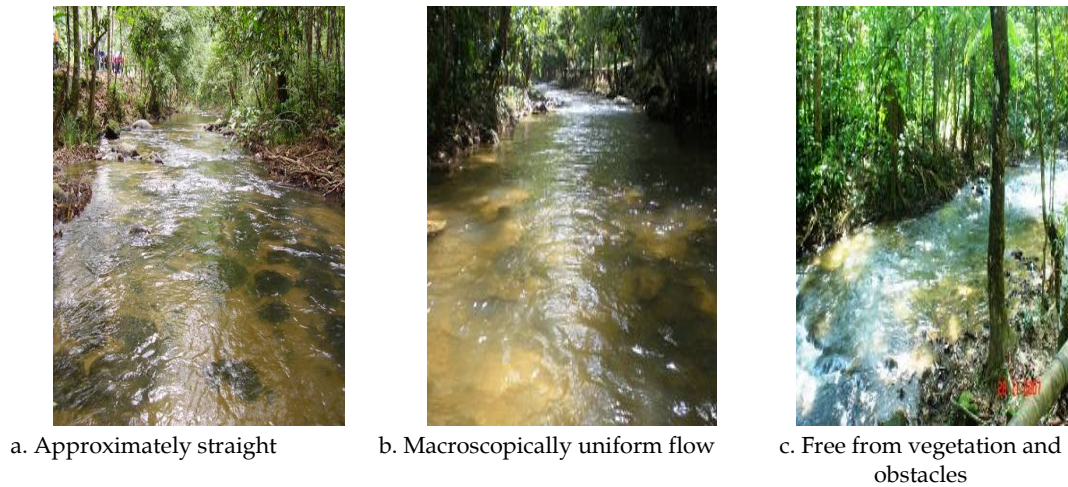
Figure 8 : Criteria to be considered during selection of sampling location

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Climate change impact on dangerous hydrological processes for mountain river basins of the Big Caucasus - a case study of the Terek river

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ABSTRACT

Analysis of dangerous hydrological processes is one of the essential component of future regional water resource systems planning. One of them is developed now for Terek river basin. Contrasts of relief and climate create the prerequisites for the development of various dangerous natural processes, constantly endangering safe living activities of people. Climate changes during last decades have found the reflection in increase of dangerous glaciological, erosive and hydrological processes repeatability in various parts of this river basin. Evaluation of the river runoff and sediment load variability and water level oscillations, working out of river runoff calculation and forecasting methods of these hydrological characteristics are the most important scientific and practical tasks.

Key words : dangerous hydrological processes, climate changes

INTRODUCTION

Dangerous hydrological processes are events which cause social, economic, and (or) ecologic damages. Among them are changes of extreme water runoff and level, water capability of rivers due to either natural combination of income and charges in water balance of the basin (or of the river's section) or their anthropogenic change. Dangerous rises of water levels are often caused by ice-jams and wind-induced surge, backwater phenomena. Activation of slope, ravine and channel erosion, silting of channels and water storages, negative changes of hydraulic and thermal conditions of water objects and their trophic status are also dangerous processes which limit security for social and industrial units situated in channels and ashore. Negative changes of water quality are should also be considered as dangerous processes. In contrast to geological events hydrological processes are highly repeatable, continual or periodical. They may be local or spread over all the river, lake or sea.

Dangerous hydrological processes result from combination of both natural factors and human impact. They are dangerous in so far as they affect population and economy and may cause damage to them. Risk of damage is equal to possible damage multiplied by its probability. Size of damage depends on population of territory covered by dangerous hydrological processes, compactness of social and economic object ashore, their status, etc. These factors as well as difference in composition and intensity of dangerous hydrological processes account for territorial variability of corresponding damages. Usage of either water objects to meet social and economic demands is inevitably accompanied by increase of probability of hydrological processes impact on safety of population and social and industrial units ashore.

Thus one of the main tasks of hydrology is to provide hydrological security for territory. It means providing for such relationships between water objects, population, its social and economic activity which enable steady water supply, eliminate (or minimize) conditions for dangerous hydrological processes and water deterioration. Within considering territory or river basin it implies detection of conditions for dangerous processes development, estimation of their repeatability and scope, directivity or cyclicity in change of hydrological characteristics. This is the basis for complex analysis of probability and intensity of floods, extreme low flow, other dangerous processes, for

development of dedicated monitoring and proposals for minimization of social, economical and ecological risks due to actual or possible impact.

This sort of work on estimation of hydrological safety of population and economy was conducted for Terek's river basin.

PECULIARITIES OF DANGEROUS HYDROLOGICAL PROCESSES IN TEREK RIVER BASIN

Basin of Terek is very complicated region in the south of Russia. It can be divided into three zones: high - altitude zone (Big Caucasus), foothills and plains. These parts differ in height and slope, water balance components, intensity of erosion, water use and composition of dangerous processes. It is located in the eastern part of isthmus between Black and Caspian Sea. This river springs from glacier on the height of 2713 m. Its length is 623 km, the drainage area is 43200 km^2 . Malka and Baksan are the largest Terek tributaries in the south-western part of this basin which spring from Elbrus glaciers. Glaciation of Terek basin is equal of 1,6%. All glaciers are located on the northern slope of Central and Eastern Caucasus.

Terek's river basin is among the most difficult for water supply regions in Russia. Analysis realized within development of the Scheme of Complex Usage and Protection of Water Resources revealed that in Terek river basin's mountain part dangerous processes are determined by glacial events. Decrease in glaciers' area created the necessary prerequisites for violent mudflows. In this background it develops a high probability of disastrous avalanches and glacier surges. There is no lack of water resources but all social and economic activity takes place in other altitude zones of the basin. In foothill part of the basin overall performance of a water management is subjected to negative influence of slope gully erosion and mudflows. During an abounding in water season there is a high probability of floods, channel deformations, landslips, etc. In low water period a lack of water resources is possible. Sharp increase of population and density of industrial objects is connected here with increase in water consumption from surface and underground sources. Simultaneously volumes of water removal quickly increase in a foothill zone that negatively affects on quality of river waters. In a flat part of the basin there is an increased probability of catastrophic floods connected with features of Terek and its inflows water regime and with exclusively high sediment load. Sharp expansion of the irrigated land area in this part of the basin indicates greater dependence of a water-economic complex on presence of necessary water resources during limiting seasons of year. Intensive channel deformations in a flat part of the basin threaten social and industrial objects on river banks and result in silting up of irrigating and supply channels, as well as radical reformation of channel network in delta that repeatedly occurred in history of delta of Terek.

CLIMATE CHANGES AND DANGEROUS HYDROLOGICAL PROCESSES

Present-day changes of hydrological conditions in Terek basin are observed on the background of global climate changes. Global warming and increasing of precipitation result in changes of glaciers and rivers regime during last years. For the reasons given above dangerous hydrological processes became more frequent. Meteorological information for period 1960-2006 of Russian hydrometeorological network was used for analysis of air temperature and precipitation changes for different altitude zones (fig. 1, 2). Besides fluctuations of hydrometeoriligical characteristics these figures suggest graphs of possible trends. Trend estimation was made by using polynomial approximation. In general it is more advisable to use third degree polynomials for analyzing these time series. Parameters for such polynomials were estimated for each series by "the smallest squares method". On the background of common tendency of mean annual air temperatures increasing both on plains and mountains regions increase of annual precipitation is observed. Moreover increase of repeatability and duration of heavy showers was marked. Principal increasing of precipitation occurs during winter period because of heavy snowfalls and during

summer period because of heavy showers. In the low reaches of Terek river runoff during May-September increased on 57% in comparison with annually averaged runoff and maximum runoff in the mouth of river increased on 17%.

At the end of XIX century reduction of glaciation began after the maximal stage of a small glacial age (Voitkovskiy, Volodicheva, 2004). Now the glaciation is in a regressive phase and the general reduction makes about 20 % from the area of 70th years of XX century (table 1). Thus there is a reduction of the area, volume and length of glaciers, increase of their number and heights of the bottom border. The sizes of a glaciation were continuing to change last decades (1970-2000), despite of increase in an atmospheric precipitation marked on the Big Caucasus (on 10-15 %) and temperatures of air on 1°C. For 1970-2000 the area of a glaciation was reduced to 12,6 %, volume of ice on 14,9 %, the number of glaciers has increased for 2,4 %. Glacier contraction continued and for 30 years they have on the average reduced length to 100 m. The increase of precipitation (especially during the cold period of year) has resulted last 20 years in snowfall increase and repeatability of snow avalanches.

From 1997 almost all glaciers of north slope of Big Caucasus increased the rate of degradation because of high increasing of air temperature during the summer period. As a result of active degradation glacial catastrophic mudflows formed (for example, the largest mudflow of last century in Caucasus in Gerkhodjan river basin). At the end of XX – in the beginning of XXI century increasing of winter snowfall, activity of snow avalanches and accumulation of glaciers was marked. But summer ablation compensated winter accumulation, so mass-balance of glaciers was negative (fig. 3). Series of accumulation and ablation have obvious increasing trend (Popovnin, 2004). Consequence of glaciation area reduction and accompanying reduction of the modulus of flow is a runoff decreasing for the rivers with an essential share of a glacial feed. This process is the result of very complicated correlation between ablation and accumulation of degenerative glaciers, decreasing of its areas and volumes and climatic changes in this region (fig. 4). In some basins where the glaciation degrades very actively, the runoff of the rivers increases. It is supposed that decreasing of glaciation area will result in reduction of glacial runoff for Big Caucasus on 37%. At the same time total runoff will increase because of increasing of precipitation. As a whole for the rivers having a snow-rain and glacial feed, trend of runoff is positive and mostly significant. In general for last 50 years general increase of naturally renewed water resources of region is marked. The area of glaciation will be continuing to decrease and its reduction will be approximately equal 20% to 2050 (Lurje, 2002).

The increase of sediment yield of the Terek basin rivers marked in last years, in particular, reflects regressive changes of a snow line and a glaciation, increasing the part of high-altitude zones in which huge volumes of sediments - a material for mudflows and suspended sediment yield "are prepared".

Floods on the rivers of the Terek basin occur in spring-summer period during intensive snow and ice melting and heavy rainfalls. Outstanding and catastrophic floods are always connected with the maximum height of the spring flood accompanying with significant or outstanding rain-flood. Such floods were observed in the Terek basin in 1931, 1932, 1958, 1960, 1963, 1966, 1967, 1970, 1974, 1998, 2000, 2001 (Taratunin, 2000; Dobrovolsky, Istomina, 2006) and in 2002. In the Terek mouth high spring and summer floods result in the breaching of the river mouth levee and flooding. In the Terek basin over 200 thousand hectares of agricultural yields including 84 thousand hectares of irrigated lands, populated areas with population of 140 thousand people are in the zone of possible inundation.

As a result of the catastrophic level rise in 2002 the territories of Kabardino-Balkaria, North Osetia, Chechnia, Ingushetia and Dagistan were flooded, 114 people were killed, 300 thousand people were injured and over 100 thousand people were evacuated. Dozens of thousands of living houses, hundreds of municipal buildings, educational establishments and other units were destroyed and damaged. Flood protecting constructions and dams were seriously damaged as well. The financial

damage made up about 530 million dollars (Lourie, 2002). In mountain regions of Kabardino-Balkaria, North Ossetia-Alania, Ingushetia, Chechnya and Dagestan numerous mud flows occurred. In the location of the Kargalinskaya station when water discharge was 1530 m^3/s the breaching of protection dikes took place. Vast territories were flooded in the delta of the Terek, living houses, bridges and other constructions were destroyed, kilometres of protection levees and dams were scoured, great ecological and economical damage was caused in the suffered areas (Gorelits and others, 2005). Duration maximum level stagnation in the rivers of the basin varied from 3 to 288 hours. Maximum water discharge probability during the catastrophic flood in the lower gauging section of the Terek made up 3%. In spite of the fact that in the 20th century at the head of the Terek mouth greater water discharges were observed (in 1931 and in 1967) the flood of 2002 was unique as for the duration as well as for the water flow and sediment load.

As a formation of catastrophic flooding is connected with the forming of significant rain high waters, change of flood characteristics under the influence of climate change has been estimated (Khristoforov etc., 2007). Probable climate changes not influence on height and form of separate flood peaks, but influence their average number and distribution during the year. For rivers of Terek basin the average number of peaks during a cold season increases and during warm season decreases with the growth of air temperature and even (at essential warming) it can reduce up to zero. The increase of annual precipitation for all researched rivers will lead to the general increase of number of floods during all seasons. Calculations show that the danger of occurrence of catastrophic floods on the rivers of Northern Caucasus will increase in nearest decades with growth of air temperature.

Owing to change of climatic conditions in this region there is also a change of a Caspian Sea level. Almost 500 years it fell fast or more slowly, it has reached in 1977 the lowest position -29,01 m BS (fig. 5). Then it began promptly (on the average 13 sm/year) to rise, having reached a maximum in 1995. As a result the part of coastal territories has been flooded, conditions of hydraulic interaction of river and sea waters and sediment yield significantly changed. During last decade the level of Caspian Sea was stabilized. The amplitude of mid-annual values fluctuations was equal 0,4 m. On the average for the period of 1996-2006 the level of Caspian Sea was on a mark -27,03 m BS.

Under the influence of floods, sedimentation, change of a reception reservoir level catastrophic reorganization of channel network in delta of the river periodically occurs. Every 60-80 years the main channel of the river within the delta considerably changes the direction. All known cycles of channel orientation change in its delta have coincided with the periods of gradual flooding number increase and occurred unexpectedly during high waters (Alekseevskiy et al, 1987).

For last 500 years in a lower reaches of Terek such 7 catastrophic breaks have taken place. Each of them has led to the occurrence of systems of water-currents under the name the Kuru - Terek (XVI century), Sullu-Chubutli (XVII century), Old Terek (the beginning of XVIII century), New Terek (the end of XVIII century), Borozdinskaya Prorva (the beginning of XIX century), Talovka (the end of XIX century) and Kargalinskiy break. Last cycle of Terek delta formation has arisen during a catastrophic high water in July - August, 1914 at discharges of water more than 2000 m^3/c. For some years the river has developed a channel which passed 80-100% of the discharge. Strongest water deficiency was typical for the cultivated left-bank part of Terek delta. Till 1927 attempts to block the source of Kargalinskiy break did not stop. Further for the decision of the problems of this part of delta watering expensive dam, systems of watering and irrigation canals were created.

The history of Terek delta evolution shows that most complicated problems in a lower reaches of the river are caused by the high sediment yield, extremely high turbidity of river waters. In conditions of gradual reduction of a bed slope and a water surface the stream loses ability to transport all sediments. They deposit in the channel, reducing its carrying capacity. As a result even rather small discharges of water can lead to the flooding of district, adjoining to a channel of the river. For the observation period (1924-1988) the average suspended sediment discharge in Terek

delta was equal 588 kg/sec that corresponds to annual sediment load 18,5 million т. In separate years the suspended sediment yield reached 38 million т, and in separate years it reduced up to 6 million т.

The increase in damage from dangerous hydrological processes last decades for Terek's basin is connected with absence of the data about these processes; neglecting of risk; development of zones of potential occurrence of these processes; mistakes of a scientific support of projects; changes of natural and anthropogenous factors; deficiency of means for realization of dangerous processes monitoring.

For decrease of dangerous hydrological processes risk it is necessary to estimate size and variability of components of runoff - the main reason of change of safety of the population and economy; to prepare a modern information basis for the characteristic of probability and scales of dangerous hydrological processes; to create methods of an estimation, calculation and forecasting of characteristics of dangerous hydrological processes on local, regional and basin level.

In more detail the problem of flooding will be discussed.

MAXIMUM WATER LEVEL VARIABILITY OF THE RIVERS OF THE TEREK BASIN

The specific features of the level regime of the Terek basin are connected with the correlation of the underground, snow, rain and glacier feed. Maximum levels of the alpine rivers are mainly provided by the spring flood connected with glacier and snow patch melting in the first decade of May and at the beginning of June. The origin and the time of the existing of the maximum levels change with lowering of the mean height of the catchments. On the plain and at the foothills the highest levels are the result of summer rain floods. The increase of the level to its highest elevation usually occurs several times a year and it is the result of heavy rainfalls.

To study the peculiarities of the formation of maximum water levels and flooding of the location rows of daily maximum $H_{\max}$ and minimum $H_{\min}$ values of annual water level over gauge datum for the observation period at the disposal up to 2005 including. Using this data water levels of 1% probability $H_{1\%}$, the maximum amplitude of the level change $\Delta H_{\max} = H_{\max} - H_{\min}$, the amplitude of the change of the level of 1% probability $\Delta H_{1\%} = H_{1\%} - H_{\min}$, the edge of flood–lands H_{fl}, the maximum flood layer of 1% probability $H_{\mathrm{jam}} = H_{1\%} - H_{fl}$ and the average data of establishment of maximum water levels $D_{H\max}$ were calculated for each observation station. On an average for the Belka, Fortanga and Assa rivers the maximum levels are observed at the beginning of June, for the Sundza river in the middle of June, for Argun, Ardon rivers at the end of June, for Malka river in the middle of July, for Baksan, Tseya, Cherek rivers at the end of July. The data of the establishment of the maximum water levels change in accordance with the altitude of the catchment area (fig. 6). The change of $\Delta H_{\max}$ depends on the peculiarities of water regime, river bed and the valley in the place of the observation station as well as hydrological and morphological characteristics of the river (fig. 7).

All the territory of the Terek basin can be conditionally divided into three parts:

– the upper reaches of the Malka river, the upper and the middle stream of the Baksan river, the basins of the Cherek, Chegem, Ardon Fiagdon rivers, the upper reaches of the Terek river (up to Vladicavcaz): the maximum registered amplitude of the level oscillations $\Delta H_{\max}$ makes up less than 2 m;

– the middle (lower the river Gedmysh mouth) and the lower stream of the Malka river, the lower stream of the Baksan river, the middle and the lower stream of the Terek river (from Vladicavcaz to Kargalinskaya station); within this territory the maximum amplitude of water level oscillations make up 2–3 meters.

– Sounzhy river basin: the amplitude of water level oscillations in this region is not high and makes

up 3–5 m. In the lower reaches of the Sounzhy river (village of Braguny) ΔH_{max} =510 cm, of the Argun river (village of Duba Yurt) ΔH_{max} = 487 cm, for the Belka river (town of Goudermes) ΔH_{max} = 789 cm.

In the Terek delta the amplitude of water level oscillations make up 15–350 cm.

The obtained regularity in many respects corresponds to the distribution scheme of water regime type and to distribution of the mean turbidity of rivers and sediment flow.

The average long-term values of water turbidity in the Terek basin are subject to substantial changes from 0,2 (the Chegem river – village of V.Chagem) up to 3.19 kg/m^3 (the Sundza river – village of Braguny). Malka waters are characterized by higher turbidity, which increases rapidly downstream the river. The average turbidity of water at the village of Khabaz makes up 0.52 kg/m^3, towards the station Prokhladnaya it grows up to 1.73 kg/m^3. The annual mean turbidity in the upper reaches of the Baksan river (village of Zayukovo) makes up 0.60 kg/m^3. It increases downstream and reaches 0.87 kg/m^3 at Prokhladnaya station. The turbidity of the Sounzha river in its upper reaches at Karabulak makes up 0.55 kg/m^3. It rapidly increases downstream and makes up 3.19 kg/m^3 at the gauging station in the village of Braguny. Upstream of the Terek river the annual averaged turbidity makes up 1.3 kg/m^3. Downstream it strongly changes. At the city of Vladikavkaz it increases and makes up to 2.6 kg/m^3. By the village of Eilchotovo turbidity decreases up to 0.6 kg/m, apparently as a result of the less saturated suspended particles of the streams. At the station of Kotlyarevskaya the turbidity of water reaches 1.14 kg/m^3. Considerable increase of turbidity takes place downstream of the Sounzha river outfall.

The largest amplitude of water level oscillations is observed in the basin of the Sounzha river. It is connected with the formation of catastrophic floods in the warm period of the year. Estimation of the dependence of the maximum water level amplitude from a number of hydrological and morphological characteristics is not less interesting and important. The first dependence reflects the influence of watershed area upon water level change (fig. 8). Irregular high value ΔH_{max} = 789 cm is registered for the Belka river (the town of Goudermes).

The altitude of the catchment area determines the degree of its glaciation and also influences the range of the maximum water level changes in rivers (fig. 9). The amplitude of level oscillations decreases up to 100–150 cm with the increase of glaciation area. At medium height of the basin of more than 2500 m the amplitude of level oscillations makes up about 250 cm. In the alpine regions the regulatory control of glaciation is felt. For the basins, where watersheds have the mean height lower than 2500 m, the level amplitudes are about 300–400 cm. On the plain considerable level oscillations are connected with great temporal and space heterogeneity of the rain and snow feed. In this situation the local factors (mezorelief, microclimatic peculiarities, etc.) play the main role in many respects.

The dependence ΔH_{max} on the medium slope of the watershed is expressed rather schematically repeating the general tendency of decreasing of the water level oscillations under the mean height of the watershed increases.

The analysis of temporal variability of the maximum water levels showed that in the 20th century almost at all observation stations of the Terek river basin the increase of the maximum water levels took place (fig. 10). The reasons of the increase of maximum water levels can be both natural and anthropogenic. According to Lourie (2000) more often repetition of extreme hydrometeorological phenomena is one of the negative consequences of the climate fluctuations. During the last 50 years the growth of atmosphere precipitation in the cold and warm periods is made up in average 5–10% in the Big Caucasus. The steady increase of maximum water levels is connected with fluctuations in precipitation and air temperature. For the Terek basin the obtained tendency of the water level changes depend on the peculiarities of the sediment load and accumulation processes, resulting in gradual growth of level marks (at Q=const) as it is observed at the Kotlyarevskaya gauging station on the Terek river.

According to the analysis of long-term variability of the sediment load the averaged annual values have decreased in the Terek river (near the village of Kazbegi), Argon river (village of Taminsk), Malka river (village of Kamennomostskoye), Soundza river (village of Braguny) and others. In some gauges (the Terek river – Vladicaucas city, station of Kotlyarevskaya), on the contrary, considerable increase of the sediment load reflects the specific river bed erosion upstream the gauging stations. The maximum increase of suspended sediment load is observed in the Terek river (Vladicavcaz city, 396%). Under the inconsiderable averaged annual water discharge oscillations the increase of maximum water levels and sediment load is observed here. Sediment load has increased here more than two times for the last 25 years.

The diking system was built on the Terek river for flood protection. Nowadays continued diking increases eventual financial losses at going over the floods of rare and very rare repetition. Breaking of the land dikes take place every year and catastrophic ones occur every 11–14 years. Such events were observed in 1958, 1963, 1967, 1970 and 1977.

Flooding of last years in a lower reaches of Terek are substantially related with sedimentation in the rivers' channels. Decrease of their channels capacity raises risk of flooding even at relative stability of water inflow during the period of higher runoff. Quite the contrary, erosion of flood-lands and bed material during floods and high water periods is accompanied by lowering of water level. Influence of alternating processes of erosion and accumulation on fluctuation of water level ($Q = const$) is the most evident in the Terek's delta.

History of development of t his territory shows both periods of reduction of the flood risk (1928-1961, 1978-1990) and periods of its increase up to annual flooding accompanied with corresponding economic and social losses (1962-1978, 1991-2004). Flood risk decrease or increase in this case corresponds with stages of delta's evolution and with fluctuations of runoff of rivers with substantial sediment load.

MEANS OF MAXIMUM LEVEL AND DISCHARGE FORECASTING

In an effort of improvement of efficiency of actions on protection of the population from floods and to use of water resources the system of techniques for short-term forecast of water level and discharge for rivers of Terek's basin is developed. For mountainous rivers which runoff depends on snow and glacial cover thawing, the physical-statistical model of runoff fluctuations during a summer high water period depending on fluctuations of air temperature is offered. The model realized for Cherek river at Sovetsky settlement allows adequately to forecast water runoff in summer period with 2-4 day lead time. For the rivers of foothills and flat part of Terek's basin considering its insufficient hydrometeorological studying the method of corresponding levels is used. It makes it possible to describe movement and transformation of flood waves in channel network on the basis of the hydrometric observations data. The method is realized for 6 sections, located on the Terek and its inflows Malka and Sunzha, and allows giving satisfactory forecasts with lead time equal 1-3 days (Khristoforov et al., 2007).

TENDENCIES OF DANGEROUS HYDROLOGICAL PROCESSES CHANGES

According to forecasts of the regional centers, for example, North-Caucasian Hydrometeorological Service as well as in compliance with the models of global change of a climate the mid-annual temperature of air in territory of Northern Caucasus will raise on 3–5°C. The increase in annual precipitation in the given territory will make approximately on 10–15%, for Terek basin this value will be about 50 mm. It is obvious, that in these conditions it is to be expected even greater activization of dangerous natural processes in the basin of Terek.

According to this script to 2050 the runoff of the rivers of Caucasus will increase for 44%, including on 34% on the Big Caucasus and almost in 3 times in Ciscaucasia. On northern slope of the Big Caucasus the runoff will increase on 37%, and on southern – on 32% that because of more significant area of a modern glaciers on northern slope. The area of a modern glaciation will

continue to decrease, and its reduction will make 30% for 2000-2050. It will lead to reduction of a glacial runoff which will be equal 37% for this period.

The possible changes of a river runoff specified above in the basins of the rivers of Caucasus will cause not only positive, but also negative consequences. So, the increase of runoff volume will lead to change of erosion on watershed and in channels of the rivers, to increase of turbidity and sediment load. The increase in a river runoff, quantity of precipitation and reduction of the areas of a modern glaciation will lead to intensification of mudflow activity. At the same time duration of mudflow period, number and volume of mudflows will increase, especially at heights above 1500 m. For the same reason increase in repeatability of catastrophic flooding will occur.

The most dangerous for population will be mudflows in a mountain and foothill part of Terek's basin, deficiency of water resources and flooding in a flat part of a basin.

CONCLUSION

The Terek river basin is one of the most complicated regions of Russia. Contrasts of relief and climate create the prerequisites for the development of various dangerous natural processes, constantly endangering safe living activities of people. The possible activation of rock formation processes, high tectonic activity, land sliding, avalanching and mudflowing, intensive slope, gully and river bed erosion, intensive sediment accumulation along the plain part of the streams, floods – these and other processes are the source of social, economical and ecological damage. Evaluation of the river runoff and sediment load variability and water level oscillations, working out of river runoff calculation and forecasting methods of these hydrological characteristics are the most important scientific and practical tasks.

ACKNOWLEDGEMENTS

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Extreme Floods in Nepal: Genesis and Consequences

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ABSTRACKT

Nepal has been frequently affected by the extreme weather events resulting in natural disasters such as floods and landslides. Nepal's fragile geological conditions, topographical extremities, climatic extremities and seismic activities coupled with population growth, poverty, illiteracy, deforestation, unscientific agricultural practices, unscientific land use changes, and developmental activities such as construction of roads, irrigation systems, hydro-powers and urbanization are making it vulnerable to several natural disasters.

Heavy rainfall in central and eastern regions of Nepal during 19-21 July, 1993 had disastrous consequences with heavy loss of life and property as well as damages to infrastructures by floods, landslides and debris flows. In 1993, 87 % of the total deaths of human life occurring in the country were resulted from floods and landslides. Within the country, more than 500,000 people of 85254 families were directly affected, 1336 people were dead and 163 injured. 25425 livestocks were lost and 17113 houses were destroyed. In agriculture sector, more than 57584 ha. of arable lands were damaged. 67 small and large irrigation projects along with thousands of farmer-managed irrigation schemes were seriously damaged. The estimated loss of properties was 4904 million NRs. This was the worst disaster in last 20 years.

On 18 August, 2008 the breach of the left embankment of Kosi river near Kusaha village in Sunsari district of Nepal affected 4 village development committees causing more than 60000 people homeless in Nepalese side and more than 3000000 people displaced in Indian side. About 6000 hectares of agricultural land has been inundated and agricultural products worth more than US $ 3.7 million have been damaged. Similarly, heavy rainfall in far-western Nepal during 19-20 September, 2008 has resulted devastating floods in Kanchanpur, Kailali and Bardiya districts causing widespread damage to life and properties.

It is seen that medium size rivers originating from middle mountain ranges such as Kankai, Kamala, Bagmati, East Rapti and West Rapti are causing more flood problems than the large rivers such as Koshi, Narayani and Karnali. This paper presents an overview of extreme flood events in several rivers, causes and consequences of those floods and the ways to mitigate flood disasters in Nepal.

INTRODUCTION

Nepal has been affected by the extreme weather events resulting in natural disasters such as floods and landslides. Nepal's fragile geological conditions, topographical extremities, climatic extremities and seismic activities coupled with population growth, poverty, illiteracy, deforestation, unscientific agricultural practices, unscientific land use changes, and developmental activities such as construction of roads, irrigation systems, hydro-powers and urbanization are making it vulnerable to several natural disasters.

Extreme precipitation events during monsoon periods are common in Nepal. Extreme rainstorms in the past 120 years (September 17-18, 1880; September 28-30, 1924; and July 19-21, 1993) have been induced by abnormal behaviour of monsoon depression paths originating from Bay of Bengal when associated with low-pressure systems in Nepal.

Land use changes, urbanization and other natural causes result in river course changing in southern parts of Nepal, aggravating the unprecedented consequences due to extreme floods. Increase of agricultural lands and settlements at the expense of forest cover, along with other socio-economic drivers also predisposes Nepal to more disaster proneness in both frequency and intensity.

Flood forecasting and warning is an effective non-structural method of flood management. This method has been well accepted by the planners and public in flood disaster mitigation and flood plain management. Recognizing this fact, the Department of Hydrology and Meteorology (DHM) is working for the development of flood forecasting and warning system in major rivers of Nepal.

This paper presents an overview of extreme flood events in several rivers, consequences of those floods and activities related to flood forecasting in Nepal.

Floods of varying magnitudes occur almost every year in Nepal during monsoon and some of them become catastrophic. Catastrophic floods could be defined as floods that give rise to inundations, which have very large impact in terms of life and property losses and major disruption to infrastructure.

Based on recurrence interval, floods could be classified into the following three severity classes:

- Large flood: recurrence < 20 year
- Very large flood: 20 year < recurrence < 100 year
- Extreme flood: recurrence > 100 years

GENESIS OF FLOODS

There are basically two causes of flooding; natural and anthropogenic.

The natural causes of flooding in Nepalese rivers are:

- Fragile geological conditions
- Extremities in Climates
- Topographical Extremities
- Seismic Activities

The anthropogenic causes of flooding are:

- Socio-economic Changes: Population Growth, Poverty and Illiteracy
- Deforestation
- Unscientific agricultural practices
- Unscientific Land use changes
- Developmental Activities: Roads, Irrigations, Hydro-powers, Urbanization

GEOLOGY

Geologically, Nepal can be divided into five major tectonic zones. These are separated by three major fault systems. The area north to Main Central Thrust (MCT) is the Higher Himalaya whereas the area between Main Central Thrust (MCT) and Main Boundary Thrust (MBT) can be divided into High Mountains and Middle Mountains. The higher Himalayas are mainly composed of gneiss, migmatites and are perpetually covered by snow. The High Mountains and Middle Mountains are mainly composed of phyllites, quartzites, schists, limestones, dolomites etc. The area between the Main Boundary Thrust (MBT) and Himalayan Frontal Faults (HFF) is called the Siwalik range and below the Himalayan Frontal Faults (HFF) is the Terai plain. The Siwaliks are composed of mollase formation represented mainly by sandstones, mudstones, siltstones, shales, sandy beds and conglomerates. The Terai is composed of thick alluvium deposited by the Nepalese tributaries of the Ganges.
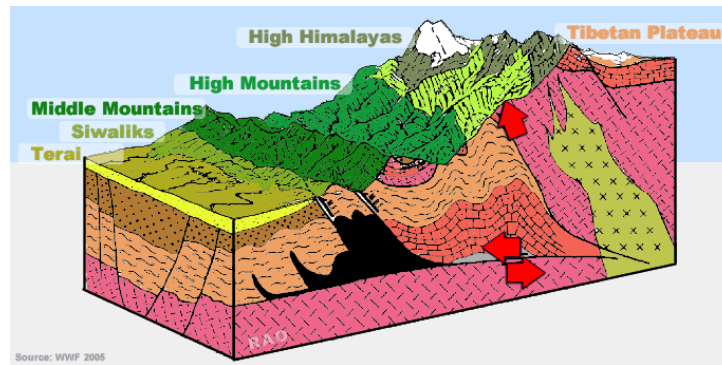
Figure 1 : Geological formation of Nepal.

The geological formation of each region is different. Geologically, Himalaya and other mountain ranges have been formed by orogeny, resulting from the collision of the Indian subcontinental plateau with the Eurasian continental plateau. The orogenic movement is still active as evidenced by numerous earthquakes in the region. The mountains and hilly land forms are young and unconsolidated and are fragile due to crustal destruction in the course of the orogenic movement. The tectonic instability of the region, the steepness of the terrain and the relatively young age of the Himalaya are also the main natural causes of disaster.

Due to the presence of major fault systems like Main Boundary Thrust (MBT) and Himalayan Frontal Faults (HFF) in the Himalaya and mountain ranges, various types of geodynamic processes are activated by extreme rainfall events (e.g. cloud burst, monsoon depressions and tropical cyclones). These are landslides (including land slips, slumps, creeps, wedge failures), proluvial processes (including debris flows, debris slides, debris torrents, mud flows, mud slides, debris torrents with mud), and erosional processes including bank cutting, sheet erosion etc. Contribution of these processes towards the flood and the sediment load of Nepalese rivers are very significant. These rivers carry high discharges with large amount of bed load and suspended load during the monsoon. They cannot confine themselves within their channels and hence flooding occurs.
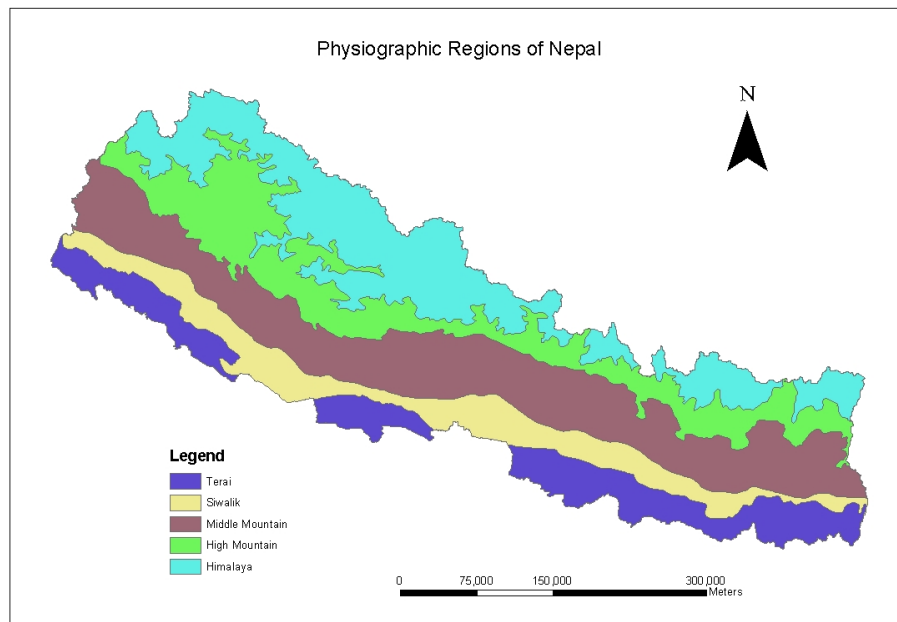
Figure 2 : Physiographic regions of Nepal.

Topographically, Nepal is a mountainous country with about 80 % area occupied by mountains and hills. There is altitude variation from 60 m at Jhapa in the South to 8848 m at Mt. Everest in the North which is quite a big variation in such a small country. The steep slope gradient of the mountains is also the cause for slope failures and landslides.

CLIMATE

Nepal's climate, influenced by elevation as well as by its location in a subtropical latitude, ranges from subtropical monsoon conditions in the Tarai, through a warm temperate climate between 4,000 and 7,000 feet in the mid-mountain region, to cool temperate conditions in the higher parts of mountains between 7,000 and 11,000 feet, to an Alpine climate at altitudes between 14,000 and 16,000 feet along the lower slopes of the Himalaya mountains. At altitudes above 16,000 feet the temperature is always below freezing and the surface covered by snow and ice.

The diversity in topography has big influence in climate of the region. The main climatic types of Nepal are the following:

- Subtropical climate in Terai with mean annual temperature 20-30 ^{0}C

- Warm temperate climate in Siwalik ranges with mean annual temperature 15-20 ^{0}C

- Cool temperate climate in middle and high mountains with mean annual temperature 10-15 ^{0}C

- Alpine climate in the Himalayas

The climatic factors of flooding are the following:

- Heavy rainfall (Monsoonal rain, Brief torrential rain)
- Snowmelt
- Ice jam breakup (GLOF)
- Avalanche, landslides etc

Generally, summer monsoon onset is observed in eastern Nepal on June 10. It advances westwards and covers the whole Nepal within a week. It is maintained until September and normally retreats by September 21. It contributes about 60-80 % of the annual rainfall in Nepal.

During the summer monsoon season, a belt of low atmospheric pressure known as 'monsoon trough' is normally established over the northern plains of India. Sometimes, it moves northward to the foothills of the Himalayas and stays there for a couple of days before retreating back. Because of the lowest pressure, it creates most unstable weather conditions in and around this area, the severity of which depends mainly upon the moisture content in the air. During this period, a heavy down-pour of rain occurs triggering severe floods and landslides. In Bagmati basin, the mean annual precipitation is 1500 mm on the Terai plain to 2500 mm at the foot of the Mahabharat and Siwalik.

In 1993, monsoon onset was observed in eastern Nepal on June 6, four days earlier than usual. It advanced westwards and covered the whole Nepal by June 14 and it was maintained until September. Generally, monsoon goes in full swing in July with consequent swelling of rivers as expected causing damages due to floods and landslides every year.
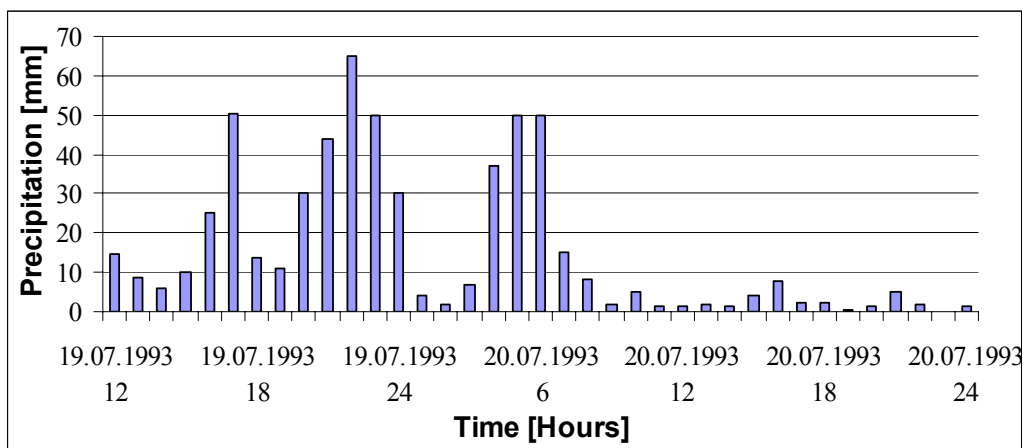
Figure 3 : Hourly rainfall at Tistung.

In 19-21 July, 1993 monsoon trough lay directly over central and eastern Nepal which resulted very heavy downpour of 540 mm during 24 hrs period with intensity as high as 65 mm/hr at Tistung of Kulekhani catchment (a sub-catchment of Bagmati basin). This became the leading cause of severe floods resulting in widespread damages of life and property. Figure 1 shows the pattern of hourly rainfall and Figure 2 shows the cumulative rainfall from 12:00 NST on 19th July to 24:00 NST on 20th July at Tistung.
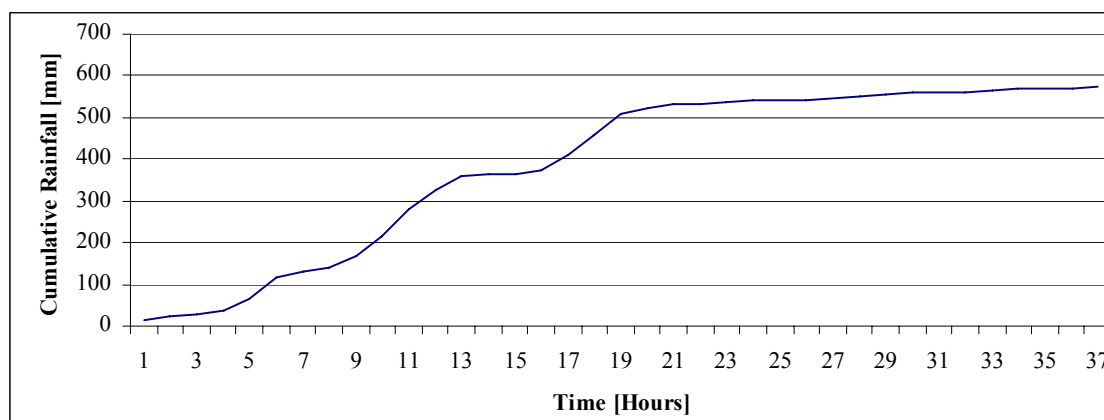
Figure 4 : Cumulative rainfall at Tistung.

A heavy rainfall has been observed during 48 hour period from 8:45 NST of 19th July to 8:45 NST of 21st July in the following four stations.

1. Ghantemadi : 599 mm

2. Nibuwatar (outside Bagmati basin): 596 mm

3. Tistung : 579 mm

4. Simlang : 431 mm

LAND USE AND LAND COVER

The monsoonal climate and huge altitudinal range found in Nepal creates a wide array of habitats, from the lowland evergreen tropical forests in the Terai (below 200m), through warm temperate evergreen, cool temperate deciduous forests and then coniferous forest to the tree line. Above this

Rhododendron scrubland extends up to the high alpine meadows before plant life gives way to the frozen wastes of the barren snow capped peaks of the world's highest mountains (the highest recorded flowering plants are found at around 6100 m). The deep river valleys create their own microclimates, and dramatic changes in the vegetation can be seen in relatively small areas with differing aspect and altitude.

A number of districts in the Terai have substantial plantations of Dalbergia sissoo, Eucalyptus spp. and Tectona grandis (Teak), particularly in Sagarnath and Nepalgunj. Plantations in the Mid-Hills comprise Pinus roxburgii, Pinus wallichiana, Pinus patula and Alnus nepalensis.

Tropical moist lowland Indo-Malayan forest (below 1000 m [to 1200 m in Churia hills]): predominantly Sal (Shorea robusta). Acacia catechu and Dalbergia sissoo replace Sal in riverine forests. Other riverine forest types include evergreen species such as Michelia champaca, or deciduous species such as Bombax ceiba. In the foothills of western Nepal Sal forest is replaced by Terminalia/Anogeissus forest.

Subtropical broad-leaved evergreen forest (1000-2000 m): central and eastern parts have Schima wallichii/Castanopsis indica forest. Riverine forest of Toona(Cedrela) and Albizia occur low down along the valley sides of large rivers (e.g. Arun Khola). Alnus nepalensis is widespread along streams and moist places.

Subtropical pine forest (1000-2200m): South facing slopes of the Siwalik and Mid-Hills in western and central regions, dominated by Chir Pine (Pinus roxburghii).

Lower temperate broad-leaved forest (2000-2700m in the west; 1700-2400 in the east): Mid-Hill forests with Alnus nitida, Castanopsis tribuloides, Castanopsis hystrix, Lithocarpus pachyphylla, Quercus spp. Alnus nitida forest is confined to the river banks of the Mugu Karnali (2130-2440m). In west Nepal Quercus leucotrichophora and Quercus lanuginosa forests and Quercus floribunda. Central and eastern parts have Quercus lamellosa forest. Lithocarpus pachyphylla forest occurs in the east.

Lower temperate mixed broad-leaved forest (1700-2200): generally confined to the moister north and west-facing slopes, with several tree species of Lauraceae prominent.

Upper temperate broad-leaved forest (2200-3000m): drier south-facing slopes of central and eastern parts have Quercus semecarpefolia forest, but this is absent in higher rainfall areas such as the Upper Arun and Tamur valleys and hills to the north of Pokhara.

Upper temperate mixed broad-leaved forest (2500-3500m): mostly found in central and eastern regions, mainly on the moister north- and west-facing slopes. Acer and Rhododendron species predominate. In the west, forests of Aesculus/Juglans/Acer can be found.

Temperate coniferous forest (2000-3000m): Pinus wallichiana is an aggressive coloniser and can be found throughout Nepal at these elevations, extending up to 3700m. In the west, Cedrus deodara, Picea smithiana, Juniperus indica and Abies pindrow forests occur. The upper Bheri River valley marks the easternmost extent to Cedrus deodara. In Nepal, Larix himalaica forest only occurs in the Langtang and Buri Gandaki valleys, and favours glacial moraine habitats. Larix griffithiana, the eastern Himalayan larch, extends up to 3940m. Cupressus torulosa forest and Tsuga dumosa forest are widespread throughout Nepal between 2130-3340m.

Subalpine forest (3000-4100m): Abies spectabilis, Betula utilis, Rhododendron spp.

Alpine scrub (above 4100m): varied associations with Juniperus spp. and Rhododendron spp. Juniperus recurva, Juniperus indica, Juniperus communis, Rhododendron anthopogon, Rhododendron lepidotum, Ephedra gerardiana and Hippophae tibetana in the inner valleys. North of the Dhaulagiri-Annapurna massif Caragana versicolor, Lonicera spinosa, Rosa sericea and Sophora moorcroftiana occurs. Alpine meadows (Kharkas) are grazed during the summer and rainy seasons.

Perpetual snow (above 5200m): Stellaria decumbens and Parrya lanuginosa have been recorded at 6100m, but beyond this point in the Arctic desert/Nival zone, even mosses do not survive.

The natural forests are degraded by the gathering of fodder and firewood. Because of population pressure, many degraded forests and the rangelands are rapidly converting into rainfed agricultural lands. Deforestation and unmanaged agricultural practices have contributed to land degradation and soil erosion.

BREAK UP OF DAMS/LEVY

Flooding may occur due to break up of dams and levies. Breach may occur either by overtopping, scouring or by piping.

CONSTRUCTION OF ROADS

Construction of mountain roads has strong effect on slope failures contributing to landslides and soil erosion, which aggravates the flood problem.

URBANIZATION

Major urban centers have developed along the river banks. For example, Kathmandu and Lalitpur municipalities lie in Bagmati river basin. Narayanghat is situated on the bank of Narayani and vulnerable to flooding. Butwal has many experiences of damage due to flood in Tinau. Many industries have been established on the Valley of these Rivers and due to rapid urbanisation, the river valley is encroached for settlement, road construction and other development activities. The household and industrial sewages are directly disposed into river. The pavement of roads by asphalt or concrete has increased the surface drainage. Urbanization has aggravated the flood problem by the following reasons:

- Decrease in runoff retarding functions which the river basin used to have; and
- Acceleration in flood flows induced by pavements and rooftops covering a large area and installation of drainage systems.

MAGNITUDE AND FREQUENCY

The Department of Hydrology and Meteorology (DHM) has a network of hydrological and meteorological stations to collect river stage, river discharge and climatic data all over Nepal. DHM publishes the record of those data annually.

According to the DHM publication, the instantaneous maximum discharge of Bagmati river at Pandheradovan from 1979 to 2007 along with the floods of 20 years and 100 years return period are shown in Figure 1.
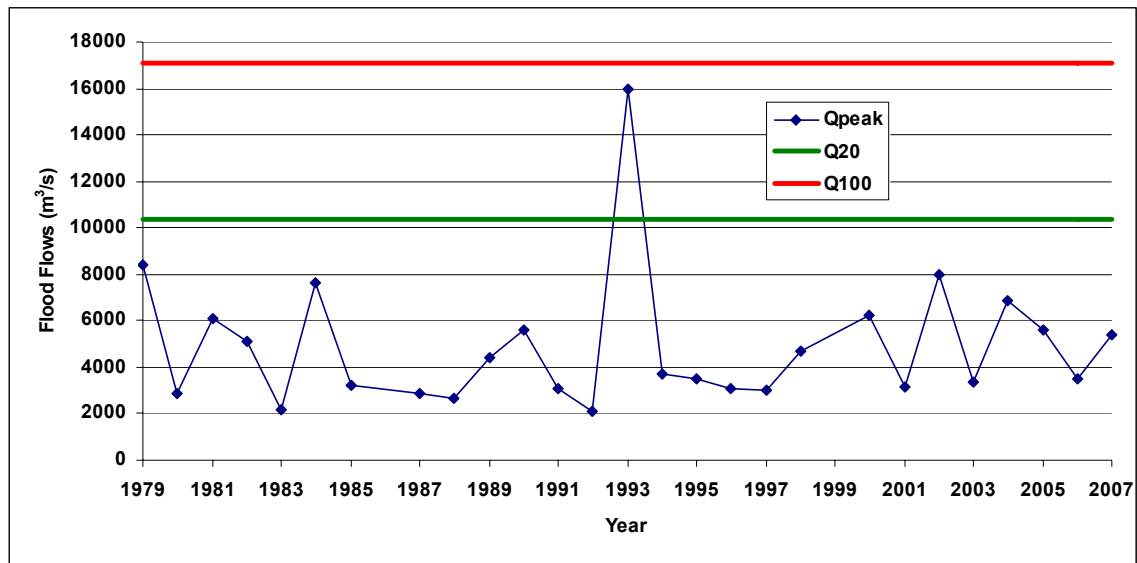
Figure 5 : Instantaneous maximum discharge of Bagmati River at Pandheradovan (Karmaiya).

The flood discharge varies from 2000 m³/s to 16000 m³/s. It is clearly seen that very large flood with return period of about 100 years has occurred in 1993 which was catastrophic.
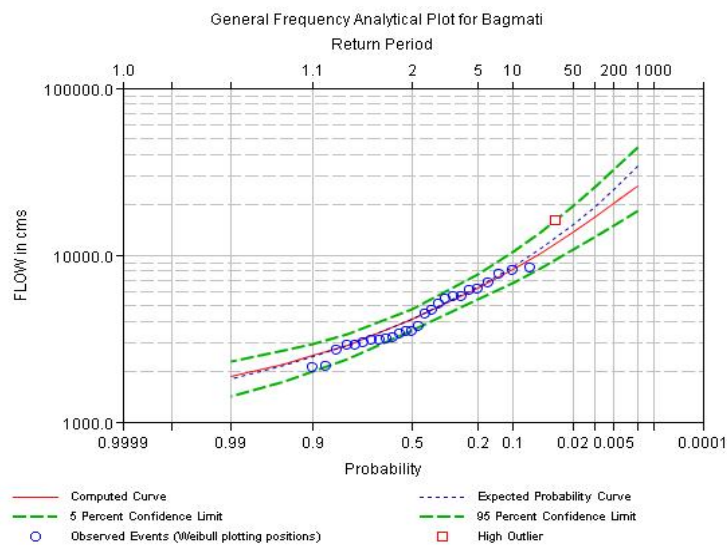
The instantaneous maximum discharge of East Rapti river at Rajaiya from 1963 to 2006 is shown in Figure 2. The flood discharge varies from 179 m³/s to 1680 m³/s. It is seen that very large flood with return period of about 100 years has occurred in 2004, which washed away gauge house, school and several houses near to the gauging site.
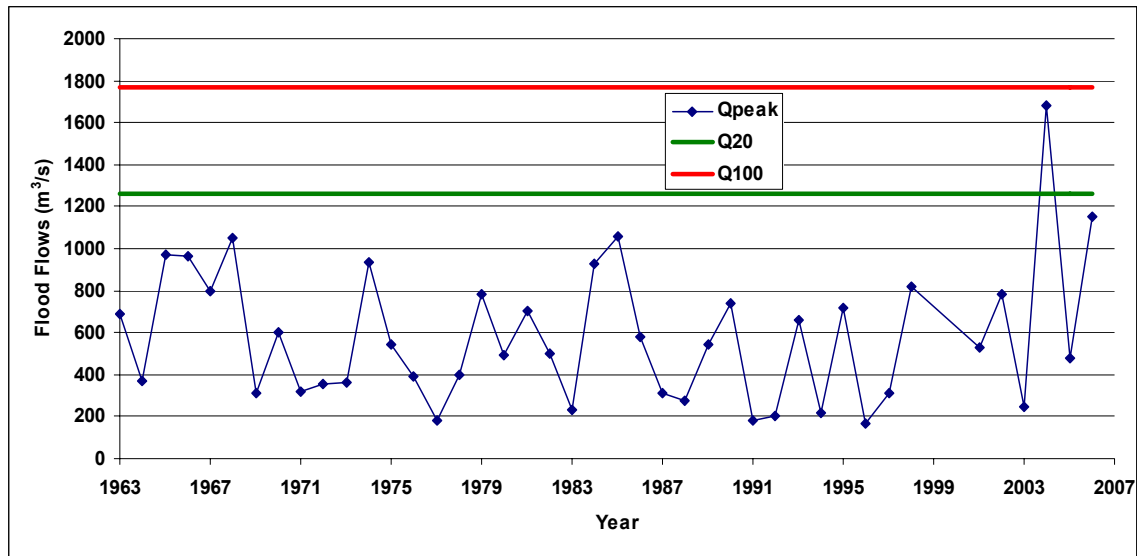
Figure 6 : Instantaneous maximum discharge of East Rapti River at Rajaiya.
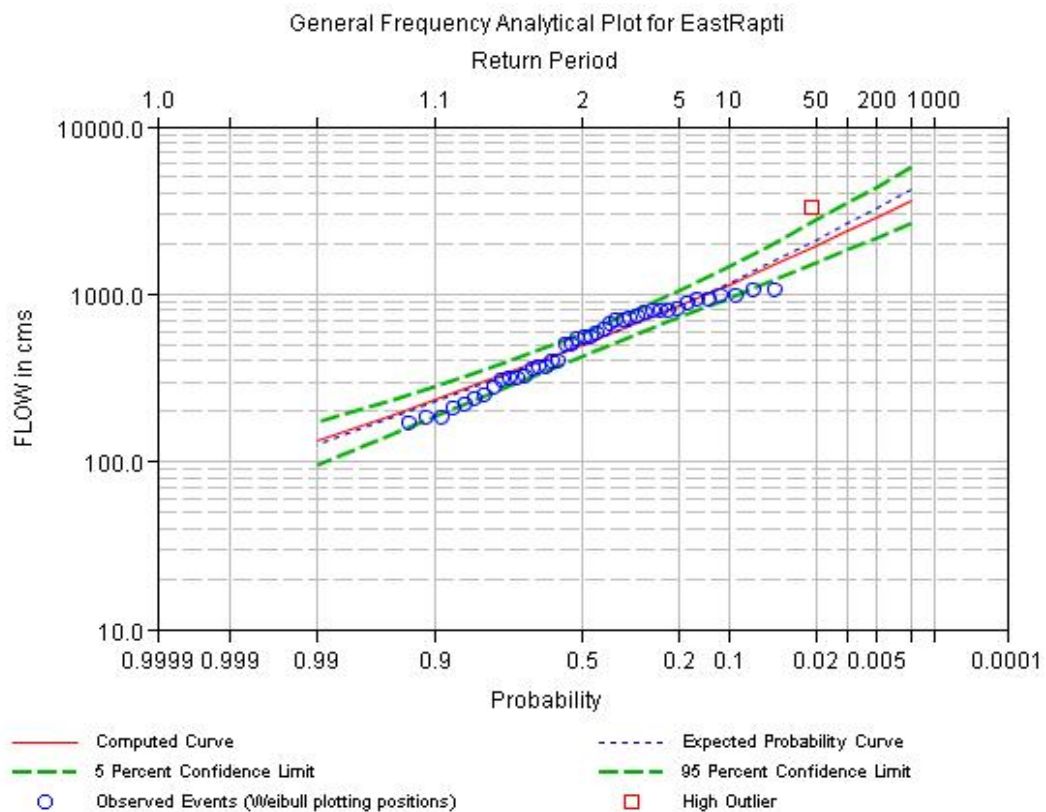
The instantaneous maximum discharge of Narayani river at Narayanghat from 1963 to 2007 is shown in Figure 3. The flood discharge varies from 6130 m³/s to 15300 m³/s. It is seen that very large floods have occurred in 1974 and 1999.
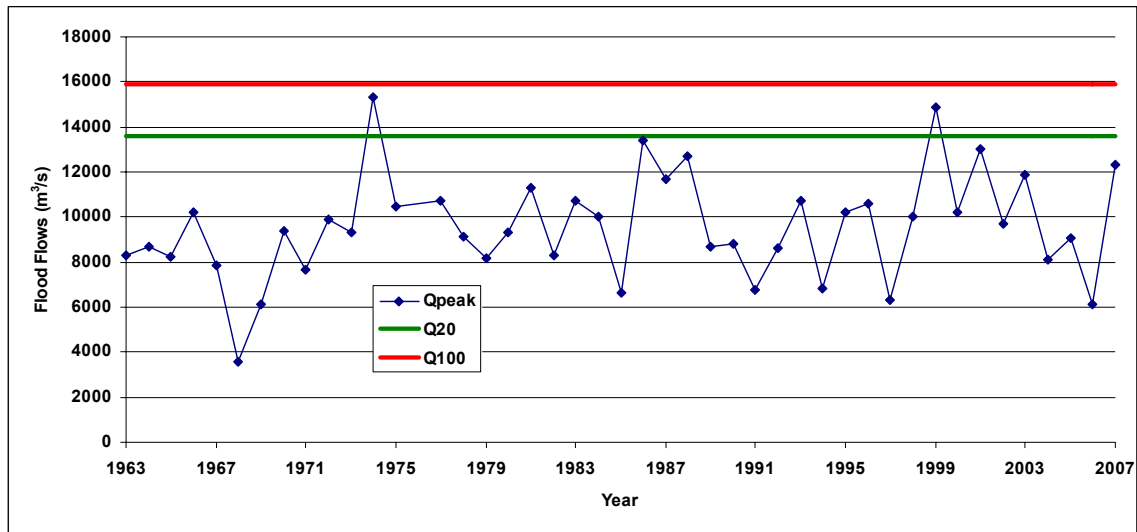
Figure 7 : Instantaneous maximum discharge of Narayani River at Narayanghat.
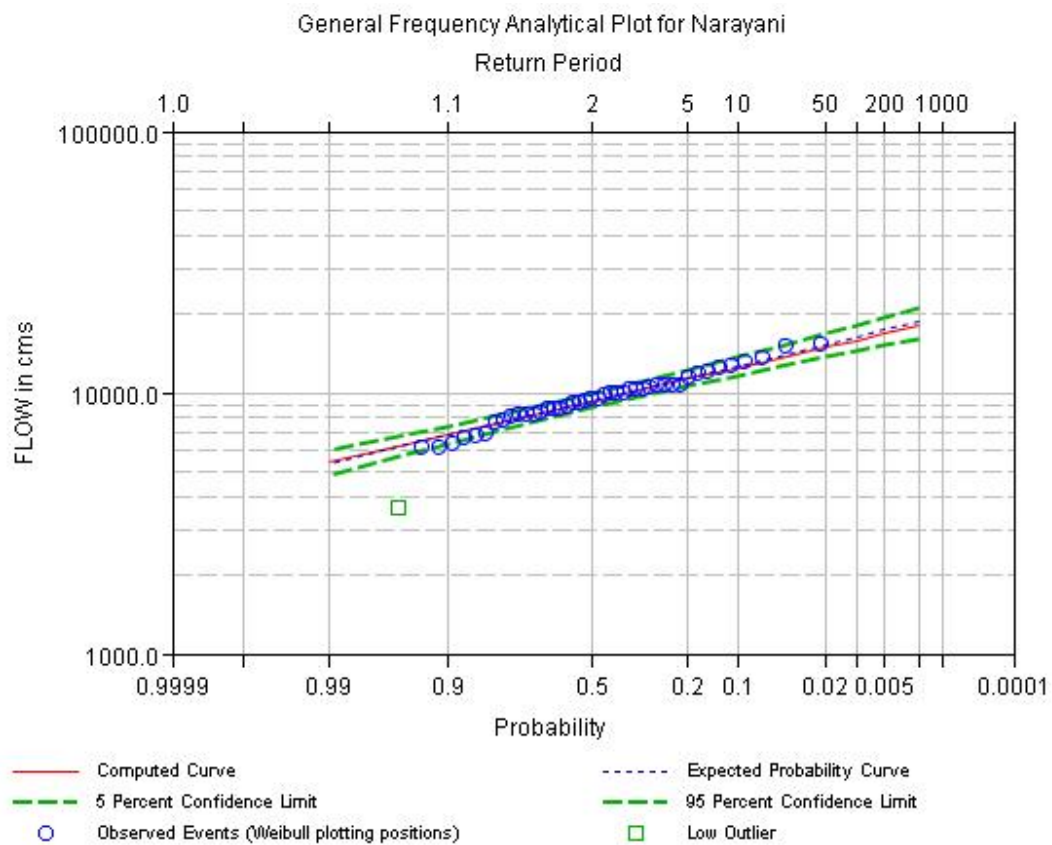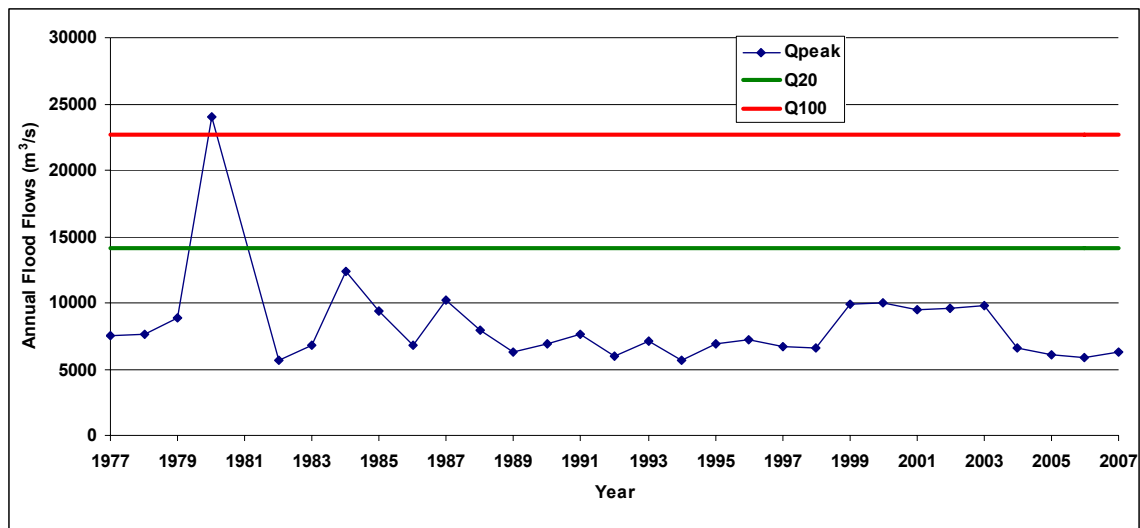
Figure 8 : Instantaneous maximum discharge of Sapta Koshi River at Chatara.
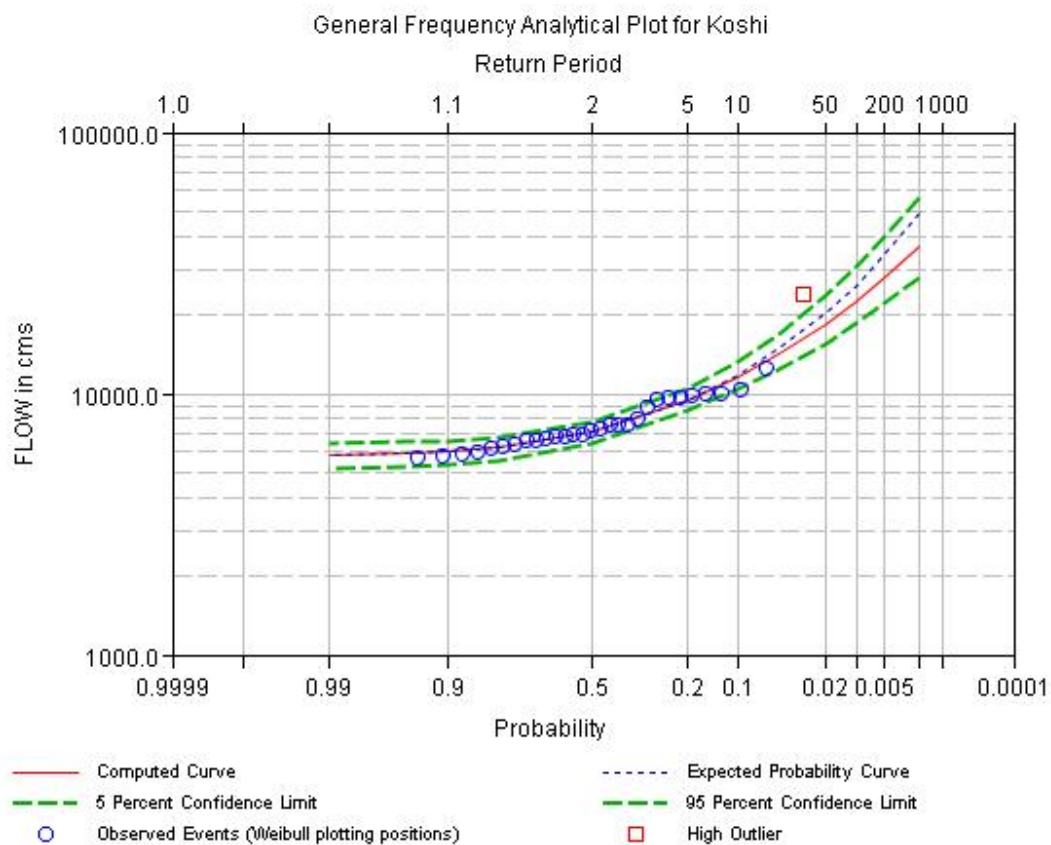
The instantaneous maximum discharge of Sapta Koshi river at Chatara from 1977 to 2007 is shown in Figure 4. The flood discharge varies from about 5630 m³/s to 24000 m³/s. It is seen that extreme

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flood with return period greater than 100 years has occurred in 1980. In July 1991, the embankment of the Sapta Koshi river immediately downstream of the Koshi Barrage was breached due to flood discharge of 6700 m³/s causing inundation over a vast area on the right bank. About 6000 persons of 12 villages had to be evacuated to safer places and 40 ha of agricultural land were washed away.
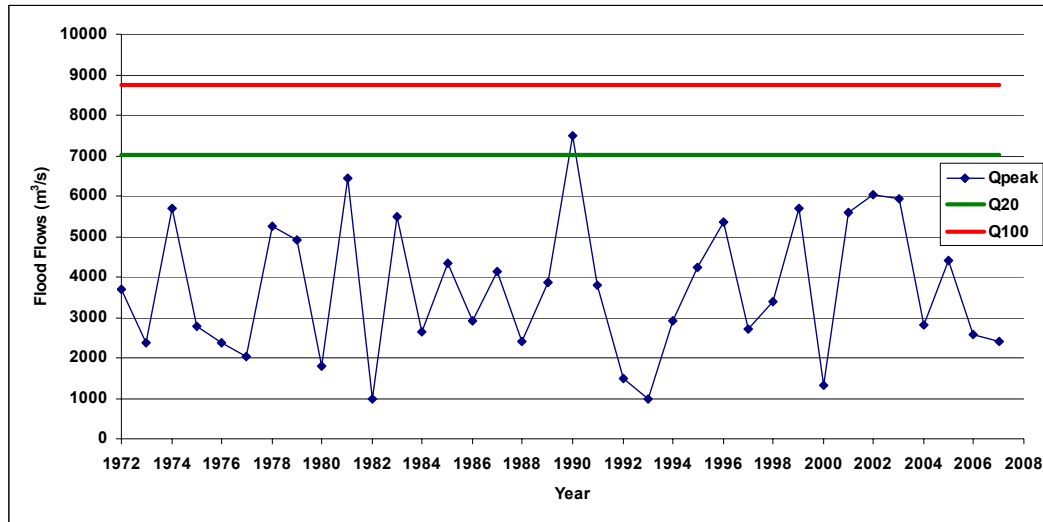
Figure 9 : Instantaneous maximum discharge of Kankai River at Mainachuli.
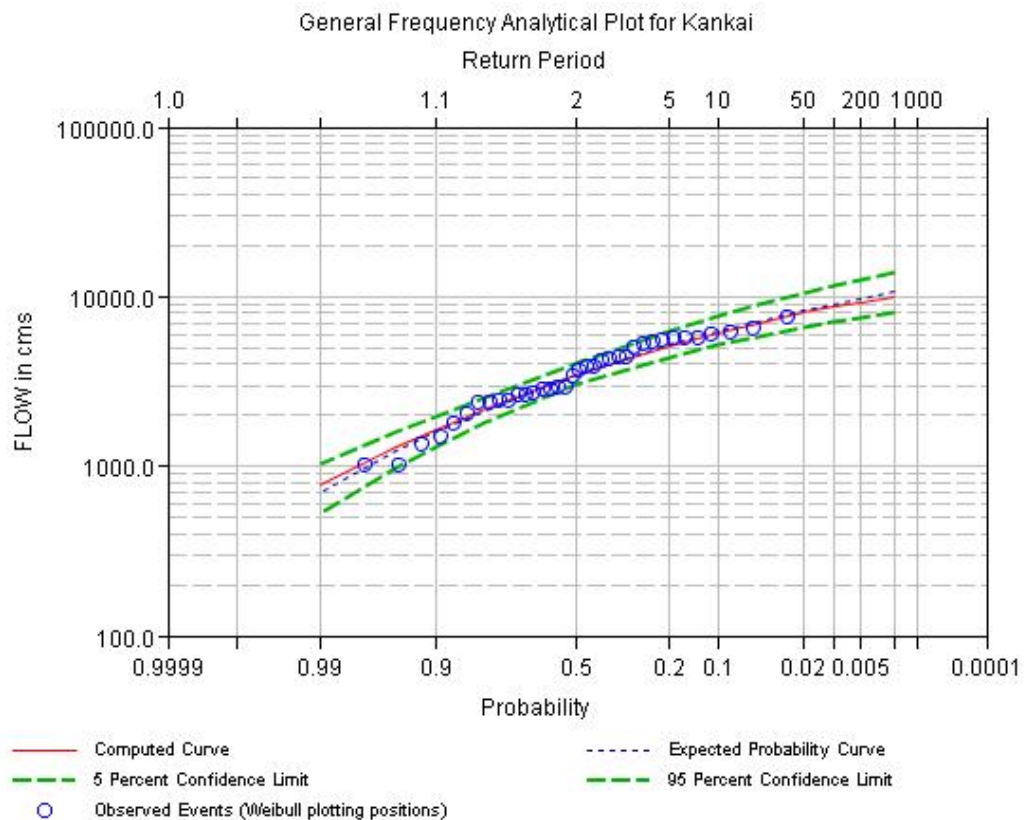
The instantaneous maximum discharge of Kankai river at Mainachuli from 1972 to 2007 is shown in Figure 5. The flood discharge varies from 992 m³/s to 7500 m³/s. It is seen that large floods has occurred in 1981, 1990, 2001, 2002 and 2003. In recent years, the frequency of large floods is increasing.
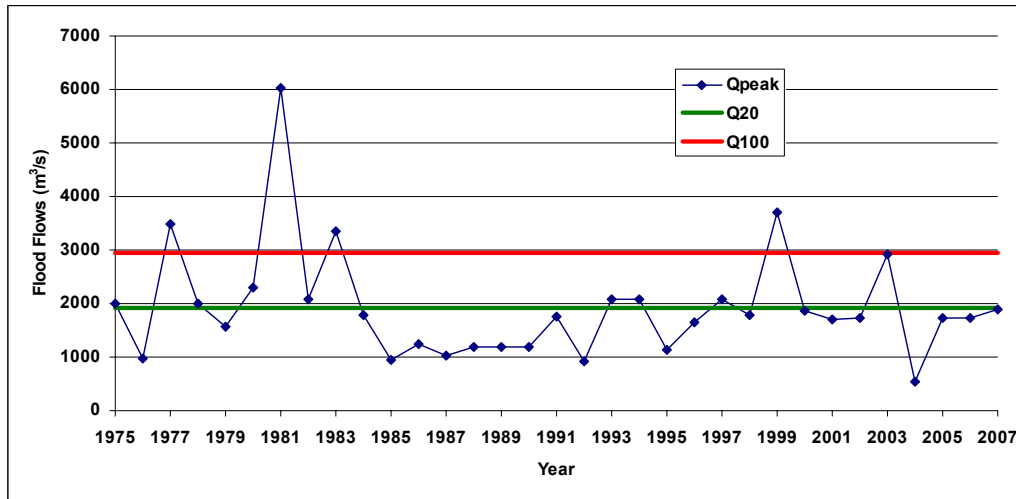
Figure 10 : Instantaneous maximum discharge of West Rapti River at Bagasoti (Bhalubang).
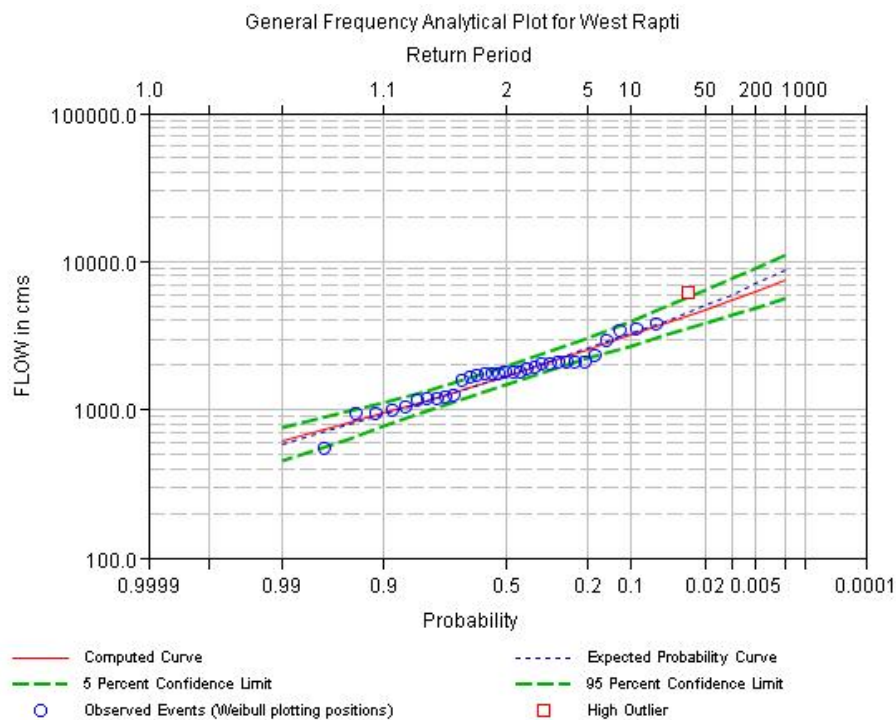
The instantaneous maximum discharge of West Rapti River at Bagasoti from 1975 to 2007 is shown in Figure 6. The flood discharge varies from 535 m³/s to 6030 m³/s. It is seen that extreme flood has occurred in 1977, 1981, 1983, 1999 and 2003. In 1981, extreme flood with return period of about 200 years has occurred.

It is seen that medium size rivers originating from middle mountain ranges such as Kankai, Kamala, Bagmati, East Rapti and West Rapti are causing more flood problems than the large rivers such as Koshi, Narayani and Karnali.

Rainfall intensities of about 40-50 mm per hour are common in lower Mahabharat and Siwalik regions of Nepal. Several instances of rainfall of more than 400 mm in a 24-hour period have been recorded by Department of Hydrology and Meteorology (DHM) such as the 431 mm rainfall at Bajura in far-western region in August 12, 1980; 446 mm at Beluwa, in western region in September 29, 1981; 500 mm at Ghumthang in central region in August 25, 1968; 540 mm at Tistung in 20 July, 1993 and 473 mm at Anarmani in eastern region in October 10, 1959. A heavy rainfall has been recorded during 48 hours period from 19 to 21 July 1993 at Ghantemadi (599 mm), Nibuwatar (596 mm), Tistung (579 mm) and Simlang (431 mm). The maximum rainfall intensity of 88 mm per hour was recorded in 1989 at Pokhara in western region, while a rain intensity of 45 mm per hour on a steeply slopping watershed had initiated landslides and debris torrent in September 29, 1991. However, with changing land use and other associated development activities, a lower threshold rainfall intensity (as low as 40 mm which are common during monsoons) could also result in damaging landslides and flash floods.

Major floods occurred in 1993 in Bagmati river, and in 1964, 1981 and 1984 in Sunkosi river. Floods in Tinau in 1981 washed hectares of fertile lands and took several lives.

CONSEQUENCES OF EXTREME FLOODS

The numbers in the Table 1 below show the annual losses due to floods, landslides and avalanches in Nepal since 1983 to 2006. About 300 peoples die and about 626 million Rupees worth of property is lost each year due to floods and landslides. It is seen that the number of lives lost due to extreme events is decreasing but at the same time the number of families affected, agricultural areas impacted and monetary damages is steadily increasing. This shows that while the exposure and even the vulnerability is increasing, the systems and institutions have been able to limit causalities but not so successful in reducing risks or preventing increasing impacts on livelihoods.

Table 1 : Annual losses due to floods, landslides and avalanches in Nepal

Year	Death	Injured	Families affected (Nos.)	Livestock Loss (Nos.)	Houses destroyed (Nos.)	Land affected (Ha.)	Public Infrastructure	Estimated Loss (Million NRs)
1983	293	NA	NA	248	NA	NA	NA	240
1984	363	NA	NA	3114	7566	1242	869	37
1985	420	NA	NA	3058	4620	1355	173	58
1986	315	NA	NA	1886	3035	1315	436	16
1987	391	162	96151	1434	33721	18858	421	2000
1988	342	197	4197	873	2481	NA	NA	1087
1989	700	4	NA	297	6203	NA	NA	29
1990	307	26	5165	314	3060	1132	NA	44
1991	93	12	1621	36	817	283	25	21
1992	71	17	545	179	88	135	44	11
1993	1336	163	85254	25425	17113	5584	NA	4904
1994	49	34	3697	284	569	392	NA	59
1995	246	58	128540	1535	5162	41867.28	NA	1419
1996	262	73	36824	1548	14037	6093.4	NA	1186
1997	87	69	5833	317	1017	663.4	NA	104
1998	273	80	33549	982	13990	326.89	NA	969
1999	209	92	9768	309	2538	182.4	NA	365
2000	173	100	15617	822	5417	888.9	NA	932
2001	196	88	7901	377	3934	NA	NA	251.1
2002	441	265	39309	2024	18181	10077.5	NA	418.91
2003	232	76	7167	865	3017	NA	NA	234.78
2004	131	24	14238	495	3684	321.82	NA	219.28
2005	141	31	2088	360	1102	NA	NA	130.56
2006	114	39	18385	9980	3334	3396.84	NA	288.63
Average	299	81	27150	2365	6725	5229	328	626

Source : DWIDP, 2007 and Ministry of Home Affairs. (NA= not available).

Heavy rainfall in central and eastern regions of Nepal during 19-21 July, 1993 had disastrous consequences with heavy loss of life and property as well as damages to infrastructures by floods, landslides and debris flows. In 1993, 87 % of the total deaths of human life occurring in the country were resulted from floods and landslides. Within the country, more than 500,000 people of 85254 families were directly affected, 1336 people were dead and 163 injured. 25425 livestocks were lost and 17113 houses were destroyed. In agriculture sector, more than 57584 ha. of arable lands were damaged. 67 small and large irrigation projects along with thousands of farmer-managed irrigation schemes were seriously damaged. The estimated loss of properties was 4904 million NRs. This was the worst disaster in last 20 years.

The flood of unprecedented magnitude along with massive debris severely damaged the Bagmati Barrage and caused extensive flooding on both sides of the river upto the Indo-Nepal border affecting many villages with the biggest loss of human lives. The floods in East Rapti breached the embankment of 850 m long and washed away several villages. Hydroelectric plant of Kulekhani was also severely damaged. The main highways were gravely damaged and several bridges were washed away.

Similarly the 1998 floods and landslides that severely affected the Terai and Middle Hill region claimed 273 human lives, injured 80 people and killed 982 cattle, affecting 33,549 families, damaging 13,990 houses, ruining 45,000 hectares of land and agricultural crops resulting in a total loss of about NRs 2 billion.

The devastating floods in the low land areas and severe landslides in the hills during July 2002 affected 49 out of the country's 75 districts causing more than 445 deaths after leaving some 12,800 families homeless, and affecting over 300,000 people over a large and dispersed area. Check dams and embankments in the Butwal area (West Nepal) which were constructed after the 1970 floods collapsed in 1981 and 41 people, 120 houses, two mills and one bridge were swept away.

In the Himalayan region of Nepal glacier lakes are common. A total of 159 glacial lakes have been found in Koshi basin and 229 in Tibetan part of Arun basin. Among them 20 are potentially dangerous as these lakes contain huge volume of water and remain in unstable condition, and can burst any time damaging life and property. 14 such glacier lake outburst floods have already been experienced from 1935 to 1998, with the last one occurring in Sabai Tsho, Dudh Koshi on 3 September, 1993. On 4 August 1985, a glacier lake outburst flood (GLOF) has occurred in Bhote Koshi River due to collapse of Dig Tsho Lake. Damage was extensive up to 40 km downstream. Namche Hydropower station was destroyed, 12 bridges and more than 30 houses were washed away.

On 18th August 2008, the breach of the left embankment of Kosi river near Kusaha village in Sunsari district of Nepal affected 4 village development committees causing more than 107000 people homeless in Nepalese side and more than 3000000 people displaced in Indian side. About 6000 hectares of agricultural land has been inundated and agricultural products worth more than US $ 3.7 million have been damaged.

Catastrophic floods could lead to outcomes that undermine development, such as crop failures, disease outbreaks, livelihood damages and losses and food insecurity.

COMPREHENSIVE FLOOD MANAGEMENT

Large areas of Nepalese Terai Region, with the largest concentration of Nepal's population and development activities, are frequently subjected to natural disasters caused by floods and landslides. Every year, it is reported that many people are killed or missing, thousands of people are rendered homeless and huge amount of public and private properties are damaged.

Several structural measures such as construction of flood control reservoirs, levees, floodways, channel improvements etc. have been taken by concerned agencies for the mitigation of floods. However, the losses from floods are not decreasing. This might be due to growth of potential losses

in flood plains caused by growing population, agriculture, industrilisation and the expansion of urban areas despite efforts to construct flood control structures. This trend can be reversed if non-structural measures such as flood plain management, flood proofing facilities, flood forecasting and warning, flood fighting and evacuation etc. have been applied in co-ordination with structural measures. This co-ordinated plan is called comprehensive flood management [9]. The comprehensive flood management which includes both structural as well as non-structural measures consists of the following activities:

1. Structural Measures

  i. River Improvement
      Dikes and Flood Walls
      Channel Improvements
      Flood Diversion
  ii. Retention of Runoff
- Reservoirs
- Retarding Ponds
- Rainfall Retention Facilities

2. Non-Structural Measures
- Conservation of Upper Watershed
- Regulation of Development
- Afforestation
- Flood Plain Management
- Land Use Regulation
- Regulation of Land Development
- Regulation of Land Reclamation
- Flood-Proofing of Facilities
- Flood Insurance
- Flood Warning and Evacuation
- Flood Forecasting and Warning
- Disseminating Flood Information

CONCLUSIONS

DHM has the responsibility to provide flood and weather information for people and agencies involved in hydrometeorological disaster management. The daily weather forecasts and climate information are provided to the decision-making requirements of the stakeholders for agriculture, mountaineering, aviation and water resources. DHM needs to build the capacity in the field of modeling and generation of a suite of high-resolution flood and weather information.

DHM has infrastructure for generating weather and climate forecasts and for developing flood forecasting and warning system but work has to be done in terms of increasing the spatial resolution and lead-time of current weather forecast products such as for floods and landslides. It is necessary to improve DHM's short range weather forecasting system. This can be done by customizing high resolution meso-scale modeling system (Weather Research and Forecast or WRF model) for Nepal. There should be a real time data acquisition and transmission system for water level and rainfall data so that the performance of the forecast model could be improved by data assimilation techniques.

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Atmospheric and Land-surface Conditions responsible for seasonal change of evaporation rate in Langtang Valley, Nepal Himalaya, 2008

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ABSTRACT

Study of land surface condition in Langtang Valley of Nepal Himalaya from the micro-climatic and meteorological point of view was carried out before to understand the evaporation process which alters both heat and moisture exchange to and from the land surface. Previous result shows that the evaporation rate in this Valley does not strongly depend only on surface condition of the land in monsoon season.

Land surface plays very important role in receiving and transferring both heat and moisture to and from the atmosphere depending upon seasons and moisture content at the surface. Therefore, further attempt has been made here to estimate Bulk Coefficient and surface moisture availability (moisture parameter at the surface) to study the seasonal variation of evaporation rate as well as to understand the surface micro-climatic phenomena in summer period. Further, the evaporation is compared with precipitation and relative Humidity assuming that the atmospheric condition can govern the seasonal change of evaporation, which shows better consistency for the result. Investigated result shows that the surface condition has no effect to the seasonal change of evaporation rate, even though the surface contains sufficient moisture in it in monsoon time in Nepal. Hence, it is concluded that the change in evaporation rate in Langtang Valley of Nepal Himalaya is strongly controlled due to atmospheric conditions near the earth surface rather than other land surface and atmospheric factors.

This study will also tries to analyze and explain different micro-meteorological parameters at the land surface in langtang Valley, which will be important for better understanding of actual land surface condition, surface meteorological condition and atmospheric conditions in other regions having similar climatic condition in the country in monsoon season.

Key words : Evaporation, relative humidity, bulk coefficient and moisture parameter

INTRODUCTION

Many studies were carried out in Langtang Valley, Nepal Himalaya since 1970. Evaporation, which was neglected almost in all those studies, was estimated, Chhetri *et al* 2000, is very important process for transferring energy in the form of latent heat flux from surface to the atmosphere, generally showed seasonal dependency on both surface and atmospheric conditions and high contribution to energy and water balance process.

Although, evaporation rate is controlled by many factors, it mainly depends on the atmospheric conditions and surface soil moisture content at the land surface. Friction velocity (u*), roughness length, bulk coefficient (C_E) of turbulent transfer of latent heat and surface moisture availability (α), the moisture parameter, which is the ratio of actual specific humidity at the land surface (q_s) to saturation specific humidity at surface temperature ($q_{sat(Ts)}$), as defined by Kondo *et al.*, (1990), control the rate of water loss from the land surface are computed and investigated in detail to analyze the surface moisture characteristics, which depend on the external atmospheric condition as well as soil surface moisture. Estimated friction velocity (u*) and the roughness length (z_o) are taken from Chhetri, 2003 which reports the actual surface meteorological condition in summer season. Comparison studies of evaporation rate with atmospheric elements, Chhetri *et al* 2000, and surface parameters, Chhetri, 2003 show that the variable rate of evaporation is mainly due to variation of moisture content at the lower atmosphere and Relative humidity in summer period from pre-monsoon, monsoon and post monsoon season in Nepal.
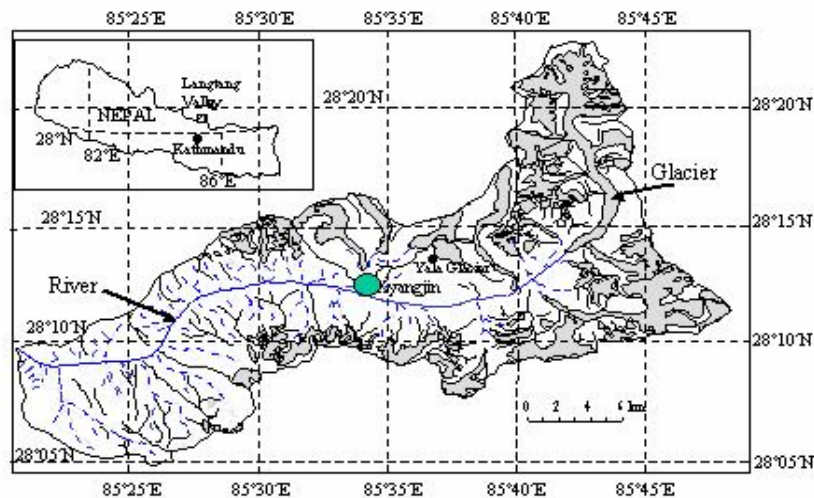
Fig. 1 Map of Langtang Valley showing Kyangjin.

STUDY AREA AND ITS LOCATION IN NEPAL

The data observation and measurement were carried out at Kyangjin in Lantang Valley which is located at $28^0 13'$ N. Lat. And 85^0 34' E. Long. at about 60 km northward from Kathmandu Valley, Nepal, Fujita *et.al*. 1996. The altitude of meteorological station at Kyangjin is 3880 m. a.s.l., (Fujita *et.al*. 1998). The locations of Langtang Valley and study area are shown in Fig. 1.

DATA SOURCE AND DESCRIPTION

The primary data collection and observation was made automatically as well as manually from May to October 1996 in the monsoon period from 7- May to 25- October at Kyangjin Station in Langtang Valley. The meteorological data which, were used to calculate the different parameters for determining the atmospheric-meteorological condition and land surface condition are analyzed from the Fujita *et al*. 1996. The calculated Latent heat flux (evaporation rate) in neutral condition Fig. 4 is used for this analysis here from Chhetri, *et al*. 2000. The wind speed data measured at two heights (0.47m and 0.47m) were used for estimation of the friction velocity and roughness length, Chhetri, 2003, paper presented/submitted to SOHAM, 2004, Nepal. The detail of meteorological data and their description is found in Fujita *et al*. 1996, Chhetri, *et al*. 2000.

COMPUTATION OF DIFFERENT PARAMETERS

a) The friction velocity and roughness length

The friction velocity (u*) and the roughness length (z_o) were calculated using the Equations as given below,

$$u* = \kappa \frac{U_U - U_L}{\ln(z_U / z_L)} --------(1) \quad \text{and} \quad z_o = \frac{z_L}{(z_U / z_L)^{U_L / \Delta U}} \text{————(2)}$$

where, u* is friction velocity (m/s), κ is von Karman's constant (0.41), U_U and U_L wind speeds

(m/s) at heights z_U =1.44 m and z_L= 0.47 m in the atmosphere respectively, z is the measurement height (m) and z_o is the roughness length (m).

b) Bulk coefficient and soil moisture parameter

The bulk coefficient for sensible heat transfer process (C_H) from the land surface under the neutral condition of atmosphere is calculated by using the bulk equation,

$$Q_H = C_H c_p \rho (T_a\text{-}T_s) U \quad ----------------(3)$$

where, T_a and T_s are air and surface temperature respectively. U is wind speed. Q_H represents for the sensible heat flux, calculated by gradient method, and other symbols represent the usual meaning, Chhetri, *et al* 2000.

Further, the surface moisture availability as noted α here, which also represents as the relative humidity of air but apparently for the soil moister content at the land surface (Kondo *et al.*, 1990) is calculated by using Equation (4) assuming that $C_H = C_E$,

$$Q_L = C_E L \rho (q_a - \alpha q_{sat(Ts)}) U \quad ---------(4)$$

where, C_E is bulk coefficient for latent heat transfer, q_a is actual specific humidity. The latent heat loss in W/m², which was estimated by residual method in the previous report, is used to determine α. Bulk coefficient (C_E) for latent heat in Equation (4) is assumed to be same with that of sensible heat under the neutral condition of atmosphere.

c) Latent heat flux Q_L (evaporation rate)

The evaporation rate was determined by residual method using net radiation, sensible heat flux and ground heat flux as given below, Chhetri *et al* 2000.

$$Q_L = - (Q_N+Q_H+Q_G) ----------------(5)$$

$$\text{Where,} \quad Q_N = (K_i\text{-}K_o)+(L_i\text{-}L_o) : \text{Net radiation}$$

$$Q_H = \rho c_p (dT/dz)(dU/dz) : \text{Sensible heat flux}$$

$$Q_G = \text{Ground heat flux}$$

$$\rho = \text{density of air and } c_p \text{ is sp. Heat capacity}$$

$$dT/dz = \text{temperature gradient}$$

$$dU/dz = \text{wind gradient}$$

RESULTS AND DISCUSSIONS

a) The friction velocity and roughness length

Calculated daily average values of friction velocity (u*) and roughness length (z_o) from 7 May to 25 October (1996) are shown in Fig. 2. This graph shows daily and monthly wise variation of both friction velocity (u*) and roughness length (z_o). High values of u* about 0.22 m/s are found mainly in rainy season in July, August and September and other three months, May, June and October show low values of magnitude about 0.15 m/s.

The high and low friction velocities during day and nighttime are due to the effect of air and surface temperature on the land. Mostly nights are found stable because of temperature inversion so that it causes very low friction velocity at nights than comparing days. However, the friction velocity is found directly proportional to the difference of wind speed at two levels and inversely proportional to the ratio of logarithmic heights of upper to lower level of the atmosphere, Chhetri, *et al* 2000. A slowly increasing trend from the beginning of May and then a rapid decreasing is obtained in October within the study period. The highest and the lowest values of friction velocities have been found as 0.4 m/s in the beginning of September and 0.04 m/s in late October. The average daily value of u* is about 0.2 m/s in summer season, although it varies in magnitude with seasons, appears as constant parameter for the entire period of study.

The diurnal analysis of calculated values of roughness length (z_o), shows that high values are in the nights and low values in daytime. Diurnal fluctuations of (z_o) are negligible in May, higher values 0.2 m in mid July to September and low values of 0.05 m are obtained in other two months on June and October. About diurnal fluctuation of friction velocity and roughness length from May to October, the detail analysis was reported in Chhetri, 2003.

Looking the seasonal variation of daily average roughness length (z_o) in the same period, low values from May to June, gradual increasing from mid June to September and a sharp decreasing value in the beginning of October are found. The gradual increasing of roughness length from May to September is considered due to growing height of vegetation on the land surface. The average values of (z_o) were found about (0.16 m) from July to September in warm rainy season, about 0.04 m in the period of May, June and October. However, the average value of roughness length for the summer period is obtained as 0.1 m.

b) Bulk coefficient and soil moisture availability

The estimated results of bulk coefficient C_H and surface moisture availability (α) are shown in Fig 3. The average values of C_H and that of α are obtained as 0.0029 and 0.7 respectively for the whole period of analysis from May 7 to 25 October.

The nature of graphs of seasonal variation of both bulk coefficient (C_H) and the parameter (α) are not similar from May to October. Interestingly, both of these coefficients show remarkably variation with seasons mainly in summer periods. The large values of these parameters are found in main rainy season from July to September and C_H shows quite high value in September. Comparatively low values are obtained in pre-monsoon (May and June) and in October as post-monsoon. The high values of bulk coefficient and moisture availability in rainy season are considered, due to high values of roughness length and soil moisture on the surface respectively, because of monsoon rain in this region.

Such dependency of bulk coefficient (C_H) with roughness length (z_o) and the dependency of surface moisture availability (α) with precipitation are examined in Figs 2,3 and 5 respectively. It can be seen from these figures that values of C_H depends on z_o and α depends partly on precipitation, since soil moisture varies with precipitation. Monsoon rain is the major source of soil moisture on the surface in Langtang, which plays important role for transferring water and energy from the surface in summer period.

In general, when the surface is not fully wet, values of (α) is less than 1, the humidity gradient occurs through the soil layer toward the land surface and then toward the atmosphere (Kondo *et al.*, 1994) evaporation rate decreases, but when the surface is fully wet (α) becomes 1.0 and the evaporation rate will be in potential rate, therefore, the main process of the evaporation depends on moisture availability at the surface, with the atmospheric condition (ie humidity in the air) and geographical location under particular climatic condition. The high rate of evaporation in May and June are due to low humidity in the air, even there is low values of surface moisture availability, in those months and the low rate of evaporation in the rainy season (July to September) is due presence of high amount of humidity in the atmosphere, even there is sufficient soil moisture availability in this season. This is seen consistency with the fact of observed and calculated evaporation in Langtang region. This is one of the very distinct and important characteristics of atmospheric condition in this region, which has been dominated by monsoon.

c) Latent heat flux (Evaporation rate)

The latent heat flux which was calculated by using by residual method under neutral condition of atmosphere is shown in Fig. 4 for the period from 7 May to 25 October in 1996, Chhetri *et al* 2000, although same flux was calculated by gradient method too, but comparison results, between different components of heat fluxes and observed evaporation for the selected days, because of limited scattered observed evaporation data by pan measurement process, confirmed that the latent

heat component by residual method was found closer with observed evaporation in rainy season. For our convenience, the correlation relationship between calculated and observed evaporation was determined for only 29 July which showed better correlation for residual flux. This is why, latent heat flux by residual method which shows better simulation with the observed evaporation, was used for further analysis, Chhetri *et al* 2000. Fig. 4 shows seasonal variation of calculated latent heat flux by residual method for the whole period of observation 7 May to 25 October 1996 at Langtang Valley. The loss of latent heat flux is found higher in the pre-monsoon season from May to early July and gradually low value in main rainy season from late July to September and further decreases in October. The large loss of latent heat flux in the pre-monsoon and lower values in main rainy season is considered due to low and high amount of humidity in the atmosphere. The values of flux vary from about -50 to -200 Wm^{-2}. The average value for the whole analysis period is found -120 Wm^{-2}.

Where as average values of sensible heat flux was obtained -35 Wm^{-2} and measured net radiation (Q_N) for the same period of analysis from May to October is 155 Wm^{-2} in average. Comparison study between these shows that the latent heat loss is about three times larger comparing to loss of sensible heat flux. The latent heat loss can be converted into averaged daily evaporation, as 4.2mm w. e. which is about equal with precipitation 4.0 mm w. e. value. Thus major incoming source of energy on the land surface at Kyangjin is net radiation almost of which is lost by evaporation of water throughout the whole season in summer from the land surface, Chhetri *et al* 2000.

COMPARISON OF RESULTS

The transport of fluxes of both heat and moisture into the air near the land surface was assumed to be dependent on bulk coefficient of turbulent process, which is directly related to roughness length and the friction velocity as surface characteristics. Therefore, to study the role of these surface parameters to seasonal variation of evaporation rate, the friction velocity and roughness lengths are compared in Fig. 2. Evaporation gradually decreases from May toward October, but both roughness length and the friction velocity are in increasing trends toward the rainy seasons, which clearly shows no consistency with the results.

Further, In particular, the comparisons are made between the evaporation rate and bulk coefficient as well as soil moisture availability to examine the effect of surface condition to relate the seasonal change evaporation rate in Fig 3 and 4. Looking the graphs, bulk coefficient as well as soil moisture availability both are in similar sense with each other but the evaporation shows low values when the soil moisture at the surface is maximum in main rainy season. Therefore, the high values of evaporation in pre monsoon is due to low values of atmospheric humidity and its gradual decreasing values toward the rainy season is due to increasing moisture parameter near the land surface because of monsoon precipitation in Langtang, valley as shown in Fig. 5.
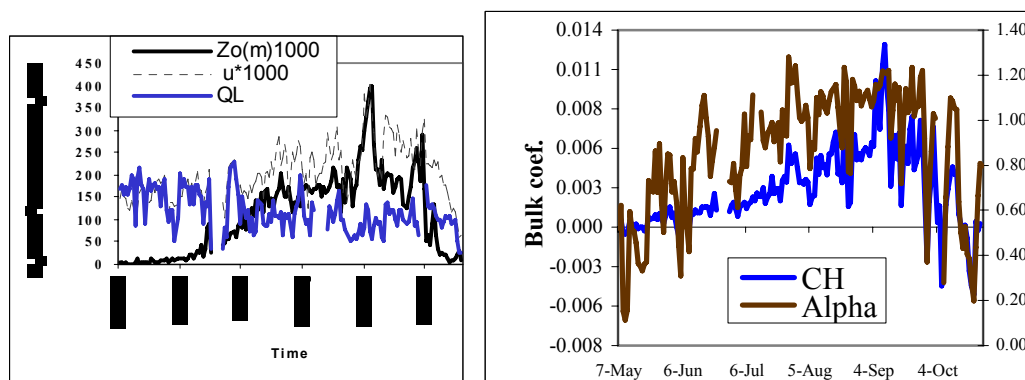
Fig, 2 : Comparison of latent heat flux with surface parameters. Fig.3 Bulk coef. And soilmoisture parameter
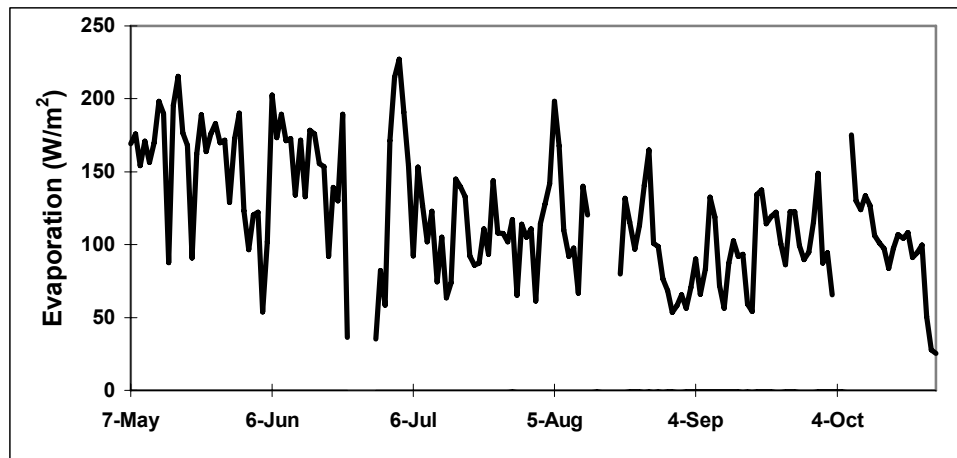
Fig 4 : Seasonal variation of latent heat flux in pre monsoon, monsoon and post monsoon season.
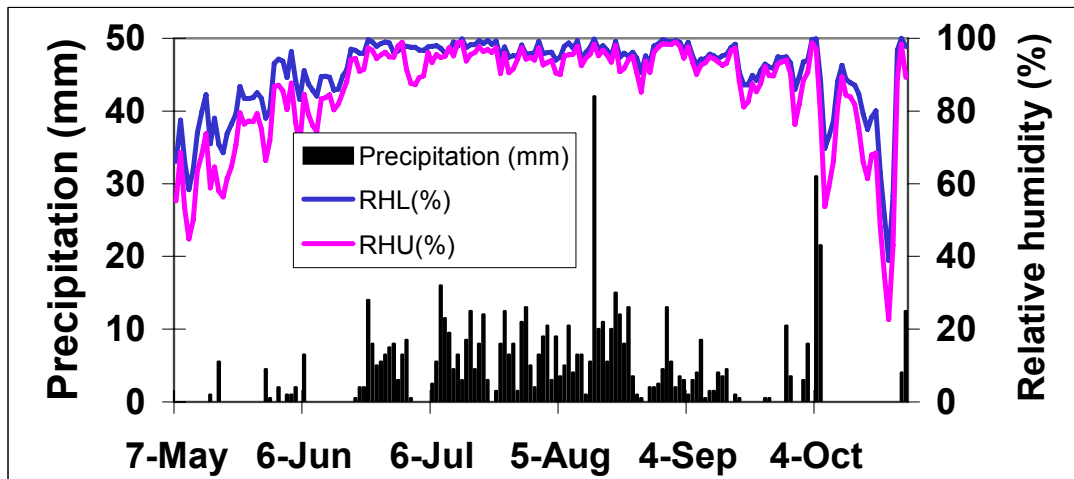
Fig. 5 : Atmospheric condition, responsible for the change of evaporation rate in Langtang valley Nepal Himalaya.

CONCLUDING RESULTS

a) Latent heat flux

1. The evaporation rate changes with season. The high evaporation rate in pre-monsoon season in May and June is considered due to low humidity in air and lower rate in rainy season (July to September) is due to high value of humidity in air because of monsoon rain in this region. Thus, monsoon is one of the important factors, which controls the rate of water loss from the land surface.

2. The major incoming energy at the land surface at Kyangjin is net radiation (155 Wm^{-2}) out of which most part is lost by latent heat flux (-120 Wm^{-2}) in average and it is about three times larger comparing to sensible heat loss (-35 Wm^{-2}). The loss of latent heat flux is corresponds to average daily evaporation of 4.2 mm w. e. which about equal with the daily precipitation value 4.0 mm w. e.

b) Friction velocity and the roughness length (z_o) and (u*)

1. Average values of friction velocity u* and the roughness length z_o have been found 0.2 m/s and 0.1 m respectively, although these values change significantly with seasons.

2. Friction velocity (u*) and roughness length (z_o) both show dissimilarity to their high values with variable values of evaporation rate in the Summer period in Langtang Valley, Nepal Himalaya. Therefore, only these two surface parameters are unable to explain and relate the seasonal variation of evaporation rate.

c) Bulk coefficient (C_H) and surface moisture availability (α)

The following are preliminary results of bulk coefficient (C_H) and surface moisture availability (α).

1. The variation of bulk coefficient is considered due to variation of surface conditions that is due to variation of roughness length on the land in summer monsoon season in Langtang Valley. The average value of (C_H) is estimated as about 0.0029.

2. The trend of soil moisture availability (α) at the surface shows a seasonal variation with a value ranging from about 0.2 in the beginning to 1.0 in mid summer. The high value of (α) is considered due to high moisture in soil surface and in the air in mid rainy season in this region. The average value of (α) is found 0.7 for the period of 7 May to 25 October in 1996.

3. The atmospheric condition controls the evaporation rate in great extent rather than the surface conditions on the land in the period from May to October in the areas like Langtang or other eastern part of Nepal influenced by South Asian monsoon.

CONCLUSION

The seasonal variation of evaporation rate depend strongly on atmospheric-meteorological condition rather than land-surface condition although the land surface consist sufficient moisture in monsoon season in Langtang Valley, Nepal Himalaya.

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Altitude Zoning of River Runoff in Mountainous Areas - an example of Mongolia.

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ABSTRACT

The dependence of the river runoff on the catchment altitude is an important characteristic of the hydrologic regime. For catchments of rivers having zones of runoff formation and runoff scattering, the dependences of the runoff from the certain altitude zone on the altitude of the next zone is very actual. Such rivers are those originating in the mountains and loosing the greater part of their runoff(or entirely scattering) in their arid lower course.

In Mongolia, the problem of the description of the runoff altitudinal zonality was investigated. The problem of the zonal runoff is difficult problem: the altitudinal distribution of the runoff values should be derived from runoff data in closing gauge stations of large and medium rivers. In this paper, the problem was solved by method of Tikhonov regularization for several regions of Mongolia, distinguished according to mountain-plain principle.

Satisfactory solution of the zonal runoff problem can be obtained only if sufficiently significant dependence of the runoff on an average altitude of a catchment area exists. Such solutions were obtained for six hydrological regions, the altitudinal boundary positions of the runoff formation and scattering zones were determined for them. In high-altitude parts of some river basins, the runoff was found to decrease with height.

The highest position of the border of the runoff formation and scattering zones (2100 m) corresponds to the most arid areas. In more humid ones this border descends up to 1400m.Maximal values of the runoff correspond to forest-steppe and forest zones.

Key words : river runoff, catchment, mountains

INTRODUCTION

The dependence of the river runoff on the catchment altitude is an important characteristic of the hydrological regime, and it is widely used for the determination of the runoff from the unexplored catchments. As a rule, to construct such a dependence, the runoff from the catchment is to be associated with the altitude of its centre of gravity. However, such an approach is not the only one possible: to investigate altitudinal zonality, the dependences of the runoff from the certain altitude zone on the altitude of this zone are used. In this case, one can obtain more detailed description of the runoff formation conditions as well as more sustainable methods of its estimations for unexplored catchments. This especially concerns the catchments of rivers having zones of runoff formation and scattering, such as those originating in the mountains and loosing the greater part of their runoff (or entirely scattering) in their arid lower course.

Such geographical features are typical for almost all the territory of Mongolia. In this paper, the data of river runoff from 48 posts in Mongolia were used.

BASIC FEATURES OF THE WATER REGIME.

Altitudinal zonality is the basic hydrological feature of the Mongolia's territory, its specific features being apparent in the zones of formation and scattering of runoff. Beginning with a certain altitude, losses for filtration from beds of transitional rivers considerably exceed an inflow from occasional showers. According to the data from (Semenov et al., 1973), average values of the runoff decrease along the river length (1 l/sec per 1 km of a river course) vary in the Great Lakes Depression from 35 during the high water periods up to 45 during the summer-autumn low-waters, and in the Valley of Lakes from 20 up to 35, respectively. Due to this feature of hydrological regime, the

territory should be considered as a set of mountain-plain complexes. As approaching to a frontier of an exit from mountains, the absolute value of the runoff in a given river system will continuously increase in accordance with increasing of the catchment area. Simultaneously with increasing of the runoff absolute value, as approaching to the beginning of the piedmont area, the specific water-carrying ability decreases, because of growth of losses.

At the beginning of the piedmont area, conditions of the surface runoff formation change. Thickness of proluvium and talus (with significant and subsidence absorbing ability) increases stepwise, that results in continuous decreasing of the water discharge in the riverbed (down to zero) as it moves down along the piedmont slope. It is a zone of the runoff scattering. Near the bottom, the subsoil piedmont waters often thin to a wedge, and a secondary active zone takes place here. Further on, the runoff can for some time change insignificantly, and then it completely disappears in intermountain depressions and on piedmonts.

Hydrological zoning of Mongolia is proposed in (Sampilnorov, 1980) based on the presence of mountain-plain complexes. The author distinguished four hydrological provinces according to water regime of rivers: Altay province (high water and floods during spring-summer period), Khangai-Khentei one (with high water in summer, floods during the warm period), East-Mongolian one (without permanent surface streams, strong showers resulting in short torrential streams, disappearing in sands of the intermountain basins), and Gobi-Altay one (rain floods in temporary channels occur).

SOLUTION OF THE PROBLEM OF ALTITUDINAL-ZONAL RUNOFF BASED ON THE ILL-POSED PROBLEMS THEORY.

3.1. Setting of the problem.

When analyzing hydrological regime of mountainous rivers, data on the runoff values can be obtained by two ways. These are method of water and heat balances and solution of inverse problems. In our case, data necessary for calculations by the water balance method, are not available, so, the inverse problem should be solved. It is formulated as the follows: the altitudinal distribution of the runoff values should be derived from data on the runoff in closing gauge stations of large and medium rivers, i.e. the problem on the zonal runoff should be solved.

Essence of the problem consists in the following. In mountain regions, when the altitudinal zonality of natural complexes is available, for demonstration of zonality of the hydrological characteristics two types of dependences are used:

$$Y = F(H_{av})$$

$$Y = \sum_{i=1}^{n} f_i y_i$$

where H_{av} is average altitude of a catchment, Y is a norm of runoff, f_i is the relative area of the ith altitudinal zone, y_i is a zonal runoff (the runoff from an ith altitudinal zone), n is the number of altitudinal zones distinguished on the catchment. If we take data from several sites of the Y-values measurements, we use a system of the equations

$$Y_1 = \sum_{i=1}^{n_1} f_{1,j} y_{1,i}$$

$$Y_2 = \sum_{i=1}^{n_2} f_{2,j} y_{2,i} \qquad\qquad (1)$$

$$\dots\dots\dots\dots$$

$$Y_m = \sum_{i=1}^{n_m} f_{m,i} y_{m,i} \ ,$$

where m is the number of gauge stations.

In the assumption that $y_{k,i} = y_{p,i}$ for any i, k, p, the system is simplified:

$$Y_1 = \sum_{i=1}^{n_1} f_{1,i} y_i$$

$$Y_2 = \sum_{i=1}^{n_2} f_{2,i} y_i \qquad\qquad (2)$$

. . . .

$$Y_m = \sum_{i=1}^{n_m} f_{m,i} y_i$$

Or in the matrix form:

$$Y=Ay, \qquad\qquad (3)$$

here, A is a matrix with elements $f_{i,j}$.

We investigated a possibility to find exact solution of the problem on the zonal runoff by means of the Gauss method and that of the least squares. With respect to the landscapes under investigation, zones of formation, transit, and scattering of the runoff are distinguished from the hydrological point of view. The last one means, that in the solution of system (3) values of the zonal runoff for lower altitudinal zones should be negative.

The realization of the Gauss method and the least squares method with the data available revealed instability of the problem. The system (3) is ill-conditioned, and the inverse problem is ill-posed according to (Tikhonov and Arsenin, 1977). In this connection, in this paper an effort to solve the system (3) by a method of Tikhonov regularization was performed.

Tikhonov regularization has been applied in different fields of hydrology, see for example (Doherty and Skahill, 2006; van Loon, and Troch, 2002).

3.2 Zones of the runoff formation and scattering.

The results of this method applied to the solution of the zonal runoff problem for Buiant-Bulgan and Ongi-Baidarag regions are presented in Fig.1 (a, b).
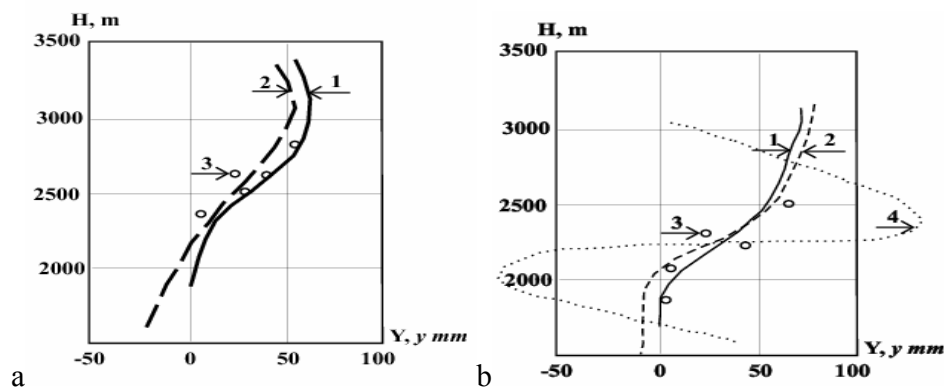
Figure 1 : Dependences of the runoff norm Y(3) and the zonal runoff (1, 2, 4) on an altitude for the Buiant-Bulgan (a) and Ongi-Baidarag (b) regions.

When solving the system (3) by regularization method, the following should be taken into account.

1. From some altitude, the regularized solution falls into negative domain (curve 2 in Fig.1). This means a presence of the runoff scattering zone. In this case, solution of the system (3) is no

longer a proper runoff, but it represents a certain balance. Zero value of this balance corresponds to equality between the inflow and losses in the riverbed. The altitude, corresponding to this value of the balance, can be taken as a boundary between zones of the runoff formation and scattering. The runoff scattering zone can be in another way called as a zone of the stream-channel losses. To obtain true values of the zonal runoff, it is necessary to exclude from calculations basins, whose closing gauge stations are sited in the runoff scattering zone. In this case, curve 1 in Figs. 3, 4 is the solution of the system. A value of regularization parameter α was assigned on the principle of the discrepancy. In this case, the error of the left part (3) was taken equal to ≈ 10 %.

2. The distribution of the catchment area over the altitudinal ranges should be taken into consideration. The point is that, in upper ranges, the catchment's area is very small, so, a contribution of these ranges into the runoff formation is smaller than errors of the runoff norm. Considerable (as compared with a share of the catchment area) value of the regularization parameter can result in essential distortion of the solution that is in underestimating of the runoff. To eliminate this "defect", it is necessary to enlarge top altitude ranges.

Let us now consider the dependences y=*f (H)* for concrete regions of Mongolia. These solutions are obtained only for those regions, where initial information made it possible. For some regions there were no such solutions (for example for the Halhin-Gol and Onon regions), and some regions have been enlarged, since the character of the dependence *Y=f (H_{av})* makes possible to consider in these cases only one region. It should be also noted, that satisfactory solution of the zonal runoff problem can be obtained only in a case, when sufficiently significant dependence of the runoff norm on an average altitude of a catchment area takes place. If such dependence is absent, then certainly no dependence of the zonal runoff on an altitude exists. Thus, satisfactory dependences *y=f (H)* were obtained for 6 hydrological regions, distinguished on the principle of the mountain-plain complexes. Due to scantiness of the information, solutions for two of them are shown in Fig. 2 by dotted lines.
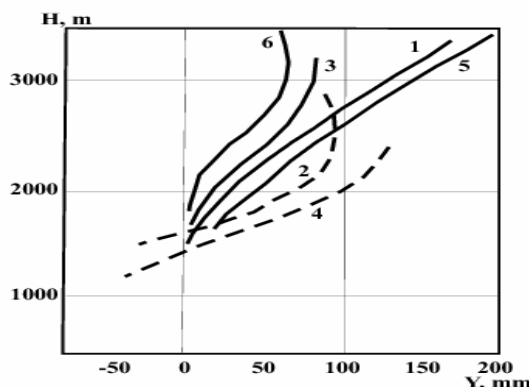
Figure 2 : Dependences of the zonal runoff on an altitude for some regions of Mongolia:

(1 - Ider-Orkhon; 2 - Bogd-Chigestei; 3 - Ongi-Baydarag; 4 - Jara-Kherlen; 5 - Hovd – Kharkhira; 6 - Bujant-Bulgan.)

a) According to character of the dependence *Y=f (H_{av})*, the Hovd and Kharkhira regions were united into one. Beginning with a height of 1700 m, the dependence *y=f (H)* falls into negative domain. As the height increases, values of the zonal runoff increase up to 200 mm. This region is located in a forest zone in the very West of the country. Existence of essential seasonal and perennial snow cover as well as the fact that the main direction of moisture transport in Mongolia is western, explains rather large values of the runoff and the whole character of the dependence *y=f (H)*. The norm of the runoff and hypsometric curves of the rivers Kobdo, Sagsai, Tsagan-Gol, and Kharkhira were used for the calculations.

b) The data of observations on rivers of the Bujant and Uench-Bulgan regions were also united into one region. The data for the rivers Bujant, Bulgan, and Uench were used. The solution falls into negative area, beginning from a height of 2100 m. Up to a height of about 3000 m, increase of the zonal runoff up to a value about 50 mm is observed. Further up, the runoff decrease begins. Here, the runoff formation zone occupies the Mongolia-Altay forest region.

c) In Ider-Orkhon hydrological region, the data of observation on the rivers Orkhon, Ider, Urd-Tamir, Khoit-Tamir and Bugsei were used. The runoff scattering zone here is rather insignificant and begins at a height of 1800 m. The zonal runoff permanently increases with height. The area is located within the limits of North-Khangai forest sub-province and steppes of the Euro-Asian steppe region. The range of altitudes, within the limits of which significant values of the runoff are observed, coincides with altitudinal boundaries of forest and Alpine mountain-meadow zones.

d) The Bogd-Chigestei region is situated within the limits of two geobotanical provinces: the Khangai mountain-forest-steppe and Mongolian-Altay mountain-steppe ones. The data on the rivers Bogd, Chigestei, Khungui, and Dzabkhan were used for the calculations. The boundary of the runoff formation zone is located at a height of 1300 m and coincides with those of the named geobotanical provinces. The largest values of the zonal runoff are recorded at altitudes higher then 2300 m.

e) The Ongi-Baydarag hydrological region is situated mainly within the limits of two geobotanical provinces: the Northern-Gobian desert-steppe and the Khangai mountain-forest-steppe ones. The boundary of the runoff formation and scattering zones lies at a height of 2100 m and approximately corresponds to the boundary between the named provinces.

f) The Khara-Kherlen region is situated in the east of the country within the limits of the Transbaikalian mountain-taiga and the Daurian-Mongolian steppe provinces. Here, the zone of the runoff scattering (up to a height of 1400 m) and the zone of the runoff increase are distinguished.

The zone of the runoff formation was outlined within the limits of each region. On Fig. 3, its general distribution over the country's territory (with consideration for geobotanical and other conditions) is shown. The highest position of the border of the runoff formation and scattering zones (2100 m) corresponds to the most arid areas. This border descends in regions with higher humidity, reaching 1400 m in the Khara-Kherlen region. Maximal values of the runoff correspond, as a rule, to forest-steppe and forest zones.
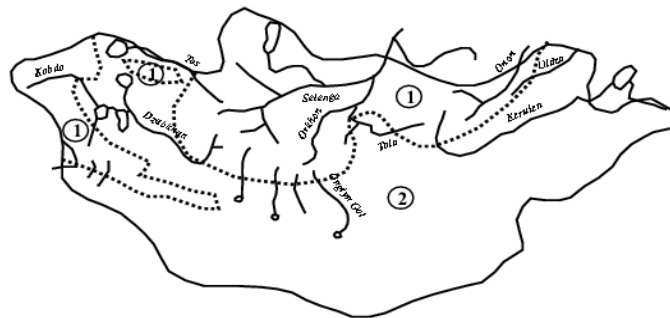
Figure 3 : Zones of the runoff formation (1) and scattering (2).

CONCLUSIONS

The main feature of a river runoff in Mongolia is the presence of zones of its formation and scattering. The determination of these zones and the elucidation of general regularities of altitudinal zonality of hydrological characteristics become possible on the basis of solution of the zonal runoff problem.

Estimations of the zonal runoff values were obtained by solution of the inverse ill-posed problem, using the method of regularization by A.N. Tikhonov. For the major hydrological regions, the altitudinal boundary positions of the runoff formation and scattering zones were determined. It was revealed, that in high-mountainous parts of some river basins the runoff decreased with height.

The dependences found can be used for the estimations of the runoff from unexplored rivers.

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Flood Estimate in Ungauged River Basins of Nepal

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ABSTRACT

Design of hydraulic structures across a river needs an accurate evaluation of design flood. Magnitude of a design flood should be estimated with an exceedance probability, which has to be safely passed during the life of structure. A design flood may be assessed accurately with the help of statistics, if there is long annual flood series at the point of interest. However, probabilistic approach can be used in the case of short-term flood data. It is important to accurately estimate the value of design flood to avoid over and under cost estimation of hydraulic structures.

In Nepal, collection of flood data has been started recently and some data are available at major rivers, although it is very difficult to get even short-term flood data at the point of interest. At the same time, it is practically impossible to establish hydrometric stations at several points, as they are very costly and difficult to establish because of topography. Hence, indirect methods should be used to evaluate a design flood in the absence of flood data. Rainfall data is used as a basic parameter to evaluate runoff from a catchment in many indirect methods. Rainfall intensity is also used in some of the methods, such as rational method but again rainfall intensities are not available because most of the rainfall stations in Nepal are non recording. The rainfall data collection is less costly and rainfall stations are easy to establish, compared to hydrometric stations.

The paper emphasizes on the use of flood data from Hydrological Similar Catchment (HSC). It is very difficult to identify a HSC in the case of Nepal, where monsoon is very much variable in time and space and catchment characteristics differ considerably. Some criteria are recommended as a guideline for the selection of appropriate HSC in the case of Nepal.

Regional estimation techniques can be used for the prediction of flood characteristics in any ungauged location by transferring information from gauged sites to ungauged ones. These regionalization approaches make different assumptions and hypotheses concerning the hydrological phenomena being modeled, rely on various types of continuous and non-continuous data, and often fall under completely different theories. Some of the regional analyses conducted for Nepalese basins are reviewed and recommended for the prediction of flood in ungauged basins of Nepal.

Some empirical formulae suitable for Nepalese basins are recommended along with suitable values for their constants, when there is no data at all. Field investigations of flood mark and river morphology are crucial when design flood is to be estimated in such conditions. Field values to be investigated for flood prediction are also included as a guideline in the present paper.

Key words : HSC, URB, GLOF

INTRODUCTION

For the successful planning and design of hydraulic structures, reliable flood study of the proposed site is necessary. In the context of Nepal, availability of reliable flood data at proposed site is very rare and it is very difficult to conduct flood analysis in most of the cases. This paper is intended to guide hydrologists and young engineers of Nepal for flood investigation and analysis at the required site of the Ungauged River Basins (URB) in the country.

OBJECTIVES AND SCOPE

The main objective of this paper is to suggest the various indirect methods for flood prediction in Ungauged River Basins (URB) for Nepalese conditions and recommend the stepwise procedures for the prediction of a design flood in accordance with the type of secondary data and the length of records available. This recommendation of flood study in the URB of Nepal can be used in various sectors like hydro power, irrigation, water supply, bridges and culverts etc. for the estimation of

design floods up to feasibility level. The paper also guide for the appropriate documentation of flood studies.

Length of records of Hydrological (H) and Meteorological (M) data is classified into Long Term Data (LTD) and Short Term Data (STD) as below for the present conditions of data availability in Nepal as recommended in the "Design Guidelines for Headworks of Hydropower Projects" prepared by Government of Nepal, Ministry of Water Resources, Department of Electricity Development in 2006.

LTD (H) and LTD (M): More than or equal to 20 years

STD (H) and STD (M): Less than 20 years

The possible combinations of Hydrological and Meteorological data availability at proposed site of URB and at HSC are given below:

> U.1 LTD (M) at proposed site and LTD (H) at HSC
>
> U.2 LTD (H) at HSC
>
> U.3 LTD (M) at proposed site and STD (H) at HSC
>
> U.4 LTD (M) at proposed site
>
> U.5 STD (M) at proposed site and LTD (M) at HSC
>
> U.6 STD (M) at HSC
>
> U.7 No data at all

HYDRO-METEOROLOGICAL STUDIES IN NEPAL

Hydro-Meteorological studies in Nepal have a short history but because of their similarity in the different parts of world, it is possible to draw experiences from other countries. Their suitability for Nepalese conditions should be carefully evaluated before inclusion in the flood study.

A lot of research studies on hydro-meteorology of Nepal by different approaches have been conducted in M. Sc. and Ph. D. dissertations of Nepalese engineers and hydrologists. Similarly, some hydro-meteorological studies have been carried out by related departments of Nepal. It is necessary to assemble all these studies and fix the guidelines and norms for better estimation of hydrology and meteorology.

Following hydro-meteorological studies are in use and recommended for flood studies in URB of Nepal as suggested in step wise procedures of this paper:

> Methodologies for estimating hydrologic characteristics of Ungauged locations in Nepal, 1990 (WECS/DHM method)
>
> MHSP Regional Approach, 1997 (MHSP method)
>
> Maximum storm flood for the design of road structures of Nepal, Prem Chandra Jha, Ph.D. Dissertation, Moscow, 1996 (PCJ method)
>
> Hydrological estimations in Nepal, DHM, 2004
>
> Guidelines for the design of head works of hydropower projects, 2007

IDENTIFICATION AND VERIFICATION OF HSC

A Hydrological Similar Catchment (HSC) with hydro-meteorological data should be identified when the data is not available in the concerning catchment.

A HSC should have the same runoff response as in the catchment under study.

For the same runoff response in a HSC following hydro-meteorological parameters and basin characteristics should be identical and hence these should be well compared and verified.

Once the HSC is identified and verified, its data can be transposed to the catchment under study.

STEPWISE PROCEDURES FOR PREDICTION OF FLOOD FLOWS IN URB

U.1 Ltd (M) At Proposed Site And Ltd (H) At Hsc

Collection of flow data should be immediately started at proposed site.

The flow data at proposed site should be established from long-term stream flow data at HSC using methods of data transposition.

Flood flows should be estimated from transposed data of HSC by frequency analysis and fitting the distributions.

Flood flows should be estimated by regional methods (WECS/DHM, PCJ, MHSP and others).

Flood flows should be estimated by Rational method and Snyder Unit Graph method

Flood flows should be estimated by empirical formulae (Dickens, Richard, Fuller and others)

Results obtained by different methods should be compared and the flood flow values suitably recommended according to project requirements. Preference should be given to frequency results obtained from the transposed flow data of HSC. The reliability of such estimates may be very good.

Maximum historical flood observed by local older inhabitants should be estimated by slope area method from flood investigations done at the time of field visit.

Investigation of GLOF and CLOF should be carried out.

U.2 LTD (H) at HSC

Collection of flow data should be immediately started at proposed site.

Flow data from HSC should be transferred to proposed site by CAR method or any other suitable method.

Flood flows should be estimated from transferred data of HSC by frequency analysis and fitting distributions.

Flood flows should be estimated by regional methods (WECS/DHM, MHSP and others).

Flood flows should be estimated by rational method.

Flood flows should be estimated by empirical formulae (Dickens, Richard, Fuller and others)

Results obtained by different methods should be compared and the flood flow values suitably recommended according to project requirements. Preference should be given to frequency results obtained from the transposed flow data of HSC. The reliability of such estimates may be very good if HSC is chosen correctly.

Maximum historical flood observed by local older inhabitants should be estimated by slope area method from flood investigations done at the time of field visit.

Investigation of GLOF and CLOF should be carried out.

U.3 LTD (M) at proposed site and STD (H) at HSC

Collection of flow data should be immediately started at proposed site.

Short-term stream flow data should be transposed from HSC to proposed site by CAR method or any other suitable method.

Positions of flow values transposed from HSC should be plotted and the flood flows should be estimated by fitting of theoretical distribution.

Flood flows should be estimated by regional methods (WECS/DHM, PCJ, MHSP and others).

Flood flows should be estimated by rational method.

Flood flows should be estimated by empirical formulae (Dickens, Richard, Fuller and others)

Results obtained by different methods should be compared and flood flow values suitably

recommended according to project requirements. Preference should be given to results obtained by regional methods and rational method. Reliability of this estimate may be good.

Maximum historical flood observed by local older inhabitants should be estimated by slope area method from flood investigations done at the time of field visit.

Investigation of GLOF and CLOF should be carried out.

U.4 LTD (M) at proposed site

Collection of flow data should be immediately started at proposed site.
Flood flows should be estimated by regional methods (WECS/DHM, MHSP, PCJ and others).
Flood flows should be estimated by rational method.
Flood flows should be estimated by empirical formulae (Dickens, Richard, Fuller and others)
The results obtained by different methods should be compared and the flood flow values should suitably recommended according to project requirements. If they differ considerably, preference should be given to results obtained by regional methods and rational method. If the difference is very small then an average value may be adopted. The reliability of such prediction will be satisfactory.

Maximum historical flood observed by local older inhabitants should be estimated by slope area method from flood investigations done at the time of field visit.

Investigation of GLOF and CLOF should be carried out.

U.5 STD (M) at proposed site and LTD (M) at HSC

Collection of flow data should be immediately started at proposed site.

Flood flows should be estimated by regional methods (WECS/DHM, MHSP and others).

Flood flows should be estimated by PCJ regional method at HSC and transferred to proposed site by Catchment Area Ratio (CAR) method.

Flood flows should be estimated by rational method.

Flood flows should be estimated by empirical formulae (Dickens, Richard, Fuller and others)

The results obtained by different methods should be compared and the flood flow values should be suitably recommended according to project requirements. If they differ considerably, preference should be given to results obtained by regional methods and rational method. If the difference is very small then an average value may be adopted. The reliability of such prediction will be satisfactory.

Maximum historical flood observed by local older inhabitants should be estimated by slope area method from flood investigations done at the time of field visit.
Investigation of GLOF and CLOF should be carried out as more as possible.

U.6 STD (M) at HSC

Collection of flow data should be immediately started at proposed site.

Flood flows should be estimated by regional methods (WECS/DHM, MHSP, PCJ and others).

Flood flows should be estimated at HSC by rational and PCJ methods and then transferred to proposed site.

Flood flows should be estimated by empirical formulae (Dickens, Richard, Fuller and others).

Maximum historical flood observed by local older inhabitants should be estimated by slope area method from flood investigations done at the time of field visit.

The results obtained by different methods should be compared and the flood flow values should be suitably recommended according to project requirements. If they differ considerably, preference should be given to results obtained by regional methods and data transferred from HSC. If the

difference is very small then an average value may be adopted. The reliability of such prediction may be poor.

Investigation of GLOF and CLOF should be carried out as more as possible.

U.7 No data *at all*

Collection of flow data should be immediately started at proposed site.
Flood flows should be estimated by regional methods (WECS/DHM, MHSP, PCJ and others).

Flood flows should be estimated by empirical formulae (Dickens, Richard, Fuller and others).

Flood flows should be calculated by rational method. Suitable assumptions can be made for rainfall intensity and runoff coefficient.

Flood flows should be estimated with the help of envelope curves developed by Kanwar Sain and Karpov for Northern Indian catchments.

Proposed site must be investigated about flood marks and other flood related informations from older inhabitants of that area. Maximum observed floods should be estimated by slope area method from flood investigation data.

At least one direct measurement of flood discharge should be conducted at proposed site.

The results obtained by different methods should be compared and the flood flow values should be suitably recommended according to project requirements. If they differ considerably, preference should be given to results obtained by regional methods, rational method and empirical methods respectively. If the difference is very small then an average value may be adopted. The reliability of such prediction may be very poor.

Investigation of GLOF and CLOF should be carried out as more as possible.

DOCUMENTATION AND REPORTING

Hydrologic studies for hydropower shall be documented in technical reports or in technical appendices to project reports. The report or appendix presents a description of the data used, methods employed, assumptions made, and results obtained. A complete and well-written report is required and must be of sufficient detail to allow an independent reviewer to follow the described analyses and support the study findings.

While conducting a hydrologic study for a hydropower project and preparing the report on hydrologic study, following contents shall be mentioned as far as possible.

Introduction, objectives, scope and methodology Catchment description and characteristics (location, size, elevation, shape, steepness of the terrain, slope and length of the main water course, the vegetation cover and the permeability of the soil, other catchment characteristics, snow area, catchment area below 5000m) Availability of data (stream flow, precipitation, snow, rainfall pattern, GLOF and CLOF records, temperature, wind, glacial flow, length of record, data quality) Field investigations (discharge measurement by different methods with date, trash mark, cross-section of river at intake and tail race sites, highest flood level according to old inhabitants, slope of the river, rough estimate of Manning's n, establishment of downstream water rights)

Identification and verification (homogeneity test) of HSC (location, size, shape, elevation, other catchment characteristics) Availability of data in HSC (stream flow, precipitation, snow, rainfall pattern, length of record, data quality)

Review of past hydro-meteorological studies within the project area Establishment and selection of a reliable hydrological and meteorological database for the estimation of design flows (average daily and monthly flows for the FDC and Hydrographs)

Low flows estimation (selection of methods according to data availability, simulation or computation by different methods, comparison of results obtained by different methods, recommendation of design low flows for different return periods with justification)

Long-term mean flows estimation (selection of methods according to data availability, simulation or computation by different methods, comparison of results obtained by different methods, recommendation of long-term mean flows with justification)

High flows estimation (selection of methods according to data availability, simulation or computation by different methods, comparison of results obtained by different methods, recommendation of high flows for different return periods with justification, estimation of Probable Maximum Flood and Construction Diversion Flood)

Flow Duration Curve (calculation of probability of flows, plotting of FDC) Average Annual Hydrograph Stage Discharge Relation (Rating Curve) and Water Surface Profiles at head works.

CONCLUSION AND RECOMMENDATIONS

It is very difficult to estimate the design flood in the absence of flood data. But for the development of water resources (Hydropower, Irrigation, Water supply etc.) and road infrastructures (Bridges, Culverts, Side drains etc) the estimation of design flood is compulsory. In Nepal insufficient flood data at the proposed site and inadequate regional methodologies bring the complexity for the estimation of design flood. The stepwise procedures presented in the paper are baseline for hydrologists and engineers involved in the prediction of design flood for hydraulic structures in Nepal.

In future for better prediction of floods in ungauged river basins following studies and research works are recommended:

Regional formulae should be developed for watersheds considering the available flood data and transposed flood data from HSC.

Hydro-meteorological Similar Catchments (HSC) should be identified for whole Nepal so that flood data may be transposed from Gauged River Basins (GRB) to Ungauged River Basins (URB).

The researches on flood investigation, GLOF and CLOF should be given priority in future studies.

The snow melting processes Himalayan Rivers should be studied.

Intensity Duration Frequency Curves should be prepared for different zones of Nepal

Development of UH in major basins is very essential for flood prediction and warning.

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Real Time Data Acquisition System for Flood Forecasting Using CDMA Wireless Technology

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ABSTRACT

A data transmission system forms the core of any flood forecasting system. Efficiency of data transmission and acquisition directly influences the accuracy and effectiveness of the forecasts. Real time data becomes critical particularly in case of flash flood forecasting for providing adequate lead time, which are common in the foothills near mountainous areas of Nepal. Recently, the Flood Forecasting Section of the Department of Hydrology and Meteorology has employed modern internet based technology for collecting the data from sensors placed at different parts of an area for forecasting flood. These data are transmitted through wireless medium over the internet to a database server where it can be analyzed and used in models for the purpose of flood forecasting. The system uses various sensors for detecting rainfall intensity and the water level of the river. These data are first stored in a data logger, which supports code division multiple access (CDMA) wireless transmission. The data are stored and transmitted at a specified interval of time that is required for the purpose of flood forecasting. This paper presents an overview of the application of such technology in Narayani Basin, Nepal.

Key words : Real Time Data, Flood Forecasting, Data Logger, CDMA

INTRODUCTION

The Department of Hydrology and Meteorology (DHM) under the Ministry of Environment, Science and Technology, Government of Nepal is responsible for all hydrological, meteorological and flood forecasting activities in Nepal. The Flood Forecasting Section is one of the five sections under the Hydrology Division of the department. There are 15 hydro-meteorological and 30 precipitation stations under flood forecasting section for the purpose of acquiring water level and rainfall data.

A data transmission system forms the core of any flood forecasting system. Efficiency of data transmission and acquisition directly influences the accuracy and effectiveness of the forecasts. Real time data becomes critical particularly in case of flash flood forecasting for providing adequate lead time, which are common in the foothills near mountainous areas.
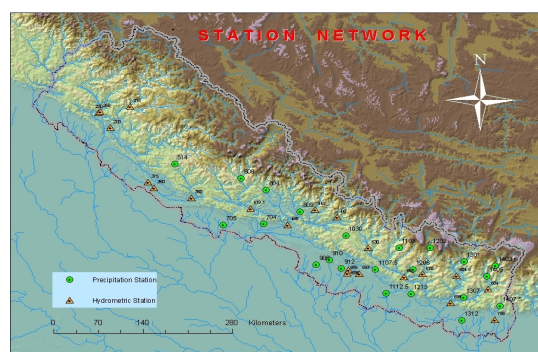
Figure 11 : Station network for flood forecasting

Presently, the data are observed by part time observers employed by DHM. They take water level reading about 3 times a day and rainfall once a day. The observed water level and rainfall data of various sites are transmitted to Kathmandu. The only transmission system used right now for data transmission in flood forecasting project is HF Transceiver. It is a very useful and conventional system used all over the world.

This system is found to be reliable and particularly useful for communication in the region, as most of the sites are remote with inadequate communication infrastructure and facilities. Because of constraints of engaging persons in shift round the clock, presently, the system is used for transmission of data only once a day. As such it is not effective for forecasting floods since flood forecasting models need at least hourly data. Another technical constraint of the system is that it is less reliable in bad weather conditions such as, thunderstorm, cyclone and rainstorm when the data are most required. No back-up communication system is available in the remote areas where the observations are taken. The existing transmission system should be upgraded and a telephone or satellite based telemetry be introduced.

Modern internet based technology can also be employed for collecting the data from sensors placed at different parts of an area for forecasting flood. These data is transmitted through wireless medium over the internet to a database server where it can be analyzed and used in models for the purpose of flood forecasting.

The system uses various sensors for detecting rainfall intensity and the water level of the river. These data are first stored in a data logger, which supports code division multiple access (CDMA) wireless transmission. The data are stored and transmitted at a specified interval of time that is required for the purpose of flood forecasting.

FLOOD FORECASTING PROCESS

The flood forecasting process consists of 3 major components:

- Data collection and transmission using telemetry and other methods
- Data processing and modeling for flow and water level computation
- Information dissemination and warning
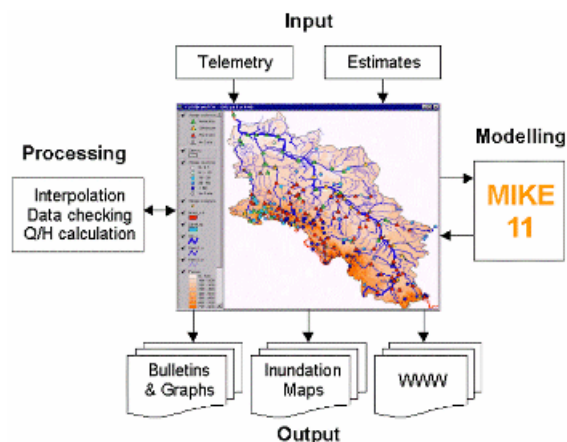
Figure 12 : Flood forecasting process

REAL TIME DATA ACQUISITION SYSTEM

The real time data acquisition system at each station consists of the tipping bucket type rain gauge, shaft encoder type water level sensor, data logger and transmission system (with built in display and Interface) based on code division multiple access (CDMA) modem. Maintenance free rechargeable batteries 12V (7AH) have been used for power supply and Solar Panel 12V (30w) has been provided for recharging the batteries where electricity is not available.

Overall requirements of the Data Acquisition System are the following:

- The data collected from the stations are to be posted through CDMA over the internet to a database server.

- All equipments should incorporate state of the art technology (e.g. microcontroller, processors etc) and provide capability for unattended operation for at least one year at remote places using a 12V single sealed maintenance-free battery.
- Standard transmission protocol to be implemented.
- All equipment should be able to withstand the hostile environment and well secured against power surge, electrostatic discharge etc.
- The system should have an inbuilt memory that is able to store data for at least one year.
- In case of failure in transmission through the CDMA module, the system should be able to store necessary backup and make it possible to retrieve data directly from the site.
- Error detection and reporting facilities to be incorporated within the system.
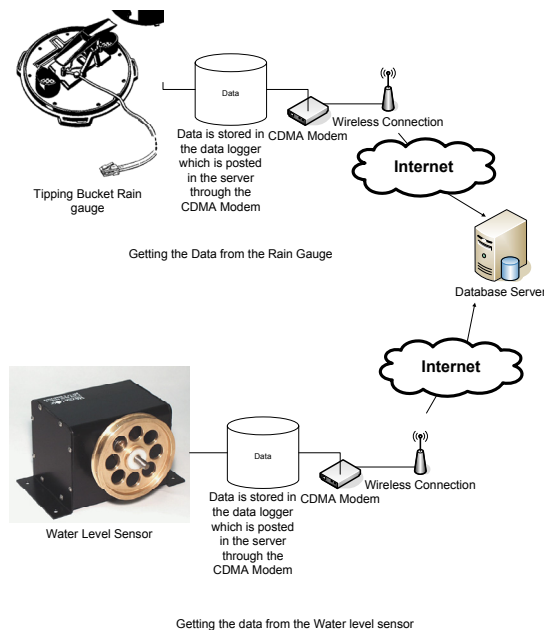
Figure 13 : Schematic representation of real time data acquisition system using CDMA modem

M2M COMMUNICATION TECHNOLOGY

M2M is an abbreviation for machine-to-machine, or technology that supports wired or wireless communication between machines. M2M is used in telemetry, data collection, remote control, robotics, remote monitoring, status tracking, road traffic control, offsite diagnostics and maintenance, security systems, logistic services, fleet management, and telemedicine. Regardless of the type of machine or data, information usually flows in the same general way - from a machine over a network, and then through a gateway to a system where it can be reviewed and acted on. The process of M2M communication begins with taking data out of a machine so that it can be analyzed and sent over a network. Monitoring a "dumb" machine may mean directly connecting to and monitoring one or more limit switches, contact closures or analog outputs. With an intelligent electronic device, it may be possible to simply connect to the equipment's serial port and ask for the data. The goal of the M2M hardware is to bridge the intelligence in the machine with the communication network. An intelligent wireless data module is physically integrated with the monitored machine and programmed to understand the machine's protocol.

A new device called M2Mlite is SCADA based system suitable for any monitoring and controlling. M2Mlite is a sophisticated technology for data acquisition and telemetry. It has not only the advantage of acquiring data at real time but also has a full fledged system for data storing,

archiving and retrieving. The most appealing feature of M2Mlite is that it is a small device meant to do big things. It comes with its own data logger and a communication unit for CDMA/GSM communication. A backup battery ensures communication even when power supply is limited. If for any reason data is not being posted on the internet it can be manually retrieved through SD/MMC card or PC interface.

Recently, M2Mlite has been used in the Real Time Data Acquisition System for Forecasting Flood in Narayani Basin. It has been installed in 10 different sites along with various sensors for monitoring rainfall intensity and water level. M2Mlite simply communicates the sensor readings to a database server via CDMA modem over the internet.

All sensors have a certain output e.g. the water level sensor gives out a 2 bit digital output in grey code format which is interpreted by the data logger to data packets to be sent through the modem. These data packets have information on the date and time the data packets are sent, the device id or the station along with the sensor output. This data is stored on an EEPROM by the data logger. The system then checks the connection with the modem once the modem is ready it sends the data from the EEPROM to the server. In case the modem isn't ready it keeps checking for the connection to be cleared and sends the data again. Thus, the data is transmitted without any loss. In case there is any communication error, the same data can be retrieved by inserting an SD/MMC card in the M2Mlite where the data is downloaded automatically.

The data sent from M2Mlite to the server uses AES (Advance Encryption Standard) for secure communication between the server and M2Mlite so that no information is leaked in between. The server side scripting decodes the AES encryption, represents the data into readable formats and stores it into the database according to the respective fields.

The main advantage of posting the data over the internet is the flexibility in the programming languages that can be used to represent the data. The Web 2.0 facilitates programmers to create web-based application from php, javascripts, .NET, AJAX, etc. creating dynamic websites with limitless features desired by the user. Another main advantage in using web-based application is that it requires less hardware resources and is compatible with any OS. It makes it easier to give the information to general public in real time. The information can be restricted, open or semi-private as required.

The M2Mlite not only communicates the data from the sensor but also gives information on its status. It also sends information on the ADC, DAC outputs, voltage level and other parameters so that the user can know if the device is functioning properly. This makes it easier for users in debugging in remote areas.

M2M communication has unimaginable possibilities yet to be discovered. It is also a cheaper solution for ongoing processes of data entry through personnel which is a constraint on budget and man power. The data are communicated at 10 kb per 0.0115 paisa which is the cheapest solution so far. With flexible hardware and software solution M2Mlite can be a powerful M2M communication tool for data acquisition and telemetry.

STUDY AREA

The hydrometric station of Narayani River at Narayanghat (St. no. 450) has been taken as the forecasting station equipped with water level data logger. The following rainfall stations are equipped with the real time data acquisition system for the purpose of flood forecasting at Narayanghat.

Raingauge stations in Narayani Basin

S. No.	Station Name	St. No.	Longitude (E)	Latitude (N)
1	Jomsom	601	83.72	28.78
2	Beni	609	83.57	28.35
3	Pokhara	804.5	84.00	28.22
4	Gorkha	809	84.62	28.00
5	Ansing	810.5	83.82	27.88
6	Danda	704.5	84.20	28.05
7	Rajaiya	925	84.98	27.43
8	Arughat	1002	84.49	28.03
9	Betrawati	1004.5	85.11	27.58
10	Narayanghat	914.5	84.26	27.43

SENSORS

A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. A sensor's sensitivity indicates how much the sensor's output changes when the measured quantity changes. There are various types of water level and rainfall sensors. Some of the widely used water level sensors are float operated shaft encoder level sensor, submersible pressure probe, bubbler level sensor, radar level sensor and ultrasonic level sensor. Tipping bucket rain gauge is the most widely used rainfall sensor. The sensors along with the accessories and facilities should be fully compatible with the data logger and transmission system.

The forecasting station at Narayanghat has been equipped with Stevens Type A-04 Chart Recorder. Hence, it is recommended to install encoder attachment having at least 1/200 of shaft rotation with SDI-12 output.
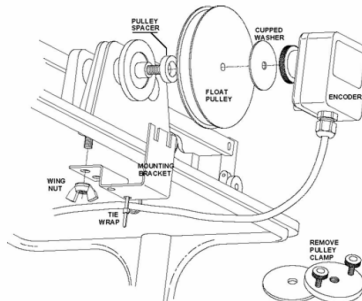
Figure 14 : Stevens Type A-04 Encoder   **Figure 15 : Tipping Bucket Rain Gauge**
(Chart Recorder Attachment)

The rain gauge used should be well capable of gathering and measuring the amount of precipitation over a set period of time. The rain collector should be designed to meet the guidelines of WMO. Hence, a Tipping Bucket Rain Gauge with magnet reed switch has been recommended. The bucket has a 200 mm (8 inch) diameter with machined aluminum rim. The bucket tips when precipitation of 0.2 mm has been collected. Each tip activates a reed switch closure which is detected by a data logger and/or telemetry system.

DATA LOGGER AND TRANSMISSION UNIT

The data logger is a device that collects the data from sensors and stores it in a memory interface. These data can be transmitted for analysis or stored them in its memory. It should automatically collect the observations from attached sensors, process the same and store them into its memory as per the pre-programmed procedure at a specified time interval and data shall be transmitted over the internet to a database server.
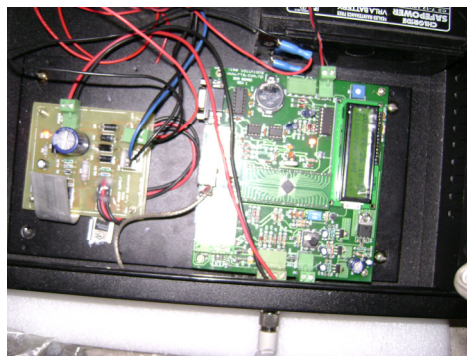
Figure 16 : Data Logger

- The number of analog/digital/SDI channels in the data logger must be compatible to the sensors being supplied.
- The sensor's signal conditioning unit should be an integral part of the system.
- Polling rate should be user configurable.
- The system should be stand alone independent of the PC/Laptop.
- The system should store observed data along with time for all the parameters in the memory. Memory capacity should be able to retain at least one year's data. Data shall be available even if the power supply to the system has failed for one year.
- The stored data should be transmitted through CDMA transmission. In case of failure of the CDMA module, the stored data needs to be retrieved via serial port/USB/Ethernet to a PC/Laptop or from the storage card.
- A LCD display for displaying current Date/Time by default and incase of errors show the latest error for one minute.
- A warning system to be provided along with the error log including the date and time of failure and also invalid data type. The error log format should be given as stated below.
- The number of analog/digital/ SDI channels in the data logger must be compatible to the sensors being supplied.
- The system should incorporate a watch dog timer, incase of software faults.

Specifications for keeping log

The log kept in the data logger needs to hold the following information for complete analysis of the meteorological parameters for flood forecasting (data log) and also the internal working of the devices used in the system. Every log should have time and date stamp except invalid date and time log. The data logger should log following information.

- System Reset Information
- Invalid Date and Time
- Watch Dog Timeout
- Data from the sensor
    - Timeout
    - Invalid range
- Log for the communication unit
    - Modem not responding
    - Modem PPP open command not successful
    - If modem connection not successful
    - Valid response from the server
    - Invalid response from the server
    - If connection close not successful

CDMA scheme

The system should implement CDMA transmission module following the given protocol:

- DNS protocol to be implemented to resolve the domain name.
- Data must be sent using secured HTTP protocol
- GET or POST method must be used for sending/setting the data in the device
- Latest encryption technology to be used for transmitting data
- Each unit of information must be separated by a unique character
- Data packet format to be used for sending information from the Server to the Device

DATE	TIME	ROP

Can be 1 or more frames

ROP: Rate of Polling to Server

- Data packet format to be used for sending information from Device to Server
    - Station Information
    - Data From Sensor
    - Device Status
    - Error Log

The data transmission system should be configured based on the following server side requirements which would be provided at the central office of the DHM:

- Relational database with at least 1 GB of data storage capacity
- 99.99% up time guarantee
- Redundant database server

OBSERVED AND TRANSMITTED DATA

The hourly and daily rainfall for 10 stations and hourly water level for Narayanghat have been posted in the website http://www.hydrology.gov.np. Those data can also be downloaded from the website.
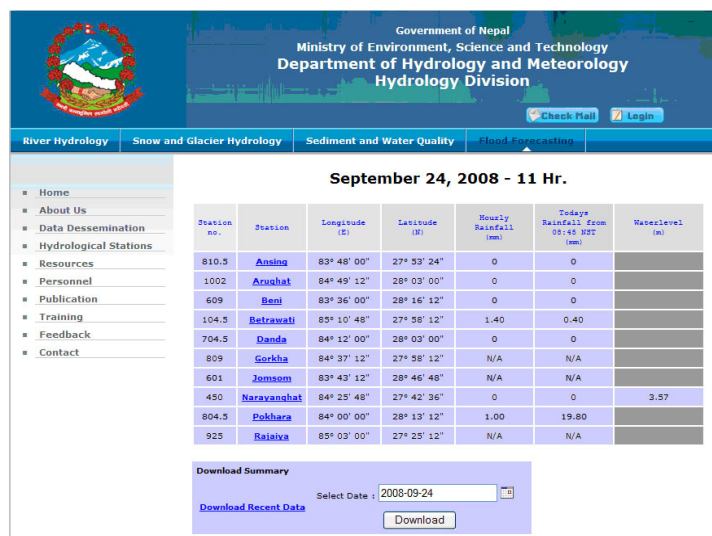
Figure 17 : Webpage for retrieving real time data.
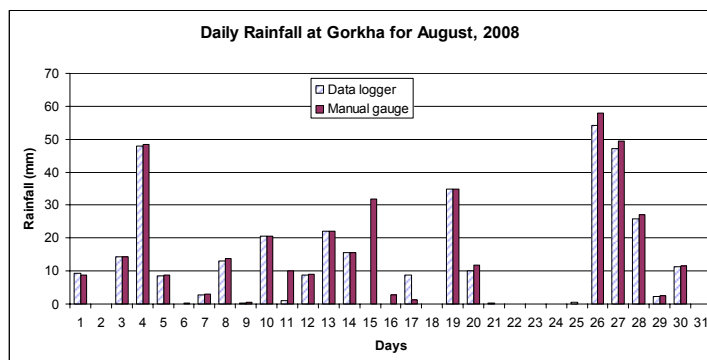
Figure 18 : Comparison of Daily rainfall at Gorkha for August, 2008

Figure 8 shows the comparison of daily rainfall obtained from data logger and ordinary rain gauge at Gorkha for August 2008. It is seen that the data given by data logger are very close to those obtained from ordinary rain gauge.

CONCLUSIONS

The Flood Forecasting Project of the Department of Hydrology and Meteorology has successfully tested M2M communication technology with CDMA wireless modem for transmitting water level and rainfall data for flood forecasting in real time. Rainfall data with hourly or even finer time resolution is now obtained from 10 rainfall stations of Narayani basin in real time. The daily rainfall data obtained from tipping bucket type rainfall sensors have been compared with those obtained from the ordinary rain gauges. It is found that these two sets of rainfall data are closely matching. These real time rainfall and water level data are extremely useful for developing flood forecasting model.

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Application of the Hydrological Modeling System in the Jhikhu khola Watershed, Nepal, for the study of Hydrograph Characteristics

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ABSTRACT

For designing hydropower and irrigation project, flow characteristics of different rivers in the watershed play a crucial role. Automatic rainfall record and stage records are found to be the eminent factor for its study. For the rainfall and runoff process of watershed there is involvement of other hydrological parameters such as initial loss, peak discharge, moisture deficit, hydraulic conductivity and so on. Due to financial constraints, installation of all types of recording instruments is almost impossible in the context of the underdeveloped country like Nepal. Hence, distributed model studies are limited in Nepal.

This paper basically uses the rainfall and runoff data obtained from Tamaghat, a station in Jhikhu Khola Watershed to develop Clark's, synthesis unit hydrograph for the major flood events, build up the optimum value of the average infiltration and unit hydrograph parameters including the establishment of the relationship between infiltration loss and rainfall using the HEC-HMS model by the optimization technique. The results so obtained may be applicable to other watersheds with similar characteristics.

Key words : Runoff process, hydrological parameters, peak discharge.

INTRODUCTION

Various rainfall runoff models have been developed and widely applied in water resources projects. However, the problem of hydrograph computation in a un-gauge basin is still interesting. The purpose of using rainfall runoff models in a watershed is to analyze the system behavior. Rainfall excess with respect to time is a key component in the study of rainfall runoff relationship. On the other hand the runoff resulting by rainfall over catchments is influenced by different climatic and physiographic factors. Measurement of runoff by river gauging, though useful, is limited due to high cost of maintenance and on the other hand the rainfall measurement is comparatively easier and usually available for many years. Due to this reason establishing a relationship between rainfall and runoff in a catchment is important for hydrological studies. Moreover, such a relation once established can be used for another sub-basin with similar characteristics. Mountain basins in Nepal experience extremes variability of climate and precipitation pattern. Inadequate knowledge of hydrology and complex interrelationship with environment impose scientific and technical limitation in utilizing the potential benefit of water resources and accurate calculation of hydrological parameters. One of the simplest methods for establishing the rainfall runoff relation is to develop a unit hydrograph and to calibrate its parameter with the biggest rainfall event (10 July 1992) basis. In this study, Jhikhu Khola watershed is chosen as a system, rainfall hyetograph as input, and the output is runoff hydrograph. The objective of the paper is to apply and optimize the hydrologic routing parameters from HEC-HMS model in middle mountain watershed of Nepal for studying the simulated hydrograph.

STUDY AREA

The Jhikhu Khola watershed is a representative mid size drainage basin from both Hydrologically and topographically. This watershed is located 45 km east of Kathmandu in between 27° 33' and 27° 42' N and 85° 31' and 81° 41' East on the Araniko highway and it covers 111.41 km² whole catchments area is suitable in Kabrepalanchowk district of Nepal. The elevation ranges from 800 to 2200 m above means sea level. About 35 percentage of land in the watershed is within 20% slope

category 11% land has slope more than 50% and remaining land has the slope in between . It has large flat valley bottom of alluvial origin. Among the land use categories agricultural land cover 55% in which about 17% is bari. The forest covers 60% grazing land 6% and shrub land 7%. The watershed has aspect towards all four directions. However about 40% towards north in the watershed (Merz, 1499)

METHODOLOGY

The highest storm with half hourly rainfall data of 10 July 1992 has been used the HEC-HMS model calibration. Probable Maximum Precipitation (PMP) of specified period within Jhikhu Khola watershed is estimated with the method mentioned by (Shakya, 2002) which

$$\frac{P_t}{P_{24}} = \sin\left(\frac{\Pi * t}{48}\right)^{0.4727} \tag{1}$$

Where, t is duration in hour

P_{24} is one day rainfall and sin of angle is radian.

For calculating half hour rainfall from daily rainfall, equation (1) is used.

The half hour rainfall data is transposed to the alternating block method. The method is a simple way of developing a design hyetograph from an intensity duration frequency (IDF) curve. The design hyetograph produced by this method specifies the precipitation depth occurring in n successive time intervals of duration Δt over a total duration T_d (Chow, 1988)

$$T_d = n\Delta t \tag{2}$$

To select the design return period, the intensity is read from IDF curve for each of duration Δt, $2\Delta t$, $3\Delta t$……, and the corresponding precipitation depth is found as the product of intensity and duration.

Sherman (1932) first developed the UH model. Number of techniques to develop UH and convolution of it to direct runoff have been investigated so far. The UH is widely used technique to transform rainfall excess to catchments flow. To construct direct runoff hydrograph with HEC-HMS model discrete representation of excess precipitation in from of a "pulse" for a time interval is used. It then solves the discrete convolution equation for linear system as

$$Qn = \sum_{m=1}^{n \le M} P_m U_{n-m+1} \tag{3}$$

Where Q_n = Storm hydrograph ordinate at time $n\Delta t$;
         P_m = rainfall excess depth in time interval $m\Delta t$ to $(m+1)$ Δt;
         M = total number of discrete rainfall pulses.
U_{n-m+1} = UH ordinate at time $(n-m+1)$ Δt.

Q_n and P_m are expressed as flow rate and depth respectively, and U_{n-m+1} has dimensions of flow rate per unit depth.

Clark developed a model of instantaneous unit hydrograph (IHU) by assuming that the outflow hydrograph for any storm is characterized by the translation and storage effect to separate basin area. This model full under the conceptual deterministic and lumped type with separate input data requirement. Being lumped model it treats each sub catchment as one unit. The parameters and variables are used for representing the average values for the entire sub catchments. To derive the UH calculation the translation time is obtain by the time contour lines represent by bar diagram (Clark, 1945).

The excess flow rate of this diagram can be routed through a linear storage by the use of routing equation. Hence the model requires time area curve (TAC), storage coefficient (R) and time of concentration (Tc) as input to develop the UH.

The linear reservoir routing is accomplished using the general equation

$$Q_{(i)} = C_A + C_B * Q_{(i-1)} \qquad (4)$$

Where C_A and C_B are routing coefficient and given by

$$C_A = \frac{\Delta t}{R + 0.5\Delta t} \qquad (5)$$

$$C_B = I - C_A \qquad (6)$$

$$U_i = 0.5(O_i + O_{i-1}) \text{ for } i=2 \qquad (7)$$

Where I = input ordinate of TAC

Q_i = Instantaneous flow at end of the period.

$Q_{(i-1)}$ = instantaneous flow at beginning of the period.

Δt = computational time interval.

$U_{(i)}$ = Unit hydrograph ordinate at end of computational interval.

R = Storage coefficient of attenuation constant

$$R = \frac{Q}{dq/dt} \qquad (8)$$

Where q = discharge at inflexion point of the falling limb.
       Q = Recorded discharge.
Kirpich's formula (1940) to determine Tc is given as
$$Tc = 0.01947 * L^{0.77} * S^{-0.385} \qquad (9)$$

Where,

Tc is the time of concentration (min), it is the longest time taken by a drop of water to reach the outlet or the point of consideration in the channel from the furthest point of the catchment.

S is the slope of the channel given by the ratio of the elevation difference between the remote point of channel and the outlet point and the maximum length of travel of water.

Time to peak plus the storm duration represents approximately the time of concentration of a basin. The lag time t_l and time of concentration Tc can be related in a simple way (Patra, 2002) as

$$Tc = 1.4 \, t_l \qquad (10)$$

Where t_l is related to peak discharge of the hydrograph. In HEC-HMS model tail of the Unit hydrograph is truncated when its volume exceeds 0.995 mm of 150 ordinates and the ordinates are then adjusted to produce a volume of unit.

RESULT AND DISCUSSION

The application of HEC-HMS model in the Jhikhu khola watershed using rainfall and discharge data of 10 July 1992 (the biggest event) is used in this study. To fulfill the objective of this study a half hourly rainfall runoff data has been used and catchment routing parameters have been calibrated on the basis of automatic optimization option available in HEC-HMS version 2.2.2. The trial and error method was utilized during simulation so as to decide appropriate values of Unit Hydrograph as shown in Figure 1.The altitude of Jhikhu Khola range from 800 to 2200 meters above sea level and the length of longest water course L is 21.24 km. The length along mainstream

from the gauging station (outlet) to a point on the stream opposite to the area of centre of gravity (Centroid) of the basin is 9.58 km. From the calculation S of drainage basin was obtained as 0.066 and the time of concentration from equation (9) is obtained as 110.06 min or approximately 2 hours. From HEC-HMS model the Time of concentration (Tc) = 1.129 (hr) and Storage coefficient (R) = 1.4714(hr) were obtained as shown in Table 1. These parameters were found from physical catchment data and observed hydrological data by optimized technique, and can be used for estimating runoff in the mountain watershed having similar characteristics.

Optimized value of Table 1 and Table 2 are used to develop Clark's synthetic UH for calculating peak discharge, total loss, direct runoff, total base flow and total excess from event rainfall data. For the validation of Clark's synthetic UH major storm events have been used to develop optimum value of parameters version (Davis Ca, 2000) 3.0.1. The computed result of Clark's synthetic UH parameters are given in Table 3. The necessary data from Table 3 has been used to obtain the relationship between total loss and total rainfall Fig 3. The magnitude of runoff coefficient with magnitude of storm can be taken into account by graphical correlation of rainfall and runoff. A plot of total loss vs total rainfall has been represented with linear equation as, Y= 0.8765 X – 3.6633
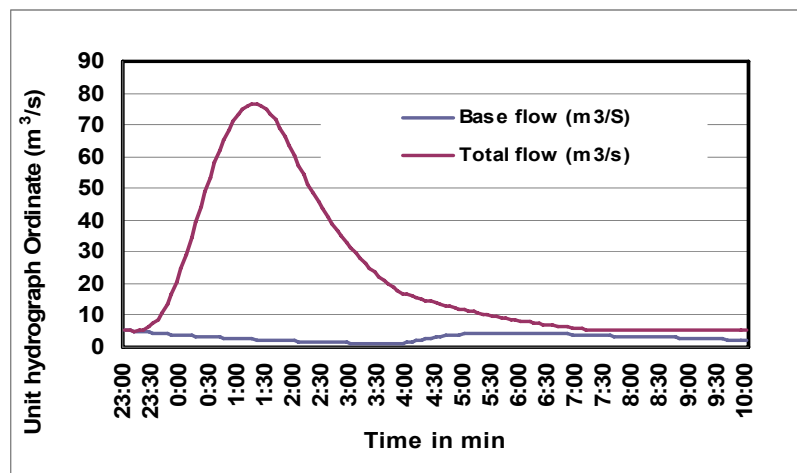
Figure 1 : Clark's Unit Hydrograph of the event in 10 July 1992.
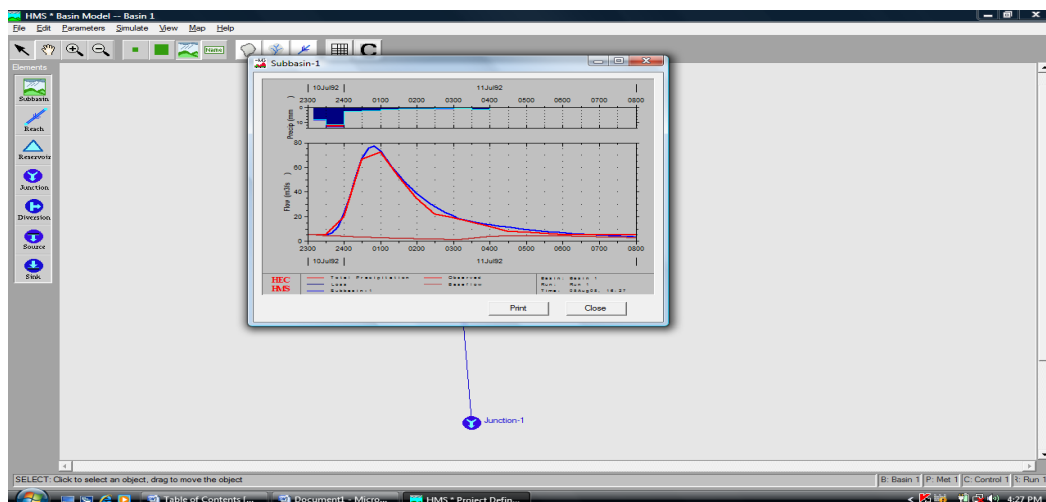
Figure 2. : Observed and calibrated hydrograph for 10 July, 1992

Table 1 : Unit Hydrograph Parameters for Jhikhu Khola watershed

Parameter	Unit	Initial Value	Constraints Maximum Minimum	Optimized value	Objective Function Sensitivity	
Initial loss	mm	5.000	0.00100	5000	5.000	0.000
Constant loss rate	mm/hr	69.378	0.00100	3000	69.3780	-14.77
Clark storage coefficient	hr	1.481	0.01000	1000	1.471	-0.08
Initial base flow	cms	3.92	0.00100	100000	4.969	-0.04
Recession constant	n/a	0.00135	0.00001	1	0.000267	0.02
Recession threshold flow	cms	18.2	0.00100	100000	17.100	-0.03
Time of concentration	hr	1.16	0.10000	10000	1.129	-0.07

Table 2. : Major Rainfall events data used for model validation.

Date	Daily Rainfall (mm)
15-May-1998	46.00
26-May-1998	33.00
21-Jun-1998	35.80
26-Jun-1998	37.50
8-Jul-1998	42.00
21-Jul-1998	40.40
19-Aug-1998	24.00
21-Aug-1998	46.50
27-Aug-1998	28.40
5-Sep-1998	28.00
6-Sep-1998	69.00

Table 3 : Computed result of Unit Hydrograph parameter from daily rainfall data.

Date	Peak discharge (m³/s)	Total loss (mm)	Total Direct Runoff (mm)	Total base flow (mm)	Total Excess (mm)	Discharge (mm)
15-May-98	39.66	40.30	2.63	1.06	2.63	3.69
26-May-98	27.45	29.05	1.75	1.07	1.75	2.82
21-Jun-98	98.01	23.33	7.45	0.87	7.47	8.83
26-Jun-98	56.63	30.87	4.16	0.94	4.16	5.10
8-Jul-98	62.43	34.62	4.16	0.97	4.61	5.59
21-Jul-98	57.53	35.32	4.11	1.19	4.12	5.30
19-Aug-98	85.31	16.05	6.34	1.64	6.35	7.97
21-Aug-98	188.95	28.33	15.07	1.63	15.1	16.70
27-Aug-98	53.65	22.56	3.97	0.86	3.97	4.83
5-Sep-98	88.31	19.26	6.88	1.06	6.88	7.94
6-Sep-98	96.09	57.43	6.99	1.49	6.99	8.48
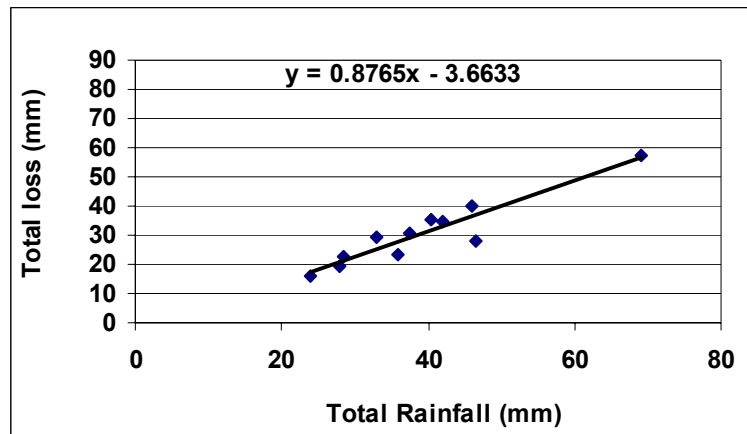
Figure 3 : The relationship between total rainfall and total loss.

Rainfall data are generally used from simple non-recording gauges in this study for the validation of model Table 2. It is very difficult to get hourly intensity from these gauges, so equation (1) is used to calculate the hourly rainfall from 24 hour rainfall data. Major Rainfall data used for model validation and converted hourly rainfall data were used as a hyetograph in the HEC-HMS program to produce Clark's synthetic UH. The comparison of observed and simulated discharge values are shown in Table 4. A good relation having average of about ±0.4% was observed between them. However there are some exceptionally high differences of +5.029% in 21 July 1998, because the rainfall was received on previous 3 days regularly in the entire whole watershed. So, the calculated peak is found to be lower than observed peak. Similarly, the difference of -3.917% in 26 Jun 1998 occurs, because of no rainfall received up to 3 days as the soil was drier and so hydrograph characteristics of calculated peak is found to be higher than observed peak. The differences of two highest peak hydrograph characteristics are presented in Figure 4 and Table 4. The relative difference is found to be ±0.399 (Table 4) from observed and calculated discharge. As there is no such variation found, HEC-HMS model can be used to estimate peak discharge from daily rainfall data.

Table 4 : Comparison of observed, simulated discharge and constant loss of selected rainfall events.

Date	Constant loss rate	Comparison of discharge		
	mm/hr	Observed Q	Simulated Q	Relative different (%)
15-May-98	25.6	6.012	6.12	-1.796
26-May-98	25.0	5.809	5.91	-1.739
21-Jun-98	11.409	8.284	8.36	-0.917
26-Jun-98	18.72	12.279	12.76	-3.917
8-Jul-98	69.378	18.174	18.27	-0.528
21-Jul-98	20.5	13.741	13.05	5.029
19-Aug-98	12.0	12.495	12.49	0.040
21-Aug-98	15.0	16.572	16.96	-2.341
27-Aug-98	13.0	11.185	11.01	1.565
5-Sep-98	10.0	9.392	9.38	0.128
6-Sep-98	35.2	27.044	27.02	0.089
				±0.399
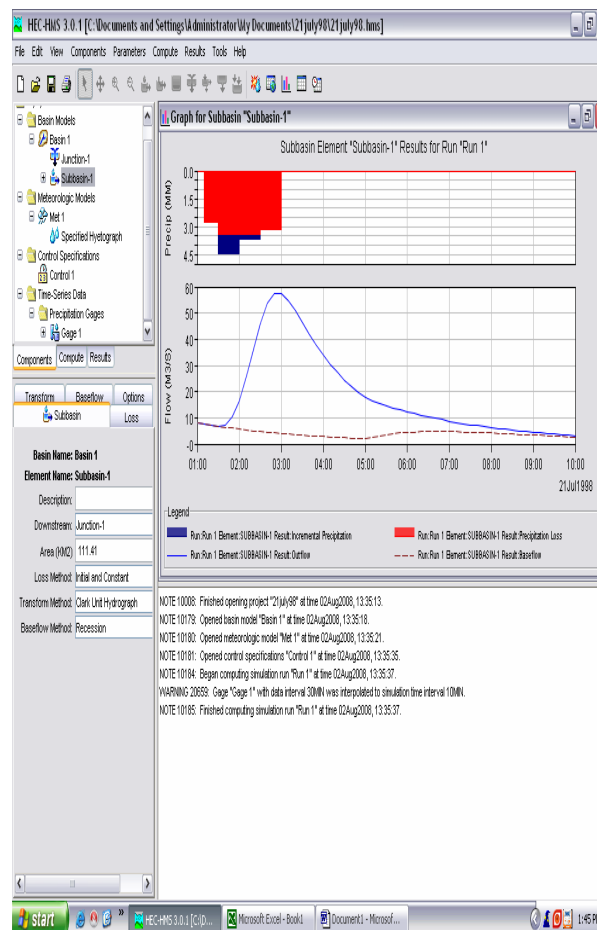
Figure 4 : Hydrograph characteristics of different two event prepared by HEC-HMS model.
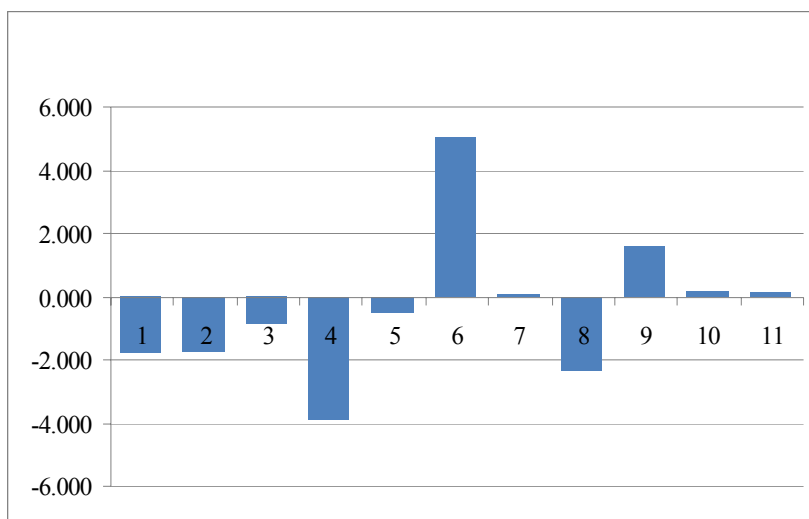
Figure 5 : Relative different of measured and observed hydrograph characteristics.

CONCLUSION

The Hydrograph Characteristics of Clark's storage coefficient (R) is 1.4714 hr and time of concentration (Tc) is 1.129 hr have been found from rainfall event in 10th July 1992. Based on these parameters a Clark's synthetic unit hydrograph has been prepared by daily rainfall (Table 2). The highest peak flood has been found as 188.95 m^3/s in 21 Aug 1998 and lowest peak flood as 27.45 m^3/s in 26 May 1998. The regression equation has been developed from the data (Table.3). A Constant loss rate value is higher in pre monsoon than in the mid to the end of monsoon as show in Table 4.

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Hydrological Modelling of Upper Trishuli 3A Cathment, Nepal.
(Comparison of Lumped and Distributed Models)

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ABSTRACT

The HBV (Lump model) and Landpine (Distributed model), precipitation- runoff models, are calibrated and validated using daily data of 10 years for Upper Trisuli Cathment, Nepal. It is found that the models are very useful and applicable for the hydrological study of the cathment even though these models have been developed in and for Scandinavian countries. The calibrated models can be used for flow simulation, filling the flow series, missing flow data, flow changes with land use changes and climate change studies. With appropriate update the models can also be used for hydropower planning, operation and energy calculation.

Key words : Lump model, distributed model, flow simulation.

INTRODUCTION

The objective of hydrological system analysis is to study the system operation and predict its internal states and output. A hydrological system model is an approximation of the actual system. Its inputs and outputs are measurable hydrological variables and the model's structure is a set of equations linking input to output.

The need of hydrological model as cited by Beven, (2002) are:

- "a result of the limitations of hydrological measurements"
- Limited range of measurement techniques
- Limited range of measurements in space
- Limited range of measurements in time

For Hydropower planning and operation, hydrological model of various types have been used extensively. Among them precipitation- runoff models are used for the present study.

MOTIVATION

Hydrological study is the first input for the water resources project development, and hydrological study needed continuously even after the project implementation.

Nearly 7,000 (big ad small) rivers flow though the lap of Nepal. In term of hydropower, we have theoretical potential of 83,000 MW and economically viable of 42,000MW. It will be crucial tool for assessing the immense water potential in Nepal.

Electricity demand is very high and not possible to meet the demand of increasing rate 300GWh per year (Acute Shortage of Electricity), 10-14 hours power cut per day. Therefore saving of 1m3 of water can produce 0.00245 KWh per meter head.

With the view of above points, appropriate assessment of water quantity will be important contribution in Nepalese energy sector, which motivated me to deepen my knowledge in Hydrology.

PURPOSE

The high Mountainous area border between Nepal and Tibet provide challenges for modelling, regarding data availability, catchments characteristics and hydrological Processes.

The purpose of the study is to investigate the applicability of the HBV and Landpine models for Upper Trishuli 3A Catchment, Nepal.

OBJECTIVE

To calibrate models in the Catchment from 2 Concepts; Lumped (HBV) and Distributed (Landpine), and finally compare the results.

SCOPE OF THE WORK

The hydrological models will be calibrated from both HBV and Landpine model in the Upper Trisuli cathment and finally results are compared.

The following components have been covered to meet the objective.

Literature review and description of project area.

Collection, preparation and analysis of input data and filling the missing gaps in data series.

Attempts to get the data form Tibet side of the cathchment.

Extract the cathchmnt and hypsographic curves from USGS Hydro 1K data set.

Evaluation of precipitation distribuition and areal precipitation computation.

Input data preparation, HBV model calibration and Validation.

Prepared distributed data, and calibration Landpine model.

Compare output from two modelling approaches.

METHODOLGY AND MATERIALS

The stream flow data and meteorological data for selected stations are collected from Department of Hydrology and Metrology, Kathmandu, Nepal. The Digital maps in raster form, downloaded from USGS website. Those maps were processed using ArcGIS with Archydro tools to find the cathment and hypsographic curve. For the Model calibration, HBV model set up in Microsoft Excel is used.

Preparations of distributed input are done in ArcGIS with Arc Hydro then used IDRISI Andes. Land Use map in the form of raster also downloaded from USGS and process for input preparation, eg, land cover, vegetation cover, and vegetation type and soil parameters.

A distributed physically based hydrological model, Landpine was used in the study

DATA COLLECTION AND PROCESSSING

Five meteorological stations are found to be applicable for the study and those are Timure station: St ID1001, Nuwakot St. ID 1004, Thamchi, St. ID 1054, Dhunche St. ID 1055, and Pansaya St. ID 1057 (Figure 1). the daily precipiations data and temperature data has been collected from thsese meterological stations for 20 years since 1986. In Tibet side, in Northern part, 2 metrological stations Tingri and Nyalam found to be comparatively relevant to the catchment, but the detail information is not available. The daily Runoff data measured at Betrawati stream Gauge St. 447 (Figure 1) is collected, for 29 years, 1977 to 2005, from Deparment of Hydrology and Meteorolgy, Kathmandu, Nepal.
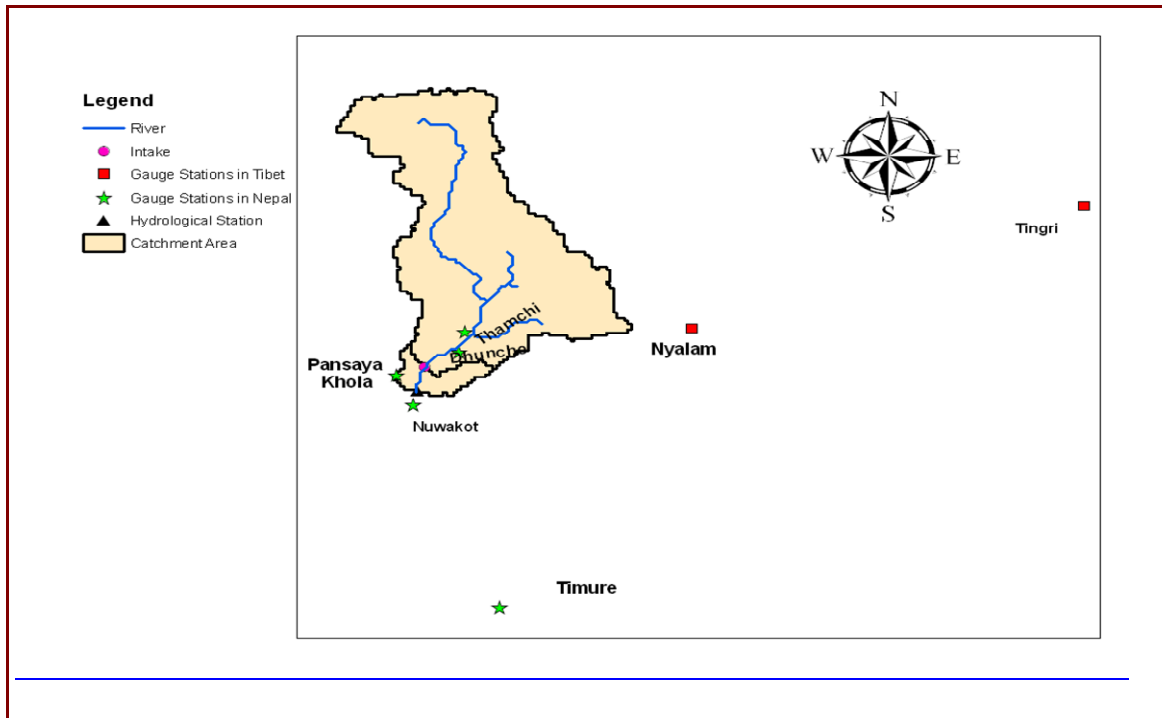
Figure 1 : aion of Hydro- Meteorological Stations

The data are processed and filled with missing gaps, consistency and quality check. Filling of missing precipitation data is done with normal ratio method. For consistency check the double mass curve technique is adopted. And finally collected data are found to be reliable and consistent (Figure 2).
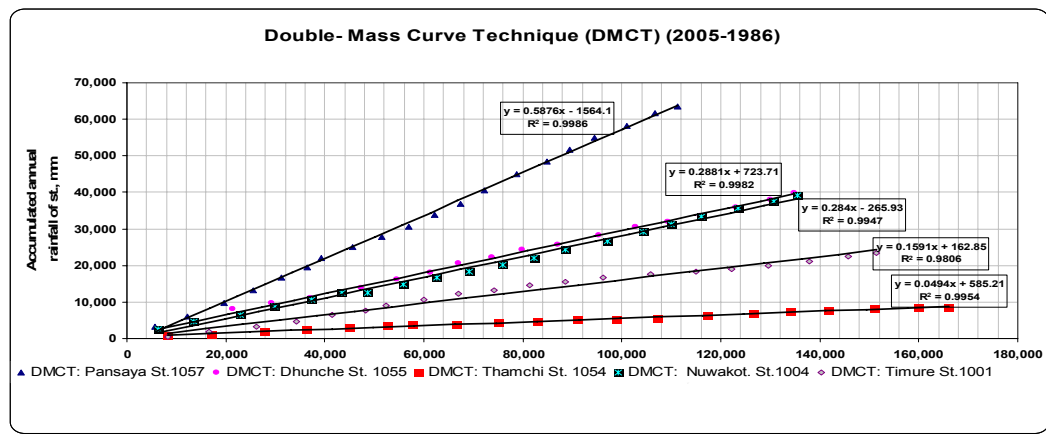
Figure 2 : Double Mass Curve Technique

CATCHMENT AREA AND HYPSOGRAPHIC CURVE

Digital Elevation model DEM (1Kx1K) data set is used for catchment area delineation and for hypsographic curve (Area Elevation curve) (Figure 4). The DEM is processed in ArcGIS with ArcHydro tool. The catchment area found to be 4589 Sqkm (Figure 3). Out of the area nearly 71% lies on Tibet province.
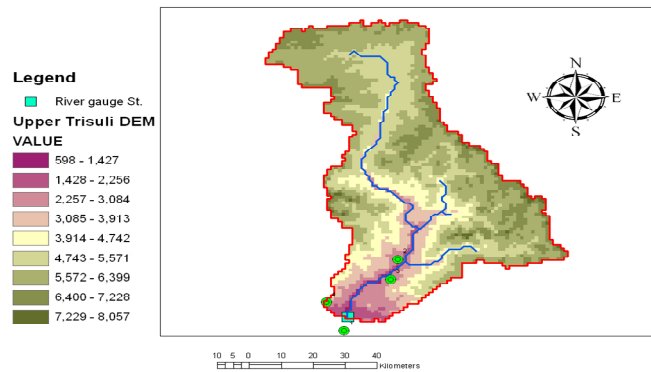
Figure 3 : Upper Trishuli Catchment delineation from DEM
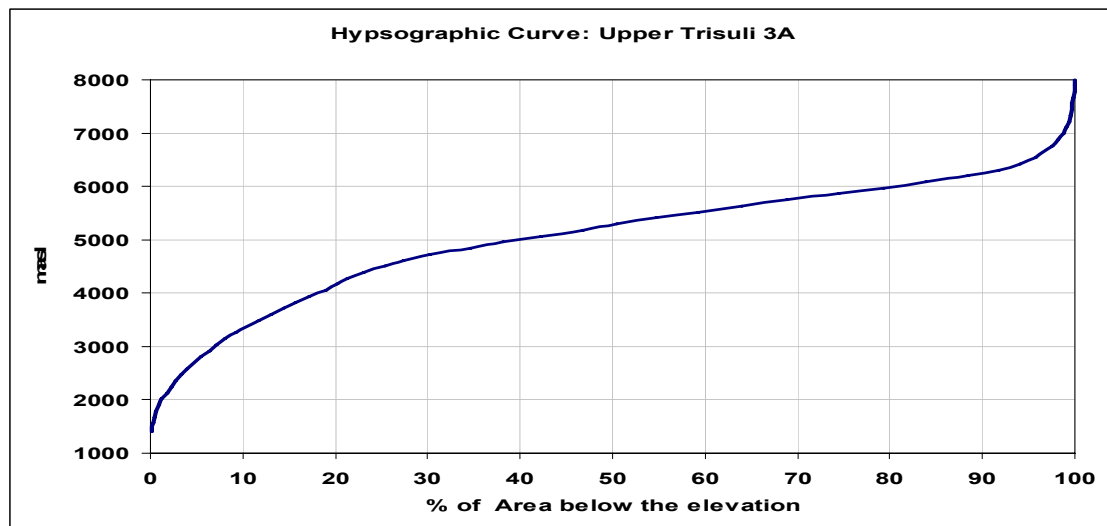
Figure 4 : Hypsographic Curve of Upper Catchment

HBV MODEL AND CALIBRATION

HBV model, precipitation- runoff model, is based on conceptual representation of a few main components in the land phase of the hydrological cycle. The runoff from a cathment is calculated from climatic data precipitation, air temperature and potential evaporation. The standard version of model has four main storage components which are Snow, soil moisture, Upper zone and lower zone (Figure 5).
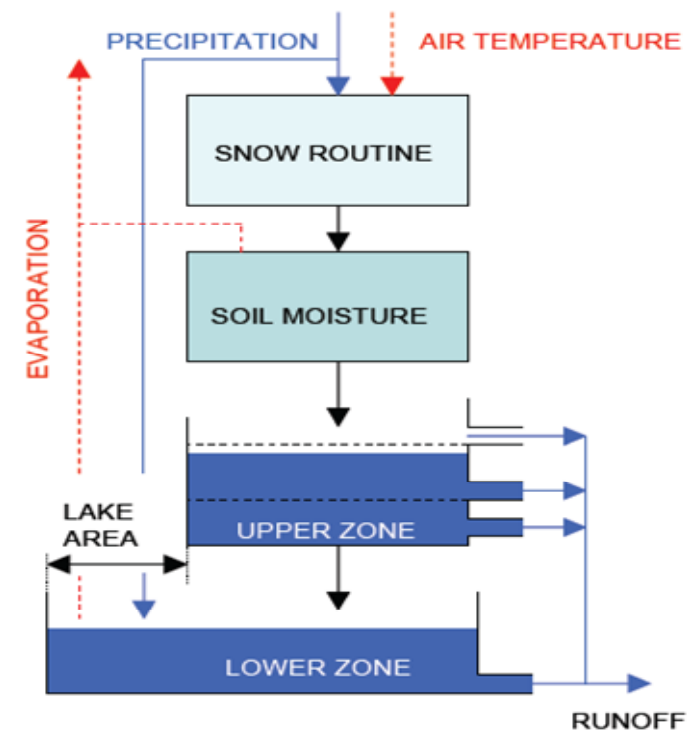
Figure 5 : Main structure of HBV Model

(Sources : Lecture Note, Autum 2007 HPD, NTNU by Prof. Ånund)

The model has 18 free parameters, of which optimal sets are to be determined during calibration. The model has 3 parameters for precipitation, 5 parameters for snow, 3 parameters for soil, 4 parameters for upper zone one parameter for lower zone, and 2 parameters for temperature.

The HBV model is calibrated for 5 years with daily data from 1995 to 1999.

Basic principles of model calibration is to determine the set of free parameters in the model that gives the best possible correspondence between observed and simulated runoff for a cathment. To decide the set of parameters which really give better fit for the model, the criteria are first set to determine the goodness of fit.

THE MAIN CRITERIA SET FOR GOODNESS OF FITTING ARE

Visual Inspection :(Subjective methods)

A cumulative plot:

Cumulative simulated hydrograph

Cumulative observed hydrograph

Water Balance:

Water balance is computed in each year and attempt is made to minimize the balance.

The equation used is,

$$W_{bal} = PREC_{cal} - Q_o - EA + dSM$$

Where, $PREC_{cal}$ Computed mean annual precipitation over the catchemnt

Q_o observed runoff

EA Actual Evaporation

dSM change in soil moisture storage, snow .

EXPLAIN VARIANCE (OBJECTIVE METHOD): R^2

Where the average flow:

Q_s Simulated runoff

Q_o observed runoff

The simulated runoff from calibrated HBV model and measured hydrograph is plot in Figure 6.
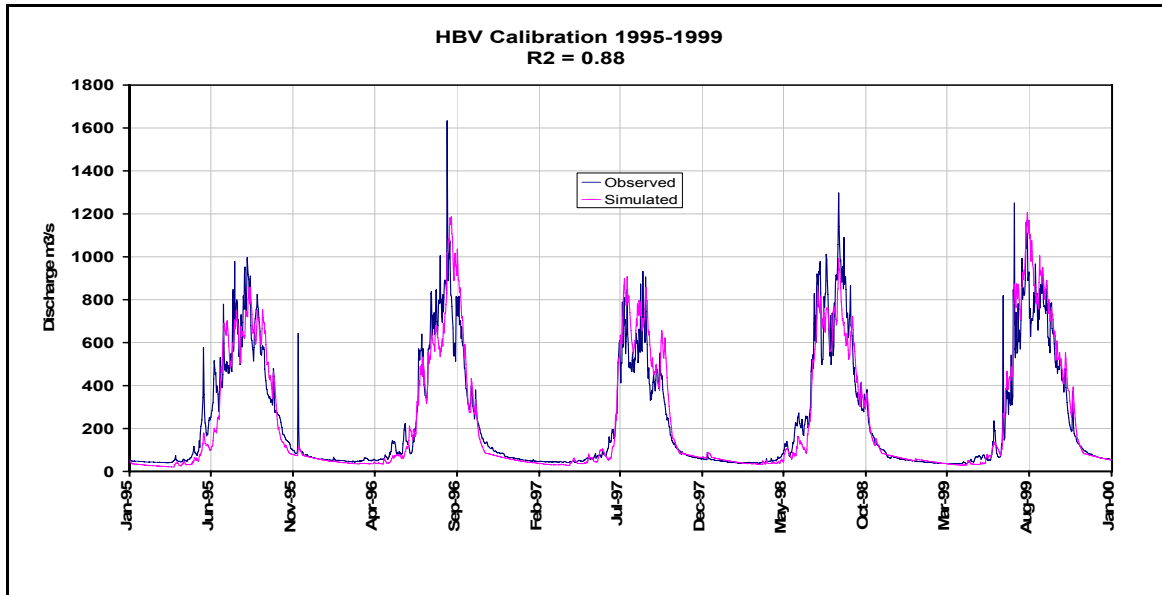
Figure 6 : Hydrograph from HBV model Calibration.

The calibrated model is validated with independent set of daily data for 5 years 2000 to 2004 (Figure 7)
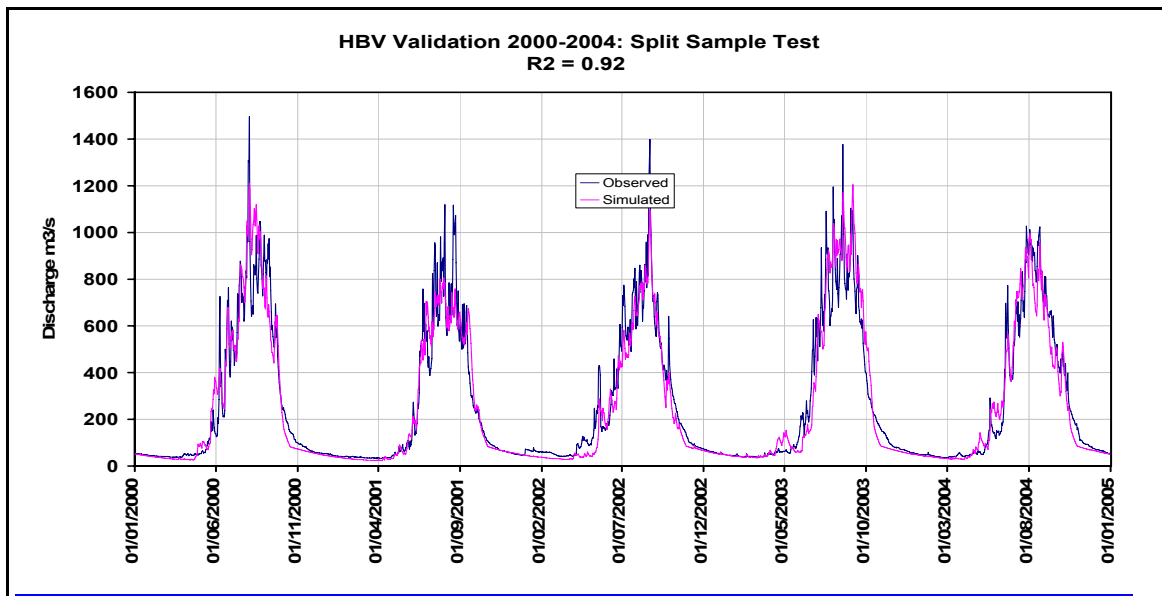
Figure 7 : Hydrograph from HBV model Validation

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LANDPINE MODEL AND CALIBRATION

Landpine has been developed as a distributed hydrological model, and used to study how changed land- use may affect the runoff from the catchments. It operates in integration with a geological information system, which is used for preparation of input data, and analysis and presentation of simulation of results. The model accounts on a distributed basis (Figure 9) for interception in high and low vegetation, storage of on the ground surface, evaporation and transpiration, accumulation and melting of snow, infiltration retention of water in the soil and generation of surface runoff and outflow from the soil. Water movement in rivers and outflows from ground water reservoirs are described by help of an aggregated response function (Figure 8).

The development of this model was a part of a 3 Year research programme, called HYDRA, was initiated and funded by the Norwegian government after the country suffered the biggest flood of this century in the spring of 1995.
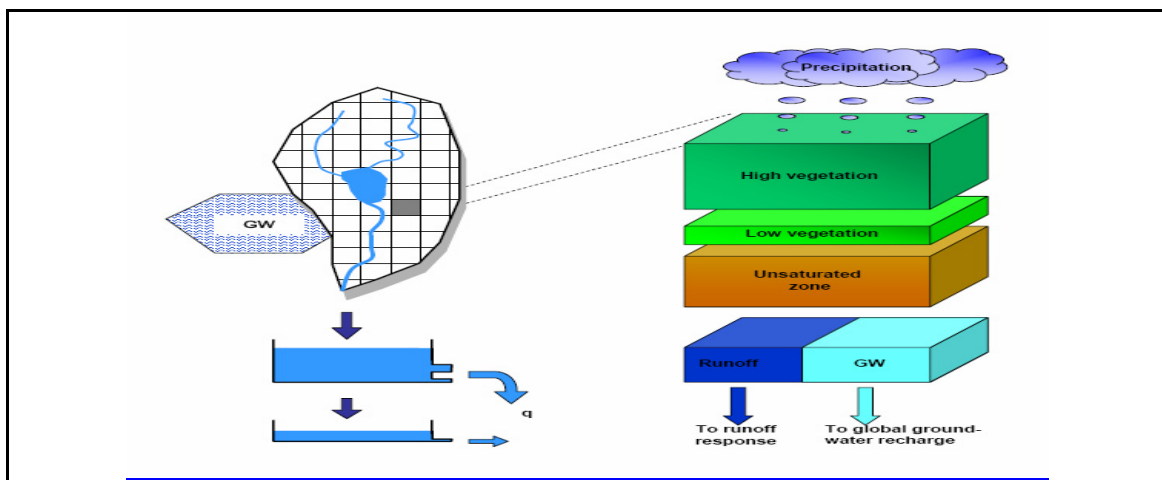
Figure 8 : Landpine structure

(Sources : Lecture Note, Autum 2007 HPD, NTNU by Prof. Knut)
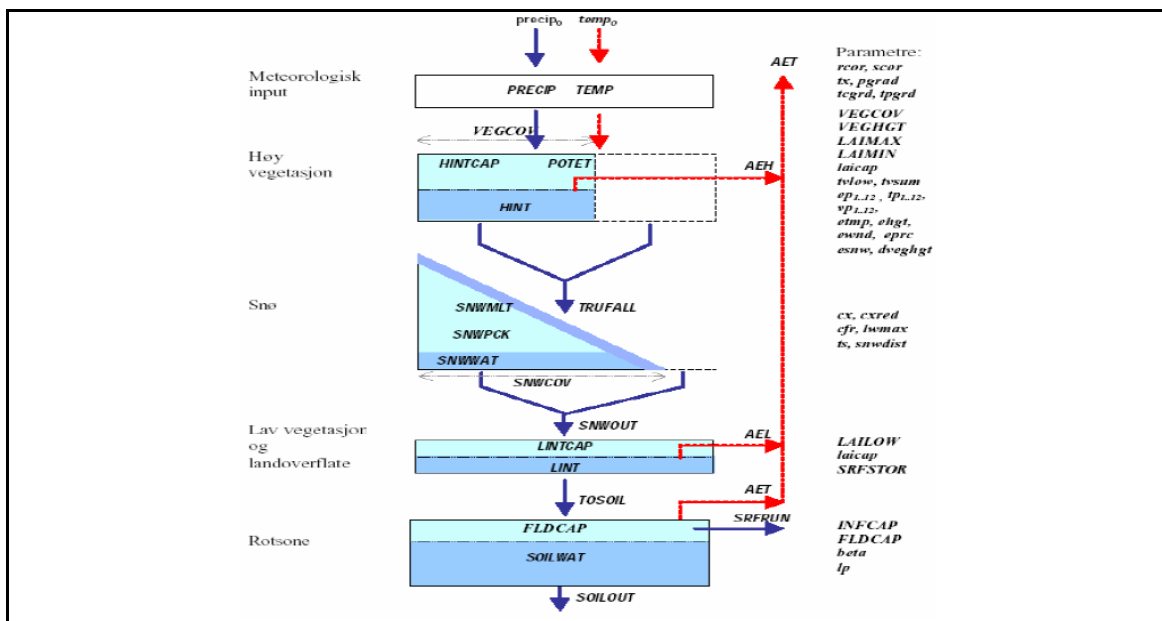
Figure 9 : Model Structure within area-elements in Landpine (After Rinde T., 1998)

The distributed input area prepared in ArcGIS and then imported in IDRISI Andes. The sample distributed input is given in Figure 10.
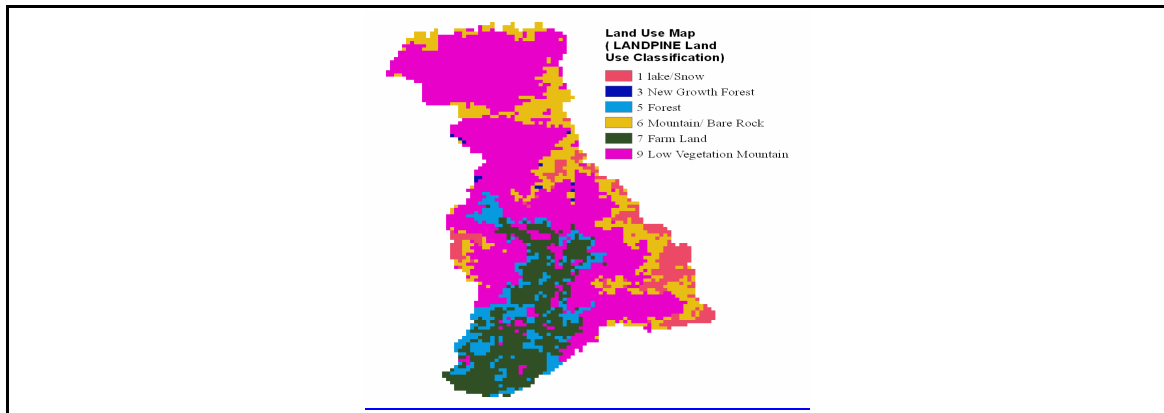
Figure 10 : Land Use Map

About 11 distributed inputs are prepared in Arc GIS following the modification in Idrisi Andes. Similarly the aggregates inputs: daily precipitation data from 3 gauge stations, daily temperature data and daily flow data for 5 years 1995 -1999 are used. During calibration, goodness of fit criteria is set as done for HBV model.

Finally 31 free parameters are optimized for calibration of the model. The calibration result is present in Figure 11.
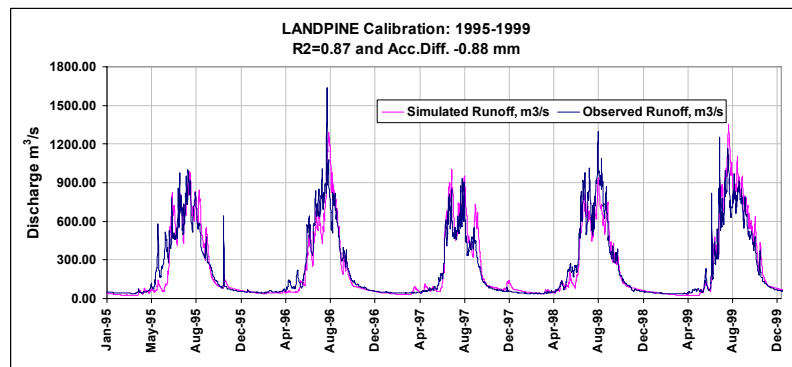
Figure 11 : Hydrograph from Landpine model Calibration

Similarly Landpine calibrated model is validated with independent set of daily data for 5 years 2000 to 2004 (Figure 12)
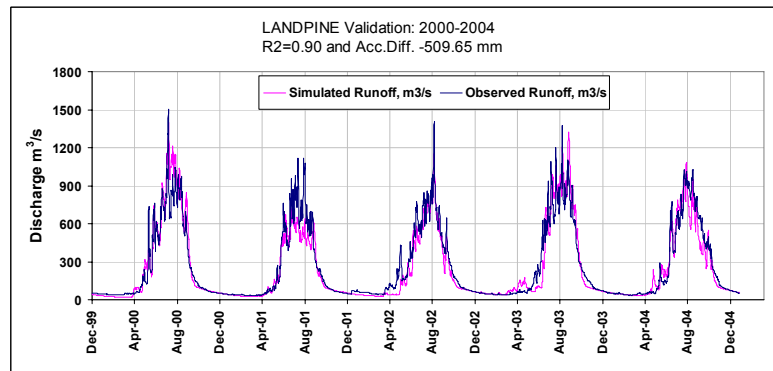
Figure 12 : Hydrograph from Landpine model Calibration

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COMPARISON OF THE RESULTS

Both lumped and distributed models are equally good and able to simulate the flow with good accuracy and the Explain Variance is above 0.87 during calibration and validation. Both models are able to simulate the low and high flow with missing few peaks (Figure 13).
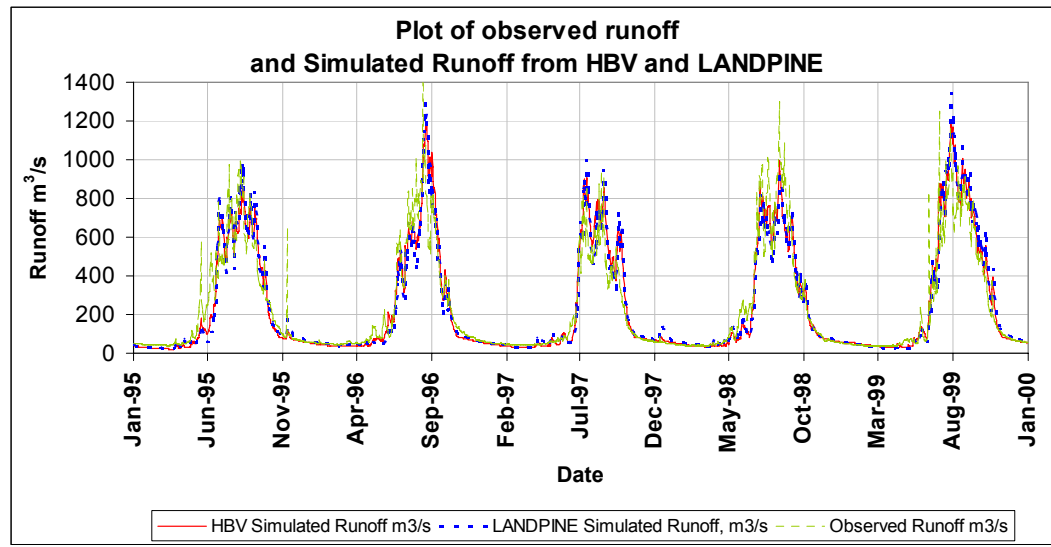
Figure 13 : Hydrograph from HBV model and Landpine model

To check the models performance the snow storage simulated on 14 January 1998 by both model is compared and found within good accuracy (Nearly 100mm of water as snow storage from both models)

CONCLUSION

Both lumped and distributed models are equally applicable and useful for Nepalese catchment though the models are developed in and for Scandinavian Countries.

The Gauge station should be evenly distributed in the catchment to calculate the areal precipitation. The weightage assigned on the gauge stations is very important for model calibration and should be based on good judgment to get the representative areal precipitation for the catchment.

The trial and error procedure will be more time consuming during calibration, the automatic technique like solver tool Add-In package available in Microsoft Excel can be used for finding the optimal sets of free parameter for calibration of the model.

RECOMMENDATIONS

Both model can be use for hydrological modelling of upper Trishuli cathcment, especially for flow forecasting, flow estimating, filling the missing flow data if stream gauge goes wrong. Similarly the model can be calibrated for other cathment in Nepal and will be applicable for hydrological studies.

Both models are equally applicable in the catchment however due to simplicity and less resource demanding HBV model setup in Excel can be used. But runoff changes due to landuse change can only be assessed by using Landpine model as it is more comprehensive and accounts more hydrological processes within each grid of the catchment.

The calibrated models are equally applicable for the study of climate changes, for example: the flow change with change in precipitation, temperature, glacier retreat, snow cover, land use change (Forest cover) etc.

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Surface-Based Sampling Techniques for Sediment Transport Measurement in High Gradient Streams

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ABSTRACT

The sediment transport measurements were carried out to obtain the suspended load, bed load and bed material characteristics of a river. Various guidelines were established to aide the researchers to select the suitable sampling tools and to practice site specific sampling procedures which is unique to low, medium or high gradient rivers. This paper reports the tools, data collection and analysis procedures that were used to conduct the sediment transport study in a high gradient streams (HGS) especially in Malaysia. Three major themes dealt here namely (1) stream classification and survey, (2) sediment data and (3) hydraulic data collection and analysis. The method suggested by DID, (2000). Federal Interagency Sedimentation Project, Rocky Mountain Research Station and U.S Geological Survey (USGS) were highly regarded as the main reference for the sampling procedures suggested here. The suggested methods here were tested with various field conditions for perennial HGSs in Malaysia can be applied to similar setting in other parts in tropical areas.

Key words : Mountain River, Field Sampling, Control Variables, Influential Parameters.

INTRODUCTION

High Gradient Stream (HGS) can be defined as reach having average gradient of ≥ 0.002 m/m (Wohl, 2000). Buffington & Montgomery (1997) and Papanicolaou & Maxwell (2000) further classified rivers based of typical morphological conditions such as cascades, step-pools, plane-beds, pool–riffles and dune-ripples. However, most morphological formations are very much dependent on gradient of the stream and considered the most dominating factor in HGS channel formations.The gradient was measured in a reach with a length of channel at least ten times the average channel width, having relatively constant morphology. Beside that, the HGS typically having coarser bed material; ranging from fine gravels to big boulders (Figure 1).

Sediment transport patent in the High Gradient Streams (HGS) in Malaysia were less studied by the researchers and hydrologists due to its inaccessibility and HGSs are always being portrait as with crystal clear waters and bountiful of native fishes. Recent development in the highlands areas such as logging, agriculture, road building, dredging, and recreational area development have the potential to add unusually large amounts of sediment to a water body, thereby markedly affecting its physical, chemical, and biological structure and integrity. Beside that, HGSs, due to their tremendous stream power, carry enormous volumes of sediment which end up at a reservoir, due to the size of reservoirs, are virtually deposited into the reservoir basin, leading to fast deterioration of a costly investment. Reservoir storage capacity reduces impacts hydroelectric power generation and flood control operation. Figure 2 shows the heavily silted Abu Bakar Reservoir and daily sand dredging activities.

Various government agencies, private sectors and NGOs had shown their concerns for the problems in the high gradient catchment areas but since there is no proper guideline to monitor sedimentation problems in HGS, the seriousness of the problem is yet to be brought into limelight. Thus, this paper is aimed provide some basic understandings of the sediment and hydraulic sampling tools, procedures and analysis to be adopted while conducting in a sediment transport study in a perennial HGSs in a tropical area.

The major field work categories are listed in Table 1. Both hydraulic and sediment data must be obtained simultaneously. It is because the sediment and hydraulic process quite unpredictable and always correlated each other especially in HGR (Yang, C.T., personal communication, April 17, 2008).

STUDY AREA

The field sampling procedures were tested in nearly 30 HGSs in Malaysia; Some of the typical views of study reach was shown in Figure 3.

RIVER GEOMETRY & WATER SURFACE SLOPE MEASUREMENT

The cross section is established perpendicular to the main body of the flow, and the points across the section are surveyed relative to a known or arbitrarily established benchmark elevation. The distance-elevation paired data associated with each point on the section may be obtained by rod-and-level survey. This typically involves making depth soundings at1 meter interval across the river, connecting the points, and integrating for area. Measuring a stream channel cross-section is the first stage in field sampling technique. The purpose of this technique is to find the flow area (A) and cross-sectional area and the wetted perimeter (P) of the river where it involves channel dimension such as width (B) and flow depth (y_0) and cross section depth(h) of the river. The data that obtained were used to plot and create a scale diagram of the cross-section by using AutoCAD. From the diagram, cross-section area and wetted perimeter were obtained. The typical cross-sectional geometry measurement shown in Figure 4.

The water surface slope is determined by measuring the difference in water surface elevation per unit stream length. Typically, the stream length is measured at least ten times the average channel width. For the measurement technique, the rod person must move upstream from the cross section to incorporate the one complete of pool-riffle or step-pool (if present) (Harrelson et al., 1994). The measurement is started at a distinct feature such as top of riffle or pool. The rod person must put the staff at the top of the said feature and it must be ended with the same features at the downstream. The water surface elevation was determined using the automatic level. The distance between upstream and downstream from the cross section is plotted against the water surface elevation in order to get water surface slope. The simple equation to get percentage of slope is shown below.

$$Slope\,(\%) = \frac{\text{Rise}}{\text{Run}} \times 100 \tag{1}$$

"Rise" is referred to water surface elevation from the defined upstream and downstream whereas the "run" is referred to the channel length from the two measured point; at least ten times the average channel width. Figure 5 shows the slope measurement procedures and Figure 6 depicts the typical slope values measured from the field sampling for the selected river during the course of study.

BED MATERIAL SIZES

The bed material particle size is analyzed by quantifying the frequency distribution of particle sizes contained within the bed material (Bunte & Abt, 2001). However, the sampling at the gravel- and cobble-bed streams is different from sampling at sand-bed stream. The sampling at sand-bedded

streams is quite straight forward compared with sophisticated sampling at gravel and cobble-bed streams. There are three methods proposed for surface sampling which are pebble counts, grid counts and areal samples. Table 2 shows the difference between all those three methods. The method used in this study is pebble counting which was first proposed by Wolman (1954).

Bunte & Abt (2001) had proposed two types of transects approach which are Wolman pebble count with heel-to-toe walk and systematic sampling at even-spaced marks along a measuring tape. The differences between these two approaches are depicted in Table 3. The main purpose is to get the percentile values of the cumulative particle-size frequency distribution at approximate 100 counts as described in Figure 7.

BED LOAD MEASUREMENT AND CALCULATION

The near bed sediment particles movement were measured as bed load. The equipment used to measure the rate of particles movement is USBLH-84 sampler (Figure 9). The sampler has a 76mm x 76mm opening to a 0.25mm mesh sampling bag that is supported by a metal frame. The sampler consists of an expanding nozzle mated to a frame, and a sampler bag. When the sampler is submerged and sitting on the streambed with the nozzle pointed into the flow, the water sediment mixture flows through the nozzle into the bag (FISP, 2001[a]). The mesh openings in the bag allow water and fine sediment to flow through the bag while trapping the coarse sediment. The time taken to measure the bed load is between 5 to 10 minutes with 7 point for every cross section (DID, 2003). However, site specific judgement are needed to increase or decrease the number of points needed depending on the width of a stream (Figure 10). The rate of bed load movement was calculated after the samples dried and weighted. The formulation used to calculate bed load transport rate as follows.

$$T_b = \sum_{n=1} G_b \qquad (2)$$

$$G_b = \frac{W_i}{(T * h_s)} b \qquad (3)$$

Where,

T_b	=	Total bed load for 1 cross section (kgs^{-1})
G_b	=	Bed load for 1 section (kgs^{-1})
b	=	B/n
Wi	=	Sample weight for 1 point (kg)
T	=	Time
h_s	=	Width of US BHL opening (m)

SUSPENDED LOAD MEASUREMENT

The suspended load rate was measured using US DH-48 Depth Integrating Suspended Sediment Sampler (Figure 11) by employing wading technique. The sampler consists of a streamlined aluminum casting, 9 5/8 inches long (less nozzle), which partially enclosed a round bottle sample container (FISP, 2001[b]). The sampler accommodates the exhaust air port where air may escape from the bottle as the sample is being collected. A wading rod is threaded into the top of the sampler body for suspending the sampler. When the sampler containing a sample bottle is submerged into the water with the nozzle is face the river flow, the stream will discharge into the bottle even the bottle is completely full. The sample should be sampled at three location; left, right and middle portion of the river width to obtain the average value (Figure 12).

Those collected samples were brought back for laboratory analysis get the Total Suspended Solid (TSS) concentration. The calculations to obtain suspended load were:

(4)

$$Qs = Cv * Q$$

$$Ts = Qs * \rho s \tag{5}$$

where Qs is sediment discharge, Cv is volumetric concentration, Q is flow discharge, ρs is sediment density and Ts is suspended load in kgs⁻¹.

RIVER VELOCITY AND DISCHARGE

The velocity of a river is the speed at which water flows along it. The velocity will change along the course of any river, and is determined by factors such as the gradient (how steeply the river is losing height), the volume of water, the shape of the river channel and the amount of friction created by the bed, rocks and plants (Duan et al., 2006). Velocity was measured using a Model 2000 portable flow meter manufactured by Marsh-McBirney (Figure 13). This lightweight device at approximate 1.6 kg was designed for both field and laboratory. The sensor which was attached with sensor cable equipped with an electromagnetic coil that produce the magnetic field. The Faraday Law of electromagnetic induction stated that as a conductor moves through a magnetic field, a voltage is produced. The magnitude is proportional to the velocity at which the conductor moved through the magnetic field. Three readings were taken from left, right and middle of the flow to obtain the average velocity of the stream. Each cross section was divided for 1 meter apart to get a clear picture of river's cross section and to obtain an accurate river discharge

$$Q = VxA \tag{6}$$

where V is average river velocity and A is area for river's cross section.

ESTABLISHMENT OF SEDIMENT AND HYDRAULIC DATABASE

The sediment and hydraulic data obtained from field sampling were processed and compiled into a database (Table 4) for further analysis.

EVALUATION OF BASIC ASSUMPTION

Sediment transport is a complex phenomenon and always subject to empirical or semi empirical treatment. Some simplified assumptions where made where the sediment rate were determined by certain dominant factors such as water discharge, average flow velocity, energy slope, shear stress and stream power (Yang, 1996). The basic concept upon which knowledge the sediment transport is based should be emphasized rather than the mathematical derivations. Most of the sediment transport equations were based of the assumptions where the concentrations were controlled by the dominant variables. Those dominant factors can be expressed in these six basic forms:

$$q_s = A_1 \left(Q - Q_c \right)^{B_1} \tag{7}$$

$$q_s = A_2 \left(V - V_c \right)^{B_2} \tag{8}$$

$$q_s = A_3 \left(S - S_c \right)^{B_3} \tag{9}$$

$$q_s = A_4 \left(\tau - \tau_c \right)^{B_4} \tag{10}$$

$$q_s = A_5 \left(\tau V - \tau V_c \right)^{B_5} \tag{11}$$

$$q_s = A_6 \left(VS - V_c S_c \right)^{B_6} \tag{12}$$

where q_s = sediment discharge per unit width of channel

Q = water discharge

V = average flow velocity

S = energy or water surface slope

τ = shear stress

τV = stream power per unit bed area

VS = unit stream power

$A_1, A_2 A_3, A_4, A_5, A_6, B_1, B_2, B_3, B_4, B_5, B_6$

= parameter related to sediment and flow conditions

c = subscript denoting the critical condition at incipient motion

Thus, before the sediment and hydraulic data obtained from field sampling were utilised into more sophisticated analysis, the basic assumption must be tested to see the relationship between dependent and independent variables. Figure 14 shows the relationship between Total Load (dependent variables) and other independent variables. The variables shows good fit will be chosen for further analysis.

CONCLUSION

The field work in high gradient stream must be executed simultaneously and according to the reliable method. The application of certain tools, procedures or analysis must be carefully selected to avoid discrepancies in the measured data. Beside that, safety precautions must be always considered because the flow in the HGSs may rise in sudden manner due the rainfall in the upper part of the catchment area.

ACKNOWLEDGEMENT

Figure 1 : Typical Bed Material of HGS in Malaysia

Figure 2 : Sedimentation problems at Abu Bakar Reservoir, Cameron Highlands, Pahang Malaysia (Sinnakaudan, 2006)
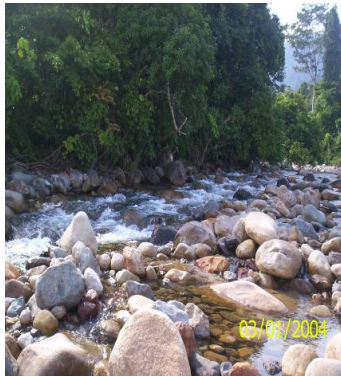
Kemia River, Pok Sek
Hulu Besut, Terengganu
GPS REF N 05°27'23.6"   E 102°31'28.0"

Rasi River, Felcra Keruak
Hulu Besut, Terengganu
GPS REF N 05°28'18.3"   E 102°27'56.8"

Telom River (Jln Ipoh)
Cameron Highland,Pahang
GPS REF N 04°33'5.8"   E 101°24'36.9"

Lata Tembaka River, Bekok
Hulu Besut, Terengganu
GPS REF N 05°35'10.9"   E 102°26'50.9"
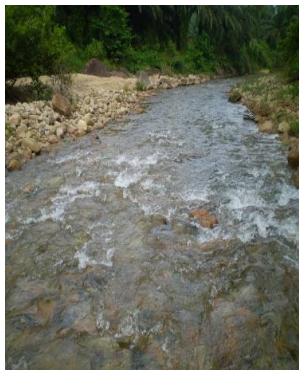
Lagus River
Hulu Besut,Terengganu
GPS REF N 05°25'20.8"   E 102°27'26.2"

Kacong River
Bekok, Terengganu
GPS REF N 05°36'0.1"   E 102°26'58.8"

Figure 3 : Typical View of Mountainous Stream in Malaysia

(i)- Cross-sectional Area, (ii)-Flow Area (A)
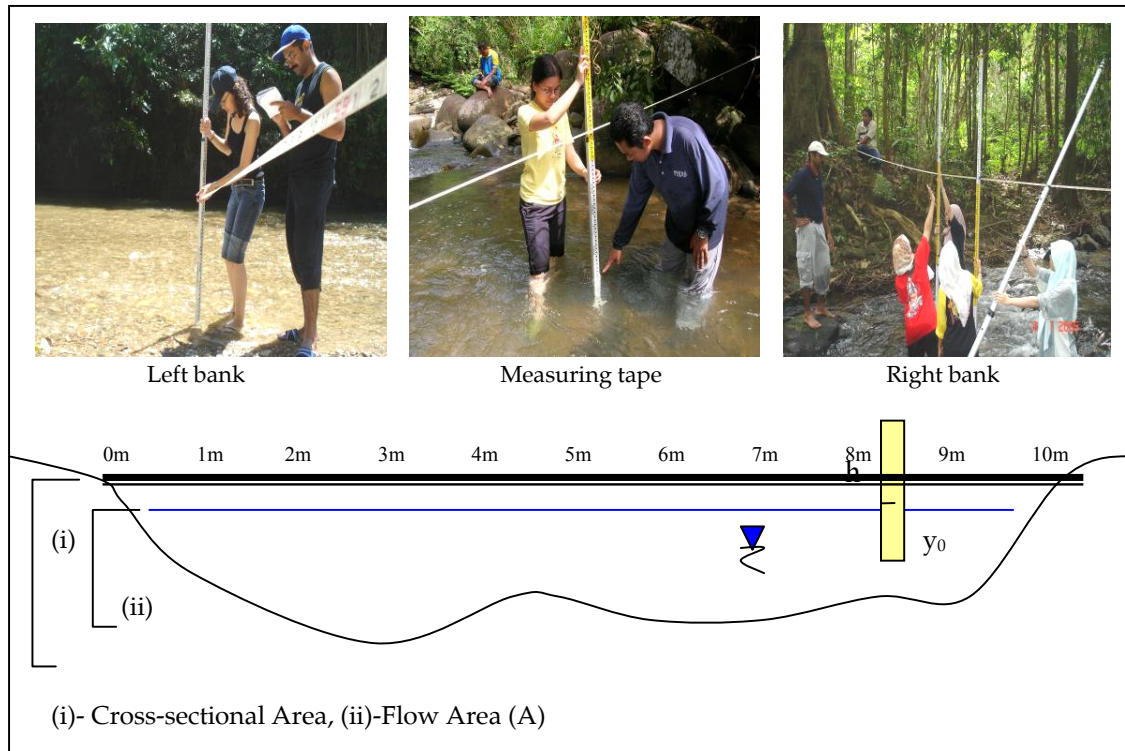
Figure 4 : Cross sectional Geometry Measurement for a HGS
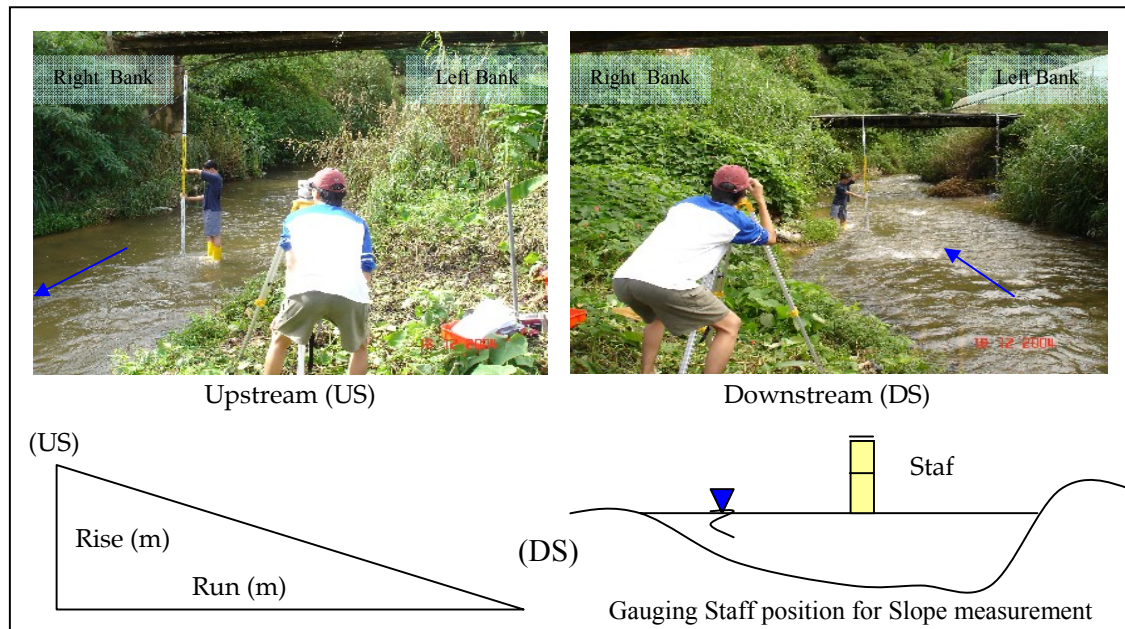
Figure 5 : Slope Measurement in a HGS
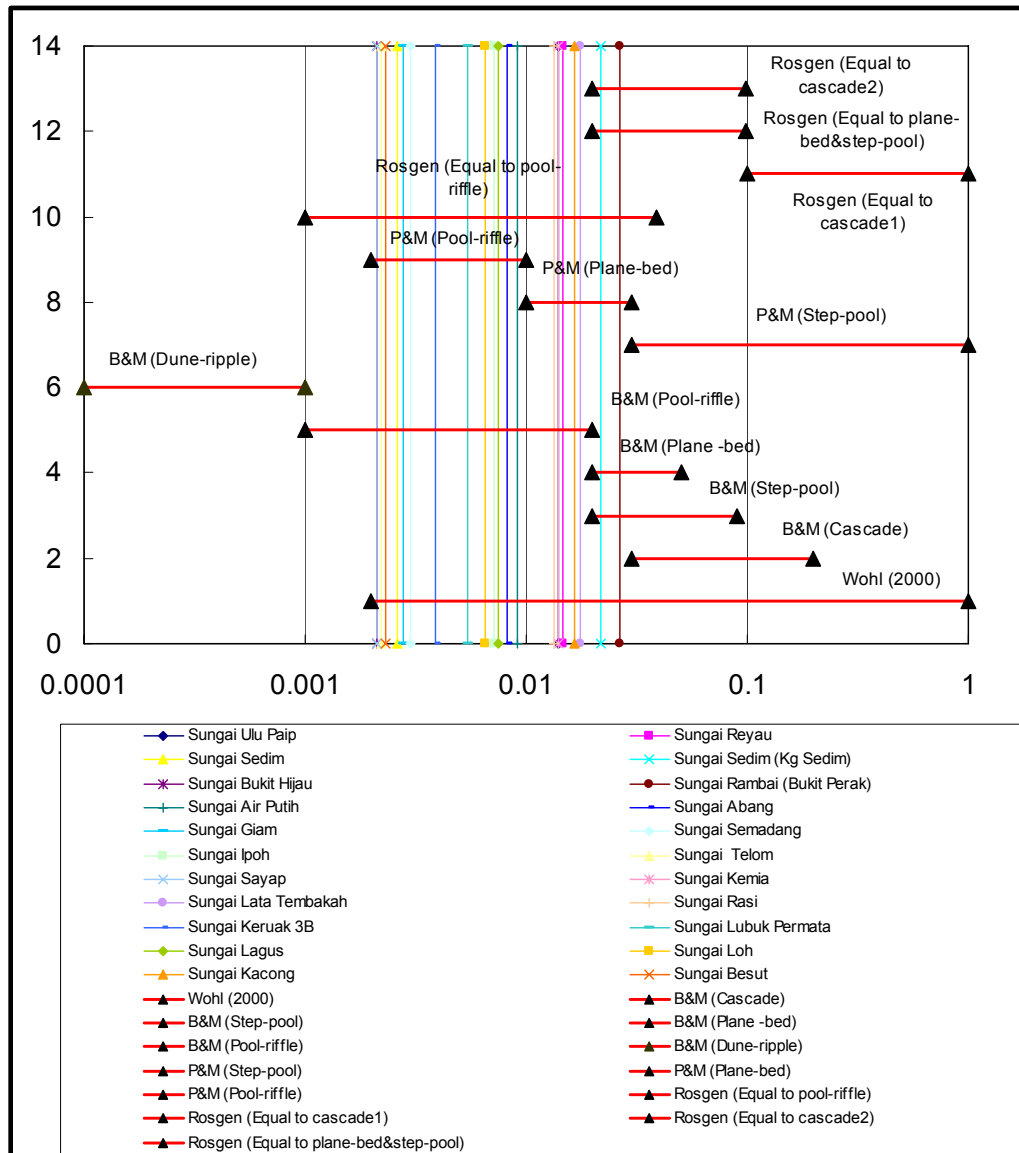
Figure 6 : Typical slope values measured for HGS during the course of study

Figure 7 : Pebble Counting
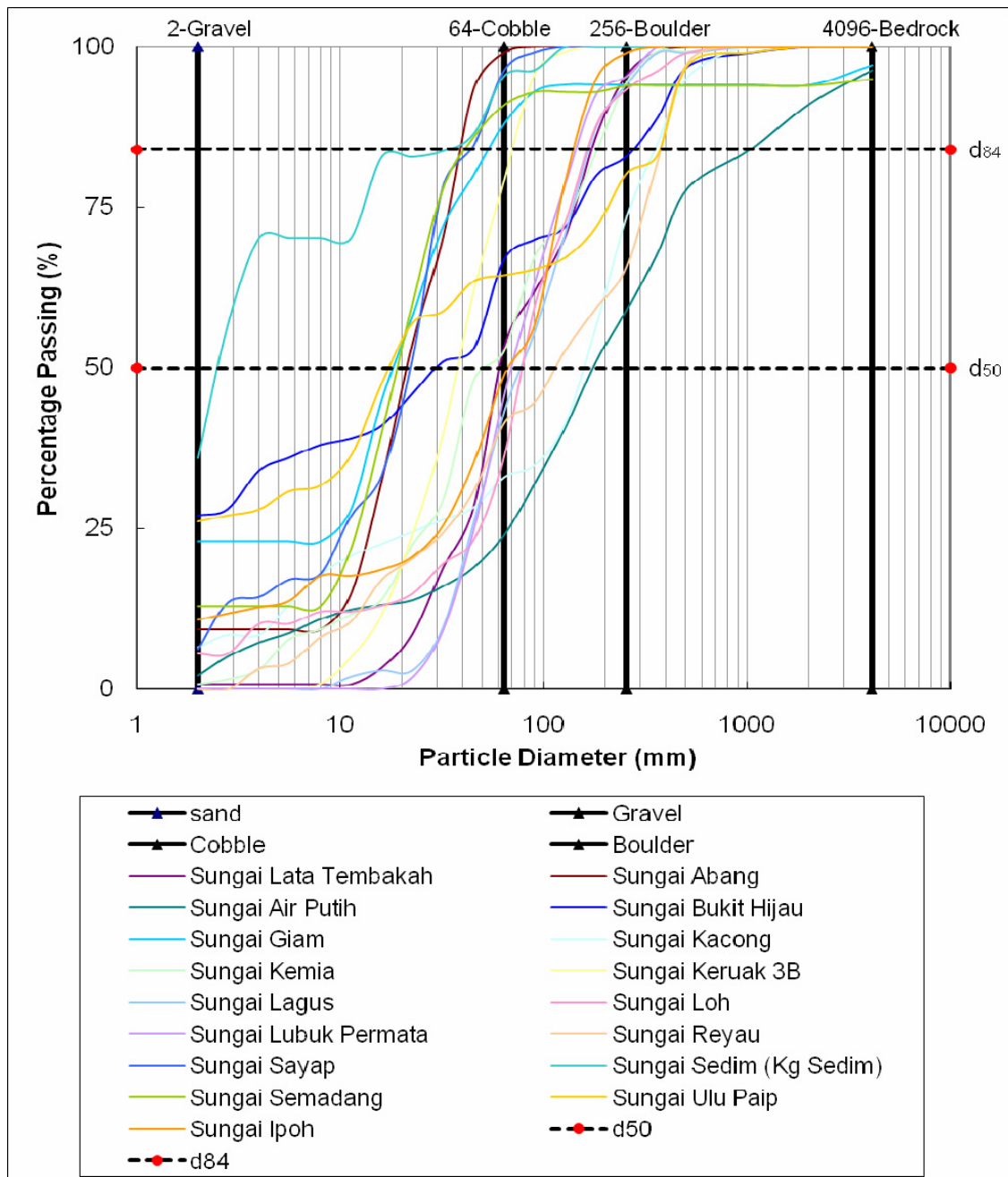
Figure 8 : Typical particle size distribution curve obtained through Pebble Counting

Figure 9 : US BHL- 84 Sampler and sampling procedures
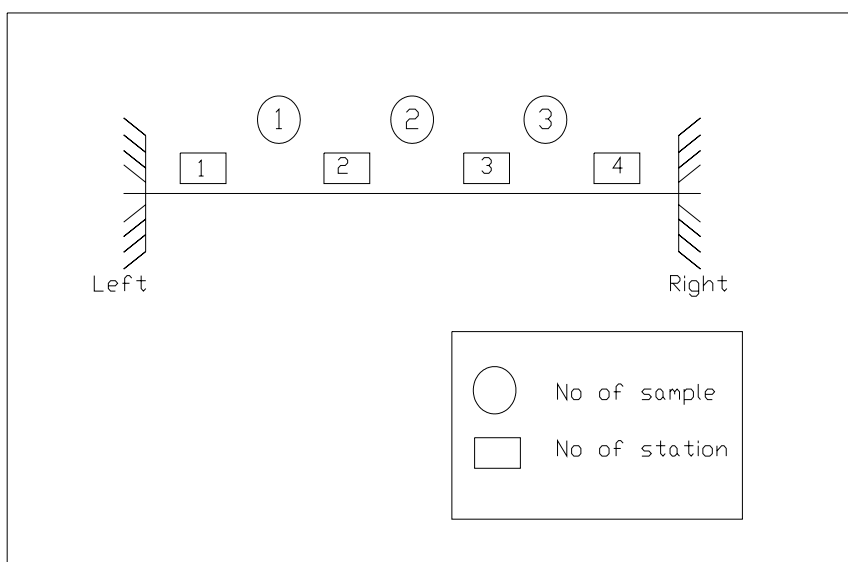
Figure 10 : Point of Measurement Depending on Stream Width
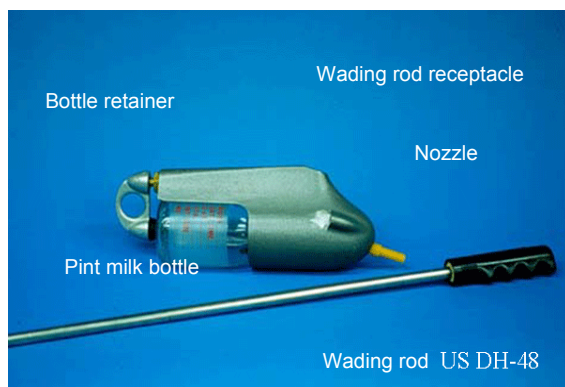
Figure 11 : US DH-48 Depth Integrating Suspended Sediment Sampler
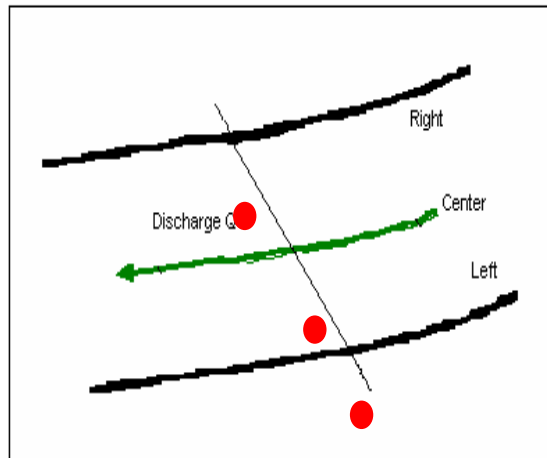
Figure 12 : Measurement Locations for US DH-48 Sampler
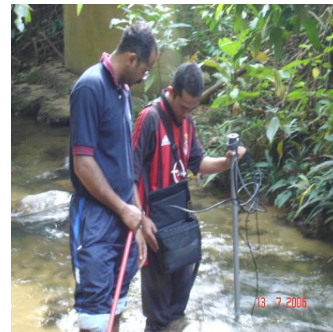
Figure 13 : Flo-Mate Model 2000 Portable Flow meter and Velocity measurement procedures
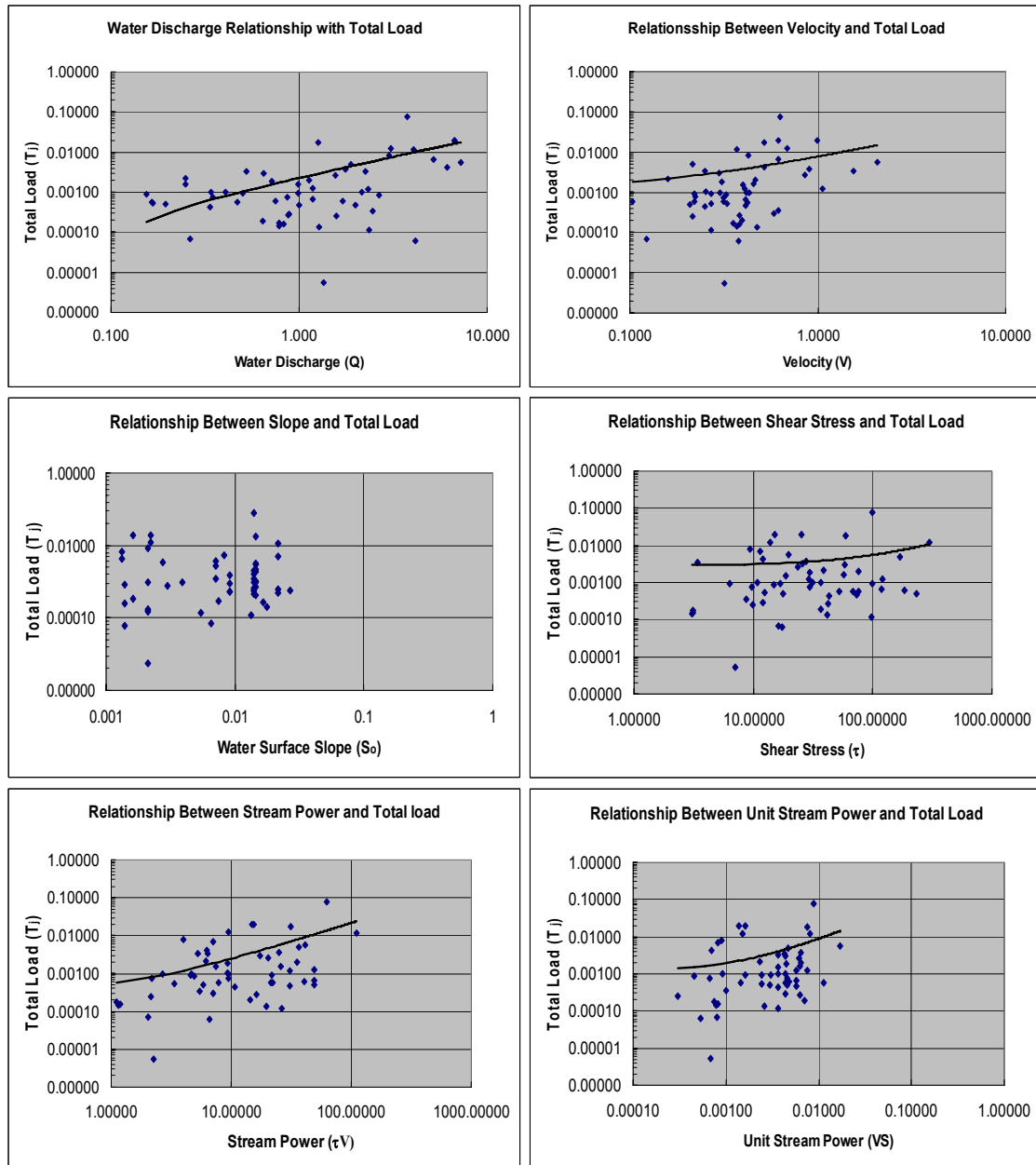
FIGURE 14 : EVALUATION OF BASIC ASSUMPTION

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Table 1 : Data themes for field work

Data Theme	Types of Data	Data Category
River Surveys	Water Surface Slope (S_o) Classification Bed Material Sizes Classification (d_{50}) Morphological Classification (Cascade, Step-pool, Plane-bed & Pool-riffle) Geometrical measurement of the river (A) Slope of river (water surface slope)	Primary Data
Sediment Data	Bed Load Concentration (T_b) Suspended Load Concentration (T_s) Representative Bed Material (d_{50})	Primary Data
Hydraulic Data	Discharge $(Q = VxA)$ Velocity (V)	Primary Data

Table 2 : Comparison between Pebble Counts, Grid Counts and Areal Samples (Bunte & Abt, 2001).

Pebble Counts	Grid Counts	Areal Samples
Sample a preset number of particles in wide and approximately even-spaced increments of at least D_{max} size.	Samples a preset number of particles under a grid of approximately D_{max} size.	Sample all surface particles within a small predefined sampling area.
Cover a large sampling area.	Sample several small areas within a reach or cover small areas of homogeneous sediment.	Focus on point locations and require several samples to be taken within the sampling area.
Suitable for gravel and cobbles, not for sand.	Suitable for gravel, not for sand.	Suitable for sand to medium gravel not for coarse gravel or cobbles.
Long field time, no lab time	Hand picking: Long field time, no lab time Photographs: Short field time, long field time	Both field time and lab time
Sampled particles sizes comparable and combinable with particle sizes from grid counts and volumetric samples.	Sampled particle sizes comparable and combinable with particle sizes from pebble counts and volumetric samples	Sampled particle sizes not directly comparable and combinable with particle sizes from pebble or grid counts, or volumetric samples.

Table 3 : Overview of the Differences between the Heel-to-Toe Sampling and Systematic Sampling along a Measuring Tape (Bunte & Abt, 2001).

	Heel-to-toe steps	Systematic sampling along a tape
Step Spacing	1-2 paces (0.3-0.6 m) regardless of bed material size.	1-2 times the D_{max} particle size, in accordance with bed material size.
Particles selection on dry surfaces:	Blind touch at the tip of the boot	Visual correspondence with even spaced marks on measuring tape.
Possible improvements	Keep finger straight to avoid touching neighboring particles	Use pin or owl for more precise identification of particle to select.
Particle selection under water	Blind touch at the tip of the boot	Visual correspondence with even spaced marks on measuring tape as best as possible; otherwise blind touch.
Sampling path	Along an imaginary line	Along a tape, strictly predetermined.

Table 4 : Sample Hydraulics and Sediment Data Range for HGR in Malaysia

River Name (No of Data)	Discharge Q, m³s⁻¹ (min-max)	Velocity V, ms⁻¹ (min-max)	Width B, m	y_o, m (min-max)	S_0, m/m	d_{50}, mm (min-max)	T_b, kgs⁻¹	T_s, kgs⁻¹	T_j, kgs⁻¹
Ulu Paip (9)	3.75	0.10	21.30	0.88	0.014	19.30	0.0240	1.624	1.6300
	0.47	0.63		0.42		13.18	0.000	0.0075	0.0100
Air Putih (4)	0.25	0.40	6.00	0.21	0.0091	175.32	0.0043	0.0050	0.0093
	0.15	0.27		0.14		99.88	0.0004	0.0000	0.0031
Reyau (9)	1.26	0.52	8.00	0.42	0.015	149.33	0.0112	0.1400	0.1420
	0.25	0.16		0.18		70.63	0.0000	0.0030	0.0030
Telom -Jln Ipoh (3)	2.32	1.06	14.00	0.42	0.0071	67.31	0.0518	0.0000	0.0518
	1.57	0.86		0.34		50.60	0.0169	0.0000	0.0169

Climate Change Impacts on Water Resources of Nepal with Reference to the Himalayan Glaciers

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ABSTRACT

The impacts of climate change on water resources of Nepal with reference to snow and glacier were assessed. The analysis has revealed that the glaciers in the Nepal Himalayas are shrinking rapidly and may disappear within less than two centuries, if the current glacier melting rate continues. Most of the small glaciers will disappear within 3-4 decades; there may be only 11% of the present glacier-ice reserve left in the Nepal Himalayas by 2200 AD even without any further warming. An accelerated glacier melt will cause an increase in water availability at the beginning but ultimately may result in a decrease in water availability after the glaciers disappear that may adversely affect Nepal's hydropower potential. Rapidly retreating glaciers and shrinking snow and ice areas in the Nepal Himalayas as a result of temperature rise may increase the likelihoods of extreme floods including glacier lake outburst floods.

Key words : Climate Change, Water Resources, Nepal Himalayas, Glaciers

BACKGROUND

Nepal is rich in water resources. There are more than 6000 rivers flowing from the Himalayan Mountains to the hills and plains. Most of these rivers are glacier-fed and provide sustained flows during dry seasons to fulfil the water requirements of hydropower plants, irrigation canals and water supply schemes downstream. The hydrology of these rivers is largely dependent on the climatic conditions of the region, which in turn is a part of global climate. Accelerated melting of glaciers during the last half century has caused creation of many new glacier lakes and expansion of existing ones in the Nepal Himalayas (Mool et al., 2001). There have been more than 13 reported cases of glacier lake outburst flood events in the Nepal Himalayas since 1964 causing substantial damage to people's lives, livestock, land, environment and infrastructure (ibid). Accelerated retreat of glaciers with increased intensity of monsoon precipitation observed during recent years has most probably contributed to increased frequency of such floods.

About 99% of the total electricity in Nepal comes from hydropower plants and only about 1% from thermal plants (NEA, 2003). Therefore, hydropower is one of the most important tools for the present and future economic development of Nepal. The major rivers of Nepal are fed by melt-water from over three thousand glaciers scattered throughout the Nepal Himalayas. These rivers feed irrigation systems, agro-processing mills and hydroelectric plants and supply drinking water for villages for thousands of kilometres downstream. Climate change will contribute to increased variability of river runoff due to changes in timing and intensity of precipitation as well as melting of glaciers (Agrawala *et al.*, 2003). Runoff will initially increase as glaciers melt, then decrease later as the glaciers disappear (ibid).

Climate change may alter rainfall and snowfall patterns. The incidence of extreme weather events such as droughts, storms, floods and avalanches is expected to increase. This can lead to loss of lives and severely reduce agricultural production. Traditional wisdom and knowledge to cope with such natural hazards that once ensured food security may no longer prove effective. Climate-induced natural hazards have very serious human implications because they affect the livelihood security of the majority of the population. About 29% of the total annual deaths of people and 43% of the total loss of properties from all different disasters in Nepal are caused by water-induced disasters like floods, landslides and avalanches (Khanal, 2005).

IMPACTS OF CLIMATE CHANGE ON SNOW AND GLACIER SYSTEM

Higher temperatures will increase the ratio of rain to snow; accelerate the rate of snow- and glacier-melt; and shorten the overall snowfall season. Since the end of the Little Ice Age, the temperatures have been generally increasing and the majority of the world's glaciers are retreating (IPCC, 2001). Some reports have noted that 1 K temperature change leads to a change of equilibrium-line altitude (i.e. the altitude where the accumulation of a glacier equals to its ablation) of 130 m in the Alps (Orlemans *et al.*, 1989). Increasing temperature shifts the permanent snowline upward. This could cause a significant reduction of water storage in the mountains, which is likely to pose serious problems of water availability to many people living downstream

The Himalayan glaciers are melting faster in recent years than before (IPCC, 2007). The Himalayan Rivers are expected to be very vulnerable to climate change because snow and glacier melt-water make a substantial contribution to their runoff. However, the degree of sensitivity may vary among the river systems. The magnitudes of snowmelt floods are determined by the volume of snow, the rate at which the snow melts and the amount of rain that falls during the melt period (IPCC, 1996). Because the melting season in the Himalayas coincides with the summer monsoon season, any intensification of monsoon or accelerated melting would contribute to increased summer runoff that ultimately would result in increased risk of flood disasters (IPCC, 2001).

Chaulagain (2007) has reported that even without any further warming, there will be only 54.8 km³ of glacier-ice reserve left by the year 2100, which is only 11.4% of the present glacier-ice reserve of 480.6 km³. Likewise, there will be no glacier-ice reserve left by the year 2180, if the current rate of melting continues (see Figure 1). The temperature in the Nepal Himalayas is increasing by at least 0.06°C per year (Shrestha et. al, 1999), which would further accelerate the glacier melt. If this rate of warming (i.e. 0.06°C per year) continues, there may be no glacier-ice reserve left in the Nepal Himalayas by the year 2070.

Figure 1: Sensitivity of glacier-ice reserve to a warming
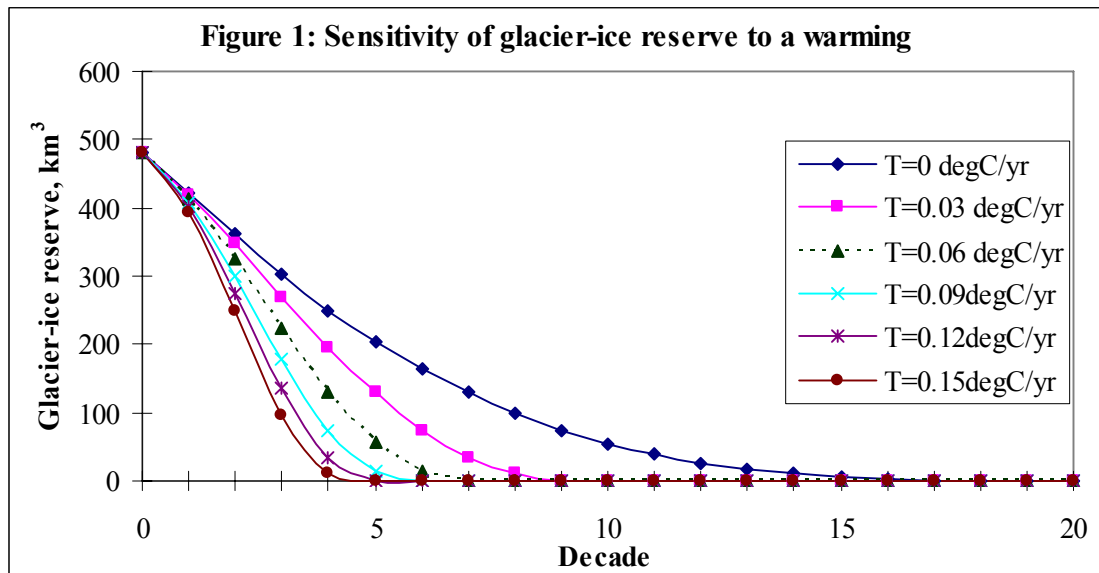
Source : Chaulagain, 2007

The projected disappearance of the glaciers in the Nepal Himalayas will undoubtedly reduce the contribution of glacier-melt water to the total water availability. Currently, glacier-melt water alone contributes to about 4% of total annual surface runoff of Nepal (Chaulagain, 2007) whether snow-melt contribution is about 10% of Nepal's annual surface runoff (MOPE, 2004). Higher rate of warming may result in the higher contribution of glacier-melt water only in the case of unlimited ice reserve in the glaciers. Otherwise, the glacier-melt contribution might be substantially reduced

even with a warming because there will be fewer glaciers left in the Himalayas to melt (Figure 2).

Figure 2: Sensitivity of glacier-melt water to a warming
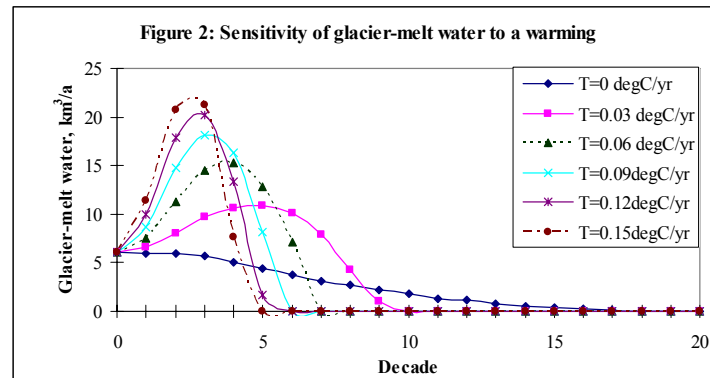
Source : Chaulagain, 2007

Total water availability depends not only on the glacier-melt contribution, but also on the evapotranspiration losses. Increasing temperatures may further reduce the total water availability even after the glacier-disappearances because of a possible increase in evapotranspiration associated with the rising temperatures. As calculated by Chaulagain (2007), the total water availability in Nepal will decrease by 2.4% in 2100 even without any further warming from the level of 2001. If there will be a warming rate of 0.06°C per year, the total water availability may decrease by 15% in 2100 and by 27% in 2200 from the level in 2001. A greater rate of warming might cause an accelerated decrease in the total water availability. For example, if there will be a warming rate of 0.12°C per year, the total water availability in Nepal may decrease by 27% in 2100 and by 51% in 2200.

IMPACTS ON THE HYDROPOWER POTENTIAL

Nepal's current theoretical hydropower potential is 83 GW (Shrestha, 1985) including the runoff collected even outside Nepal's territory. Assuming the theoretical hydropower potential in proportion to the basin area, Nepal's hydropower potential excluding the runoff outside Nepal can be taken as 63 GW (i.e. 76% of the total hydropower potential). Using the long-term average runoff data observed by the Department of Hydrology and Meteorology of Nepal and the snow and glacier melt rate, Chaulagain (2007) has calculated an all-Nepal average monthly hydrograph as given in Table 1.

Table 1 : All-Nepal Average Monthly and Annual Hydrograph

Months	Rain-water, km³	Melt-water , km³			Total, km³	Melt-water,%
		Snow	Glacier	Subtotal		
January	3.40	0.75	0.05	0.8	4.20	19.0
February	2.83	0.78	0.05	0.83	3.66	22.7
March	2.49	1.07	0.08	1.15	3.64	31.6
April	2.56	1.12	0.10	1.22	3.78	32.3
May	3.67	1.36	0.39	1.75	5.42	32.3
June	10.88	2.18	1.17	3.35	14.23	23.5
July	32.63	2.60	1.62	4.22	36.85	11.5
August	37.96	3.69	1.55	5.24	43.20	12.1
September	31.05	2.31	0.93	3.24	34.29	9.4
October	13.20	0.65	0.11	0.76	13.96	5.4
November	6.18	0.35	0.02	0.37	6.55	5.6
December	4.18	0.16	0.01	0.17	4.35	3.9
Annual	153.00	17.00	6.08	23.08	176.08	13.1

Source : Chaulagain, 2007

The annual and the monthly hydrographs of Nepal are generally influenced by monsoon rain. There is a significant contribution of melt-water during the dry season (March-May). Most of Nepal's hydropower plants are run-of-river type, which are designed for the dry season flows (i.e. minimum flows). Although the melt-water contribution to the annual average flow of Nepal is only about 13%, it is relatively higher during dry season, up to 32% during dry March-May (Chaulagain, 2007). Chaulagain (2007) has indicated that hydropower potential of Nepal initially increases with a temperature increase due to increased glacier-melt. However, further warming might add no more hydropower potential rather might reduce it at later stages due to reduced glacier-ice reserves. The glaciers in the Nepal Himalayas have been retreating so fast in recent decades that there will be about 6% decrease in hydropower potential at the end of this century without any further warming. In case of a warming of 0.06°C per year, the theoretical hydropower potential of Nepal will rise by 5.7% by 2030 but will decrease by 28% by the end of this century (Chaulagain, 2007).

When the glaciers disappear as a result of warming, the current glacier-fed rivers may be converted into rain-fed rivers. Glacier-fed and rain-fed rivers in Nepal have a visible difference in the monthly hydrographs. The hydrograph of rain-fed rivers might have more pronounced peak during summer monsoon than that of glacier-fed ones. Snow and glacier-fed rivers accumulate water as a snow during rainy season and discharge them during dry season. Snow-melt contribution to the dry season flow of these rivers acts as a "back-up battery" which is charged during rainy season and discharged during dry seasons. Therefore, snow-fed rivers have less pronounced peaks compared to the rain-fed rivers, which has been compared by Chaulagain (2007) taking average specific monthly runoff of glacier-fed Langtang River and rain-fed Bagmati River in the central part of Nepal (see Figure 3). Possible warming might reduce the storage of these glacier-fed rivers, might result in reduced non-monsoon flows and increased risks of floods during monsoon season (Chaulagain, 2005).

Figure 3: Comparative mean monthly hydrographs
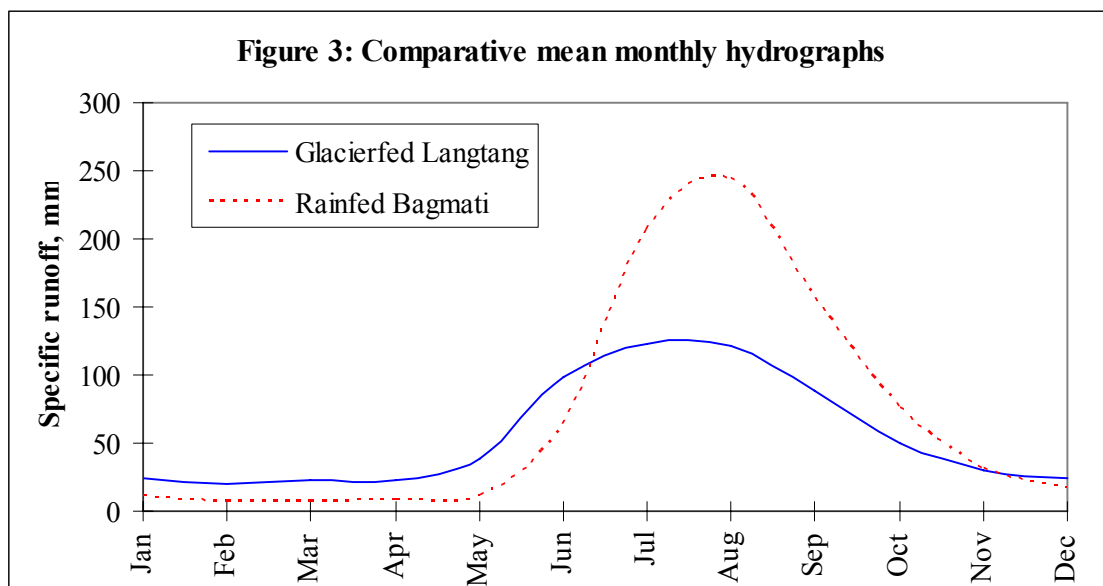
Source : Chaulagain, 2007

Because of monsoon dominated climate, Nepal's rivers have an unbalanced distribution of annual runoff among the seasons. Around 80% of annual runoff occurs during 3-4 summer monsoon months. The expected climate change along with increased temperature may worsen the situation.

Stream-flow in most of the rivers in Nepal is at a minimum in early spring because flows recede rapidly after the summer rains. This period of minimum flow is problematic for the run-of-river hydroelectric facilities (Kattelmann, 1993). Snow-fed rivers provide sustained flow even during this

critical period through the melt-water contribution. Agarawala *et al.* (2003) have also reported that a possible decrease in river runoff, as indicated by most projections, would reduce not only the electricity generation of existing plants but also the total hydropower potential of Nepal. In addition, there might be significant declines in the dry season flows and an increasing trend in the number of flooding days because of climate change, which is critical for hydropower generation (Agrawala *et al.,* 2003). The flows of glacier-fed rivers first increase due to warming, as more water is released by the melting of snow and glaciers. As the glaciers get smaller and the volume of melt-water reduces, the dry season flows will no longer be supported by melt-water and eventually will decline (Shrestha, 2005). Therefore, the reduced dry season flow caused by a temperature rise could result in reduced hydropower potential.

The hydropower potential will be affected not only by the increased seasonal variability but also by the decreased water availability due to climate change. The current hypothetical value of the total hydroelectricity potential in Nepal excluding the runoff collected outside the country is equivalent to about 15,000 billion US $ per year using a current energy charge of 0.047 US $/kWh (i.e. NRs 3.5 per kWh) of the Nepal Electricity Authority for wholesale consumers (NEA, 2003). The monetary value of the annual hydroelectricity potential would rise to about 16,200 billion US $ in 2030 and would decrease to about 7,200 billion US $ in 2200, if the temperature rises by 0.09°C per year. The glaciers in the Nepal Himalayas are already melting so rapidly that there will be no more glaciers left in 2180 even without any further warming. The equivalent annual hydroelectricity potential in Nepal in 2200 would decrease to 13,800 billion US $ even without any further temperature rise and to 8,600 billion US $, if the temperature rises by 0.06°C per year. Unfortunately, this potential cannot be trapped without appropriate infrastructures, functioning energy markets and the sustainable development of water resources.

IMPACTS ON THE EXTREME EVENTS

Rising temperature that causes retreat of mountain glaciers is one of the main factors responsible for the formation and expansion of glacier lakes (Mool et al., 2001). Almost all glaciers in the Himalayas have been retreating since the Little Ice Age (1400-1650 AD) and on average they have retreated about 1 km since then (ibid). Such a retreat has provided a large space for retaining melt water that has led to the formation of glacier lakes. A rising water level in these lakes makes them vulnerable to collapse. The collapse of such lakes may result in the instantaneous release of the stored lake water that may create devastating floods. Such floods are termed as Glacier Lake Outburst Floods (GLOFs).

Chaulagain (2007) has carried out a sensitivity analysis of glacier-melt and rainwater to temperature rises and revealed that the formation and growth of glacier lakes in the Nepal Himalayas will be most significant during the next three to five decades. The formation and growth of glacier lakes will continue, though at a slower speed, even after the annual volume of liquid water stops increasing because cumulative volumes of these lakes generally continue to increase. The growth of lakes and subsequent rise in water levels will generally increase the risks of the GLOFs. Increasing temperatures would accelerate the glacier melt on the one hand and increase the proportion of rain-to-snow on the other, which could result in the formation and expansion of glacier lakes in the mountain valleys. The supporting dams of these lakes generally consist of loose moraines, which are not strong enough to resist the growing hydrostatic pressure on them caused by rising water level in the lakes. An increasing volume of liquid precipitation (i.e. rainwater) and accelerated melting of glaciers are the main causes for the rising water level in glacier lakes in the Nepal Himalayas. Both of these events jointly may create an additional volume of liquid water in the high mountain valleys. The GLOFs are the new threats of climate change in the Nepal Himalayas (Horstmann, 2004). Empirical and model studies suggest that there will be more new glacier lakes and existing glacier lakes will grow rapidly in the Nepal Himalayas in the future because of climate change. Historical records of past GLOFs suggest that the frequency of these events appears to be increasing (Agrawala *et al.,* 2003).

Chaulagain (2007) has reported that there is an inverse relationship between the ratio of maximum to minimum instantaneous flows and the snow-covered areas (see Figure 4). As a result of warming, the snow and glacier areas are expected to be reduced. Decreased snow-covered area, as shown in the Figure 4, might increase the ratio of maximum-to-minimum flows exponentially, which indicates that there might be decreased minimum flows as well as increased maximum flows as the snow-covered areas shrink.

Figure 4: Snow-covered area and extreme floods in Nepal

$$y = 1796.85x^{-0.90}$$
$$R^2 = 0.74$$
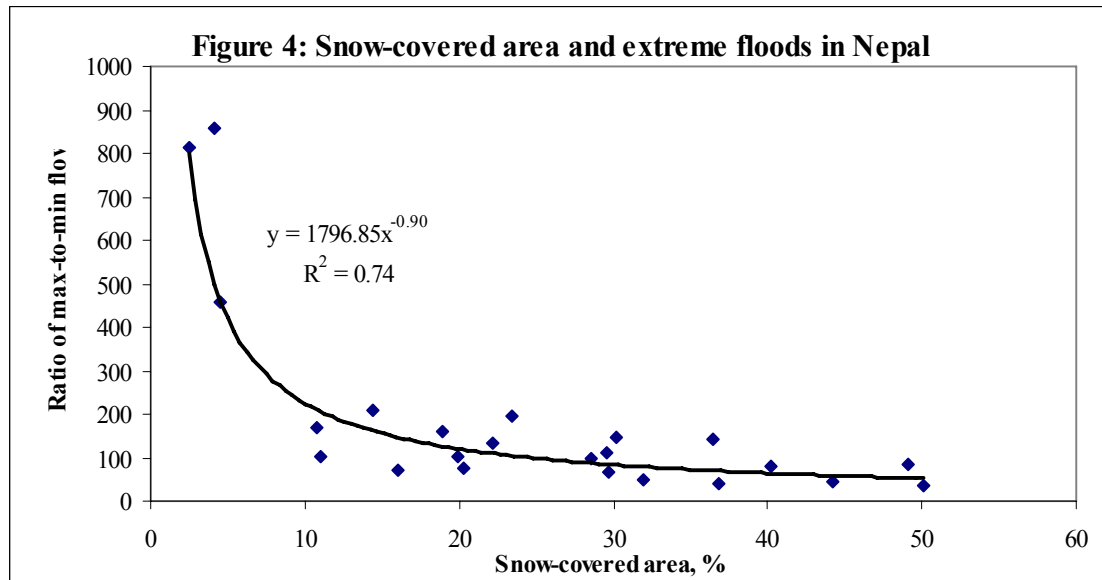
Source : Chaulagain, 2006

The permanent snowline in Nepal Himalayas lies close to 5000 m elevation (MOPE, 2004). About 43% of the total area in Nepal lies above 3000 masl (CBS, 2004), where a significant amount of precipitation currently occurs as snowfall. A decrease in the snow-to-rain ratio due to warming may have a substantial effect on the river runoff not only in the high mountain areas but also in the plains downstream. An increase in rainfall due to a decrease in snow-to-rain ratio, even without any change in total precipitation will ultimately increase the likelihoods of landslides and floods.

Climate change will lead to increased climatic variability, which would lead to increased frequency and magnitude of weather-related extreme events (Becker and Bugmann, 1997). Because the melting season of snow coincides with the summer monsoon season, any intensification of the monsoon or any further warming is likely to contribute to flood disasters in the Himalayan catchments (IPCC, 2001). An extreme climatic event will result in higher losses of life in a developing country than in a developed country because of a different adaptive capacity (IPCC, 2001). An extreme climatic event combined with the socio-political characteristics of the region can become a social catastrophe in the developing countries (ibid). In Nepal, the normal daily life of a large section of the population is already not so different from the living conditions of those hit by a disaster (Dixit, 2003). Climate change brings additional threats to the livelihoods of these people (McGuigan et al, 2002).

CONCLUSION

Increasing temperatures would accelerate the glacier melt in the Nepal Himalayas, which has direct impacts on water resources of Nepal including hydropower potential and water induced extreme events, particularly, floods. Hydropower is considered as one of the most important vehicles of Nepal's social and economic development. But, the hydropower sector of Nepal is one of the most vulnerable sectors to climate change. There are very limited studies done so far to quantify the

impacts of climate change on hydropower potential of Nepal. Conventional approach of designing a hydropower plant, which mainly analyses the past flow records and generally does not consider the glacier-melt contribution and glacier ice-reserve inside the basin, may not be adequate to address the issue of climate change in the development of hydropower. As the preliminary results show, the dry season flows in the snow-fed rivers in Nepal are increasing because of the increasing temperatures, which may continue for some decades to come. Unfortunately, the dry season flows in these rivers start decreasing as the glaciers, which are currently supplying water will disappear. Therefore, there is a need of critical review and open discussion on how to make the best use of hydropower for Nepal's benefit. The developers as well as civil societies and government officials should be aware of the fact that Nepal may not have the same hydropower potential after 50 years from now because of the rapid melting of glacier-ice and decreasing amount of snowfall as a result of global warming.

Increasing temperature will accelerate the glacier-melt and increase the proportion of liquid precipitation, which may create favourable conditions for the formation and growth of glaciers lakes in the mountain valleys of Nepal. Being supported by loose moraine dams, any increase in water levels in these lakes may result in the increased likelihoods GLOFs. Besides, increased temperatures may result in decreased the seasonal storage of water from monsoon to non-monsoon seasons because a large portion of liquid precipitation (i.e. rainwater) immediately flows out from the area of its occurrence unless is artificially stored.

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Seasonal snow modeling in Tien Shan mountains, Central Asia: role of stratigraphy and metamorphism

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ABSTRACT

A model of snow cover has been developed and tested against data observed at several experimental sites. The model includes layer-by-layer snow accumulation, metamorphism of snow crystals, snow densening and/or loosening, evaporation and melting, changes in albedo and liquid water holding capacity. The snow cover model is combined with a model of heat/water transfer between soil, vegetation and atmosphere. The model complex reproduces full cycle of heat and water transformations at the land surface with a time step of several hours. The model has been tested against data obtained at several sites in mountains of Eurasia, specifically western Tien Shan in Uzbekistan. Comparison with a single-layer snow model shows that inclusion of the multi-layer structure allows significant improvement of the model quality. Uncertainties of calculations resulting from meteorological parameters, snow properties, as well as vegetation and soil features, can lead to significant scatter of evaluated variables.

Key words : Snow cover, numerical modeling, snow metamorphism, Central Asia

INTRODUCTION

Numerical modeling of the snow cover is a comprehensive tool for evaluation of the snow water equivalent (SWE) and other characteristics important for hydrological applications and climatological studies. SWE is the most important hydrological characteristic of the snow cover, because it provides the information on the amount of water stored in the snow cover. New-generation snow cover models which profit from the progress in knowledge and technological development (data acquisition, computing) are developed permanently. Current models of snow cover evolution strive to simulate also some internal properties of the snowpack such as snow stratighraphy, temperature distribution in the snowpack, mass and energy fluxes, etc. (Essery et al., 1999, Lehning et al., 1999).

Although some snowpack models are rather sophisticated and allow explicit description of processes on crystal or even molecular scale, they usually require tremendous computer resources and detailed information about physical properties of the snow layers. An alternative approach (the so-called index models or day-degree schemes) usually oversimplify the processes in the snow cover and can be used for a limited class of application. Intermediate options, with explicit description of main physical processes in snow, but using large-scale parameters only (such as snow temperature, humidity, type of crystals, etc.), and few empirical relationships, could be an optimal way for a wide spectrum of tasks. A model of this class has been developed and tested at the Laboratory of Climatology, Institute of Geography, Russian Academy of Sciences. In this study, the model is tested against the data observed at Dukant avalanche station in Western Tien Shan (Uzbekistan).

MODEL

The SPONSOR model (Shmakin, 1998) is the updated land surface model using the multi-layer snow scheme that includes physical properties of each layer. The density of each snow layer is taken into account during its evolution. After the snowfall a new snow layer appears. Its physical properties change according to meteorological conditions and previous evolution of the snow layers according to certain criteria (Kominami et al., 1998; Pomeroy et al., 1998; Golubev, personal communication; and others). Snow layers are united once their properties are close enough.

Among the main physical processes in the snow, included in the model, the following should be mentioned:

- fresh snow accumulation;
- viscous densening of dry snow;
- densening due to wind;
- heat fluxes and change of snow temperature;
- shortwave radiation transfer and transformation;
- melting, liquid water transfer, its re-freezing;
- change of main types of snow crystals, such as small grains, large grains, depth hoar, etc. (totally there are 10 types of the snow crystals).

The snow cover model is combined with numerical model of heat/water exchange on land. The latter one provides all energy/water fluxes at the top of snow cover (precipitation, evaporation, etc.), using meteorological variables, and describes thermohydrophysical interaction between snow cover and soil. Influence of vegetation is taken into account too. The land surface model describes all components of the heat and water budget on land, as well as the parameters of the soil-snow-vegetation system (such as temperature profile, liquid and solid water content in the soil, albedo, etc.). The model should provided with meteorological variables (air temperature, precipitation, wind velocity, radiation fluxes, etc.) at each time step, which should not be larger than 6 hours. Also, several parameters of the soil and vegetation, as well as relief features and other landscape parameters, must be provided. Deep ground temperature and water table depth should be specified as external conditions.

EXPERIMENTAL SITE

Dukant avalanche station (41°09′ N, 70°04′ E, 2000 m a.s.l.) is located on a horizontal ridge, protruding to the east from Chatkal Range (Western Tien Shan, Uzbekistan). The observations, including regular meteorological and snow pit measurements, are carried out for the avalanche service of Uzbekistan and for hydrological applications. We had time series from 1988 until 1991 at our disposal. The solar and infrared radiation fluxes were calculated using the data on cloudiness and view factor according to the radiation model [Shmakin, 1998]. The soil consists of gray soils, with gravels underlying it, and vegetation is short grassland. The climate conditions at Dukant are characterized by rather mild winters with a lot of precipitation, especially in the second half of the cold season. The snow pit data included measurements of snow temperature, type of crystals, location of layers, density and depth of each layer. The snow pit data were collected several times during winter (usually 5-7 times).

RESULTS

The results of model calculation and observed values of SWE at Dukant are shown in Fig. 1. There were several numerical experiments carried out, setting different values of key parameters. The parameters such as threshold air temperature determining type of precipitation (snowfall or rainfall), albedo of fresh and melting snow, etc. cannot be specified with absolute accuracy. At any conditions, unless all of the parameters were observed directly (which is unrealistic situation), there is some uncertainty for a number of them. Especially uncertain are parameters which can have different values depending on specific weather conditions during a season (for example, those threshold air temperature and snow albedo). So, in fact one has to deal with not a single set of parameter values, but with a range of uncertainty for each parameters, and with a range of solutions for the entire set of the uncertainty ranges. Thus, we can consider the results good if the observed points fall within this "unavoidable uncertainty range".

As one can see from Fig. 1, in general the quality of the modeled results is rather satisfactory, as in most cases the observed points fall between the modeled curves.
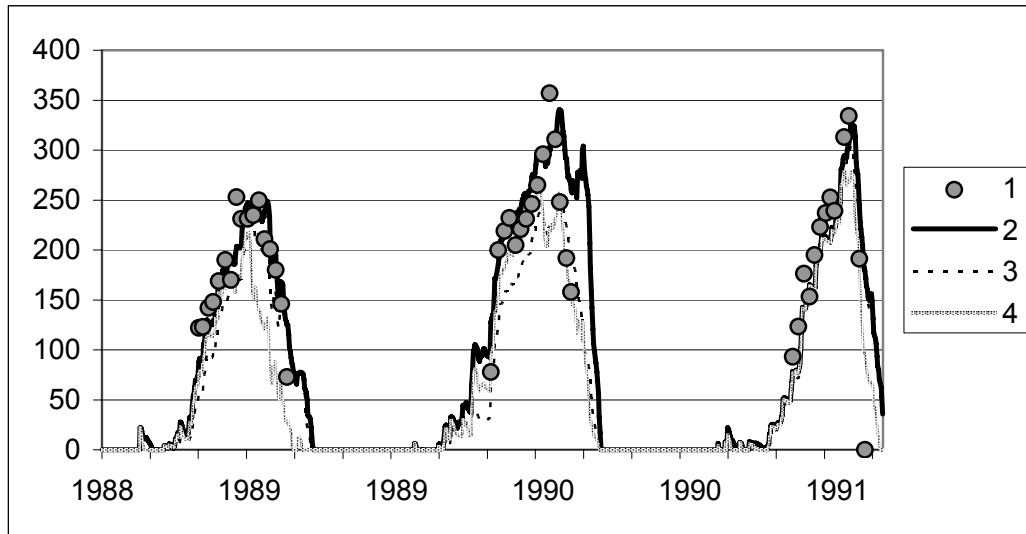
Fig. 1 : Snow water equivalent (kg/sq.m) at Dukant in 1988-91 according to measurements (1), modeling with snowfall/rainfall threshold air temperature 1.5°C, fresh snow albedo 0.9, melting snow albedo 0.55 (2), threshold air temperature 0°C, albedo 0.9 and 0.55 (3), threshold air temperature 1°C, fresh snow albedo 0.8, melting snow albedo 0.4 (4).

Unfortunately, due to specific regime of the avalanche station, the observations are not so often during the snowmelt period, as well as at the time of snow disappearance. It can be noted that difference between the curves becomes significant near the middle of the snow season, when heavy snowfalls take place in the region. The differences between the curves do not disappear completely until the very end of the snow season, unlike in other climatic conditions (for example, in dry continental climate of North Canada which we tested too). Thus, for Dukant the computed time of snow disappearance, as well as speed of the snowmelt and total snow mass, are rather sensitive to the values of model parameters. Probably, the same can be concluded about the other mountainous regions of Central Asia and Hindu Kush – Himalayan region, where heavy snowfalls and mild weather during winter are typical.

Contrasts between different experiments are rather logical: if the threshold air temperature rises, more precipitation falls as snow, and its accumulation increases. The same effect can be seen for albedo: with its rise, the melting occurs less often, and one gets more snow. It should be noted that in winter 1990-91, the model sensitivity to the mentioned parameters was relatively low as compared to other years. This fact can be explained by the prevalence of cloudy weather, which resulted in quite low role of albedo variations, and relatively low air temperature (it fell in the critical range 0-1.5°C rather seldom during that season).

CONCLUSIONS

A numerical model of snow cover has been developed, which considers the snow seasonal metamorphism and layered structure. The snow model is combined with energy/water land surface model SPONSOR, earlier developed at the Institute of Geography, RAS. The model is quite low-consuming in terms of computer resources. It has demonstrated its ability to reproduce seasonal evolution of the snow water equivalent in the mild climate conditions with heavy snowfalls typical for Western Tien Shan and other mountains of the Central Asia. Probably, it will be suitable also for other mountain massifs of Hindu Kush – Himalayan region. The model evaluates the snow cover characteristics successfully under considerable interannual variability of the weather conditions. Unavoidable uncertainty of a number of model parameters results in the

results scatter, with the latter being different depending on specific conditions of a certain location. In general, in snowy climates, the sensitivity to the model parameters is quite large, and at any circumstances it is maximal in the middle of winter, somewhat decreasing during the snowmelt season.

Next stages of the model improvement can include developing of new procedures for certain specific situations to evaluate the snow density, its seasonal albedo dynamics, description of evaporation and condensation. Future testing of the model will include experiments on temperature regime of the snow pack and soil under the snow, as well as role of different vegetation types, including those in the forests. Ability of the model to reproduce the vertical structure of the snow pack (its crystal types) will be also checked. To this end, a database of observed detailed snow pits is under creation at IG RAS.

ACKNOWLEDGEMENTS

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Introduce the watershed management for conservation of watershed with emphasis on soil and water.

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ABSTRACT

For unify of necessity and desires in different part of developmental and economical of country with opinion of conservation of water and soil and another Natural resources, and based on in scientific and experimental basis, from second mid century (20) e new idiom in modern countries are current reputed and famous to "watershed management" that today is to be income the science and technique.

The strategies of watershed management are permanent on three axis, "reparation and reconstruction, Keeping and prevention, extension and exploitation"

In as much as all of axis of activities and obtain result's of those are resulting from water, and then managing of this resource with emphasis to climatic conditions must to be special sensitiveness.

Water as an important elements in sustainable development countries, has a main and serious role and influence human existing.

Watershed management with different practices (mechanical, biological, biomechanical and managing) makes positive effective in conservation of water, water resources management and etc.

In this article wants to introduce this new knowledge and particular this science and necessary spacious in water management and the suitable method for prevention of water disaster.

Key words : water_ watershed management_ Basin managements- water and soil conservation.

INTRODUCTION

Soil erosion and demolition of watersheds are economical and social complexities for developing countries. Especially for them which have breakable and sensitive alpine and nomadic ecosystem. This phenomenon is mostly arising of apparent facing of establishing functions with protection of natural resources and environment. One can reduce apparent facing such this with executing comprehensive planning and creation of proper environmental and protect ional principles for soil and water resources.

With due consideration to a great deal of economic and social losses arising of soil erosion and unnatural ruining floods which caused by watershed destroying that affect on agriculture, infrastructures, electricity networks, communications, settlements, natural resources etc. it is clear that if we want using large amount of government investing capital in these fields end to long duration development and stability of economy, we should "extend soil and watershed protection" plans as functional activities beyond to stable development.

Nowadays, basically, watershed is a hydrologic unit that has accepted as physical, biological, political, economical and social unit for planning and management of all existing resources in nature.

Watershed management is an integrated and regular management for natural resources, agriculture, and social-economic condition of a watershed provided that well protection of soil and water resources without negative course.

From a planning point of view, watershed management is one of the more new and most accepted methods in planning that performs base on systematic perception and systematic and evolutional planning. One of characteristics of this management is final and comprehensive observation to environment and watershed.

APPLIED CHARACTERISTICS OF WATERSHED MANAGEMENT IN SOLVING OF PROBLEMS

This method perhaps is known as appropriate solution in different sectors such as water, agriculture and natural resources for remedy difficulties of the category of flood, sediment, reducing of underground water resources, forest and range degradation and reduction of rain fed lands efficiency. Hereunder is mentioned some of specialties of watershed management programs:

2-1 The watershed management programs have the prevention aspect and radical solving viewpoint of problems. It does not have sectional facing and challenging case by the functions, but it is permanent.

2-2- The watershed management programs have generalization ability and fast execution at all around the country.

2-3- The watershed management programs are multidimensional and multipurpose; because:

2-3-1 Type of its program is popular. It attracts partnership and acceptance of residents in watershed area at the most and comprises facing and social difficulty at least.

2-3-2- It is cheap and economical.

2-3-3- It has simple technique.

PRINCIPLES OF THE INTEGRATED WATERSHED MANAGEMENT

1. Promotion of effective collaboration as well as balanced and adequate planning and management for sustainable utilization of soil, water and other resources.
2. Improvement and conservation of water quality for agricultural, municipal, industrial, and recreational user.
3. Controlling of the current trend in land degradation and reversing of soil degradation to improve soil resources where possible in order to make sustainable resource utilization possible.
4. Conservation of environmental resources in catchment's areas and protection of sensitive ecosystems.
5. Achieving effective cooperation in watershed management by the authorities and the private sector within the framework of the general guidelines and policies adopted in the integrated management plan.
6. Identification of degraded natural resources, their improvement as far as possible, and assisting in their reclamation through improver land management and watershed management.
7. Ensuring sustainability and productivity of land resources in each catchment's through water resources development, water quality conservation, and improving upon the productive vegetation cover in each catchments.
8. Ensuring that in each catchment's land is used on the basis of its capacity according to sustainable utilization principles so that natural potentials are preserved for future generation.
9. Developing long-term objectives and defining operational polices for the management of catchments areas; and

10. Ensuring the attainment of the objection of integrated watershed management through coordinated efforts by local organizations and through public participation within the framework of the plans adopted.

GOALS AND OBJECTIVES

The WMD states at WM are a comprehensive, legislative and coordinated management and utilization of agricultural, socio- economic and environmental resources through the following objectives:

1. Maximizing productivity

2. Improving income generation

3. Creating employment

4. Achieving above three objectives by means of optimum utilization of natural resources are incurred.

These objectives are achieved through a series of sub-objectives as follows:

1. Erosion control: the control of rill, and gully erosion in farming and rangelands (the increasing productivity/unit area), roadsides, and rivers

2. Sediment control: increasing the useful life of reservoirs, irrigation channels, reducing floods and environmental damages.

3. ater quality and quantity improvements: increasing the availability of water and decreasing hydrologic and agricultural drought and decreasing the salinity lever.

4. Land quality improvements: emphasizing on the mitigation of desertification on productive lands.

5. Preservation of biodiversity; including preservation of plant spices, and oxygen in water to increase aquatic productivity

6. Ecotourism development.

7. Reduction of rural- urban migration (WMD).

The WMD strives to achieve these goals and objectives through implantation of Wm interventions divided into four categories

CONCLUSION AND RECOMMENDATION

Attention to watershed districts as natural units of land logistics, meantime take account conditions of basins and adjacent effective factors.

• To make operational the purposes and relevant achievements with long time development of country water resources in direction of watershed districts management as a perspective for national document of country developing.

• Comprising structural and nonstructural management in directional processes of watershed districts for strengthening comprehensive view in integrate and stable management of land.

• Going out of crisis management and coming in hazard acceptance management for remove backwardness appearances and lack of planning due to crisis management, and more adaptation with stable development realities.

• A comprehensive outlook to water resources development, farther up of physical and natural environmental confined in frame of national strategy for economical, social, cultural and political development.

- Attention to accidents and profits of project from the beginning to end of designing and revenue duration in direction of minimum making injure to environment for national development.

- Attention to reduction of pollution and necessity of water resources protection of pollution damages by different manners such as decreasing pollution level.

- Comparison with difficulties opposite to water resources meanwhile adopting appropriate achievements and policies for protection of basic resources and remedying production insufficiencies, possibility of access to stable development, food security and applying suitable management methods while executing developmental complementary designs for water resources.

- Comprehensive management of watershed districts regards to land logistics outlooks and stable development principles.

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Regional Flood Frequency Modeling for Predictions in Ungauged Basins

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ABSTRACT

Extreme environmental events such as floods cause a lot of damage to life and property of human society. A reliable estimation of magnitude and frequency of occurrence of such extreme events is of great significance in minimizing damages by facilitating proper planning and design of civil engineering structures.

The problem of estimating flood frequency at an ungauged catchment has often been approached through regionalization techniques. In the present study, the Index flood procedure is used for regional flood frequency modeling of Upper Krishna Basin. Annual flood series of 8 to 41 years or so of 38 sites in the basin have been used for the study. Different delineation options are considered and the homogeneity has been verified using USGS homogeneity test. For each option the percentage absolute error in flood estimation using regional parameter is compared with flood estimation using at site parameters for two test sites. The results are further validated through 10 more validation sites, and an attempt is made to check the effect of sample size on accuracy of flood predictions.

Key words : Regionalization, Homogeneity, Return period, Index flood, Mean Annual Flood

INTRODUCTION

Information on flood magnitudes and their frequencies is needed for design of hydraulic structures such as dams, spillways, road and railway bridges, culverts, urban drainage system and flood plain zoning etc. A complicating factor is that the return periods of interest, from design point of view, often exceed the length of data recorded at the site. Inadequate hydrological data introduces uncertainty in both the design and management of water resources system. In India, practicing engineers in the field of hydrology are facing the problem of inadequate information about the quantity and quality of water resources data that arises from poorly developed hydrological networks.

To overcome this constraint, flood formulas are developed for different hydro meteorological zones of India. But these conventional flood formulas developed are empirical in nature and do not provide estimates of desired return period.

Obtaining an accurate estimation of the relationship between extreme flows and the associated return period is more complicated in ungauged catchments where there is no record at all. Therefore, there is a need of hydrologic modeling for predicting flow characteristics at ungauged sites.

There are two basic approaches for determination of designed peak flood, namely, deterministic and probabilistic approach. The probabilistic approach is based on flood frequency analysis of past flood records and require lesser data as compared to the deterministic approach. In flood frequency modeling the sample data (usually annual maximum series) is used to fit frequency distributions, which are used to extrapolate from record events to design events. Although number of frequency distribution methods viz. EV-1, GEV, P-III, LN-III, GL, wakeby etc. are popular and widely used in

flood frequency modeling, in the present study the Index flood procedure given by Dalrymple (1960) is used to develop flood frequency formula for ungauged catchments in upper Krishna Basin after regionalization.

HYDROLOGICAL REGIONALIZATION AND REGIONAL FLOOD FREQUENCY ANALYSIS

The estimation of flow characteristics of ungauged catchments is usually based on transferring or extrapolating information from gauged to ungauged sites, a process called regionalization. Information from additional sites can compensate for the inadequate temporal characterization of extreme flows through the use of regional flood frequency analysis.

An important component of regional flood frequency analysis is the identification of the region that is used to effect the spatial transfer of information. A region, in this context, means a group of catchments that can be considered to be similar in terms of hydrological response.

According to Wiltshire (1986), hydrologic regionalization, the classification of gauged watersheds into regions according to preset criteria, provides a way to extend information from gauged watersheds to ungauged ones. The preset criteria are generally based on stream flow or watershed and climate variables.

Lattenmair et al. (1987) studied the effect of regional heterogeneity and intersite dependence in regional flood frequency analysis. They suggested that if a regionalization scheme is successful, strong relationship between stream flow properties and watershed variables can be realized. These relationships can be utilized to develop useful stream flow information at ungauged watersheds.

The importance of regional homogeneity for flood frequency analysis has been demonstrated by, among others, Hosking et al. (1988), Hosking et al. (1990), Cunnane (1988), Burn (1988), Burn et al. (1997), Chaing Shih-Min et al. (2002), and particularly in Indian context by Seth et al. (1995), Seth et al. (1997), and Kumar et al. (1999).

Thus, the goal of the regionalization process can thus be viewed as the identification of grouping of catchments, called regions that are sufficiently similar to warrant the combination and transfer of extreme flow information between sites within the region.

DESCRIPTION OF STUDY AREA

The Krishna basin for which sufficient annual peak flood series at number of gauging station were available is selected as the study area. The total catchment area of the basin considered for the analysis is 90,000 sq. km and is located between longitude of 73^0 E to 78^0 E and latitude of 15^0 N to 19^0 North. It comprises the part of Maharashtra and Karnataka states. The figure 1 shows the river system and gauging stations with all its tributaries of river Krishna. The drainage area of these gauging sites varies from 540 km^2 to 69,863 km^2. The main tributaries of river Krishna are river Bhima, Koyna, Panchganga, Malprabha and Ghatprabha.

Figur 1 : Location Map of Study Area

LOCATION MAP OF STUDY AREA
UPPER KRISHNA BASIN EXCEPT TUNGABHADRA & PENNAR
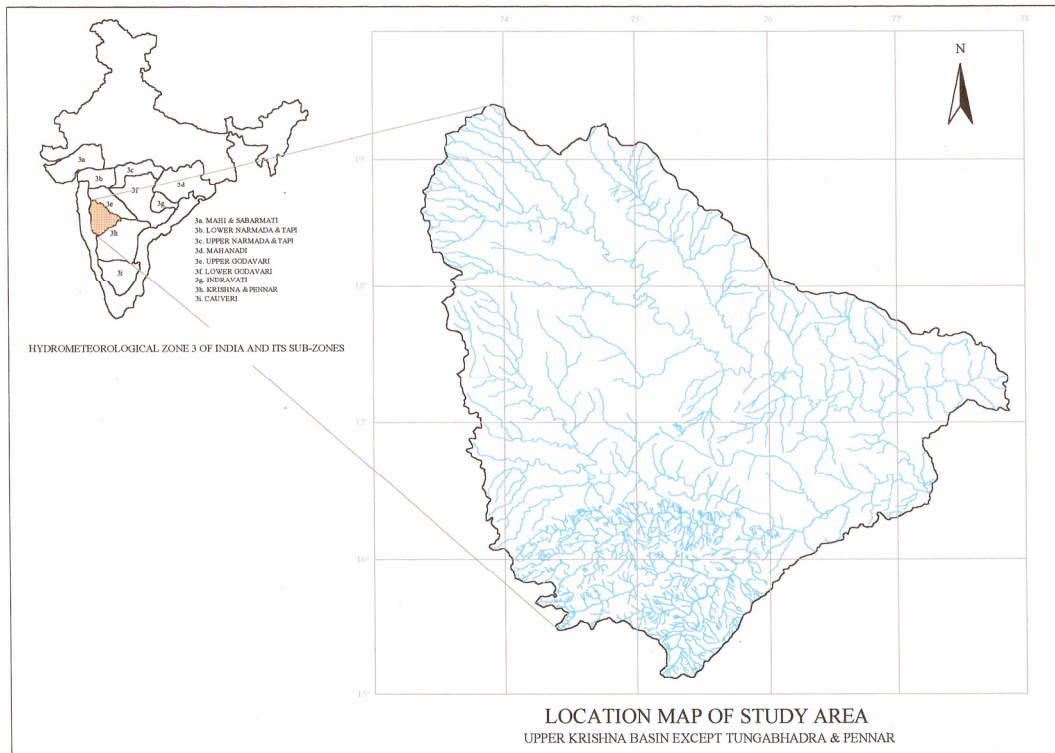
Data availability for Study Area

Table 1 : Data Availability for Study Area

Data supplying agency	Number of RG sites	Data availability period	Length of Data available (Years)	Catchment area Range (sqkm)
Central Water Commission (CWC) KG Basin Org. Hyderabad	24	1969-2004	25-41	630-69,863
Hydrological Data Users Group (HDUG) CDO, Nasik	14	1982-2004	08-26	26.43-1940.34

METHODOLOGY

1. The preliminary statistical analysis is carried out to determine the at site average annual flood, standard deviation, coefficient of variation, coefficient of skewness and coefficient of kurtosis and presence of either a high or low outlier.

2. The at site flood frequency curves are developed using Gumbel EV-1 distribution method.

3. The USGS homogeneity test proposed by Dalrymple (1960) has been used for testing the homogeneity of data in a region considering the entire catchment as a whole and for all possible delineation options.

4. The regional flood frequency analysis is carried out using Index Flood Procedure; and also the growth factors are determined for a range of desired return period.

5. The relationship between Mean Annual Flood and Catchment Area is obtained by linear regression using least square method.

6. A regional flood formula is derived and validated for two test sites which are considered as ungauged and not used in the derivation of regional flood frequency analysis.

7. The results obtained are tested for 10 more validation sites and an attempt is made to study the effect of increasing the number of sites on the prediction accuracy.

USGS HOMOGENEITY TEST

The USGS homogeneity test proposed by Dalrymple (1960) has been widely used for testing the homogeneity of data in a region. The steps involved in USGS homogeneity test are-

1. Compute the EV-I reduced variate corresponding to 10 year return period flood.

    $Y_T = (-\ln(-\ln(1-1/T))$

2. Compute the 10 year flood putting $Y_{10} = 2.25$ in the developed at site flood frequency formula. Thus;

    $X_{10} = u + \propto Y_{10}$

    $X_{10} = u + 2.25 \propto$

3. Repeat above two steps to compute 2.33 year flood, which is the annual mean flood for EV-I distribution for different catchments.

4. Compute the ratio of 10 year flood to annual mean flood at each gauging site. The ratio is known as the 10-year frequency ratio.

5. Average the 10 year frequency ratios of all the gauging sites to obtain the mean 10 year frequency ratio.

6. Determine the EV-I reduced variate corresponding to the products of annual mean flood and the average 10 year frequency ratio from the flood frequency curve developed for each catchment. Thus;

    $Y_T = (X_T - u) \propto$

7. Plot the EV-I reduced variate obtained in step (6) against the length of record on a test graph where upper and lower regional limits of 95% confidence are already plotted using the following coordinates.

Sr. No.	Sample size (n)	Lower limit	Upper limit
1	5	-0.59	5.09
2	10	0.25	4.25
3	20	0.83	3.67
4	50	1.35	3.15
5	100	1.52	2.88
6	200	1.80	2.70
7	500	1.97	2.53
8	1000	2.05	2.45

If the plotted points for all stations under consideration falls within the upper and lower regional confidence limit developed by USGS then the data are regionally homogeneous and applicable for analysis. Any station for which the plotted points lie outside the envelope curve is to be excluded from homogeneous region and hence from the analysis.

INDEX FLOOD METHOD

One common form of regional flood frequency procedure is based on dividing annual flood maxima by the mean annual flood, $Q_{2.33}$. Dimensionless flood series within a hydrologically homogeneous region are pooled together and a regional average frequency curve (Index flood) is

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fitted to the combined data. This curve can be applied to any ungauged site within the region and is rescaled using an estimate of the standardizing parameter (mean annual flood) obtained from basin characteristics.

Thus the index flood method extrapolates information of runoff events for flood frequency analysis from gauged catchments to ungauged catchments in the vicinity having more or less similar catchment and hydrological characteristics.

DATA ANALYSIS

Preliminary statistics and determination of at site FF curves

The preliminary statistical analysis is carried out to determine the at site average annual flood, standard deviation, coefficient of variation, coefficient of skewness and coefficient of kurtosis. The data series for susceptible systematic record are checked for presence of either a high or low outlier. The high outliers are retained as historical records and low outliers are omitted from the respective flood series and the statistics is recomputed.

The at site flood frequency curves for all gauging site in the study area are developed using Gumbel EV-1 distribution method. The at site flood frequency curve i.e. the relationship between mean annual flood and EV-1 reduced variate has been established following the method of linear regression by least square approach.

POSSIBLE DELINEATION AND TEST FOR HOMOGENEITY

It was decided to use 24 CWC sites for regional flood frequency analysis and remaining 14 HDUG sites for validation purpose. The number of sites in a group after possible delineation should not be too less (10 to 12). Therefore, instead of using a sophisticated regionalization method such as cluster analysis, Euclidean Distance, method of residuals, region of influence, (Zrinji et al. 1996; Burn et al. 1997); a simple partitioning technique (Wiltshire, 1985) is used for delineation. The Delineation options considered in the RFF analysis are given in the Table 2.

The USGS homogeneity test is carried out for the different options considered in the RFF analysis. The homogeneity plots for option A is shown in Fig.2 as a sample case. The results of USGS Homogeneity test for different options of delineation are summarized in Table 3. From such homogeneity test plots of each option, the sites which fall outside of the envelope curves are identified and considered as statistically non-homogeneous and are excluded from the further analysis.

Table 2 : Delineation options considered in the RFF analysis

Opt No.	Delineation Criteria	No. of sites	Remark
A	Entire catchment	24	All CWC sites
B	Based on catchment area	11	CWC sites with Catchment area more than 5000 sqkm.
		13	CWC sites with Catchment area less than 5000 sqkm.
C	Based on Runoff per sqkm	11	CWC sites with runoff more than 0.29 cumecs / sqkm.
		13	CWC sites with runoff less than 0.29 cumecs / sqkm.
D	Riverbasinwise	14	Proper Krishna River basin (only CWC sites)
		10	Proper Bhima River Basin (only CWC sites)
E	Riverbasinwise	28	Proper Krishna River basin (including HDUG sites)
		10	Proper Bhima River Basin
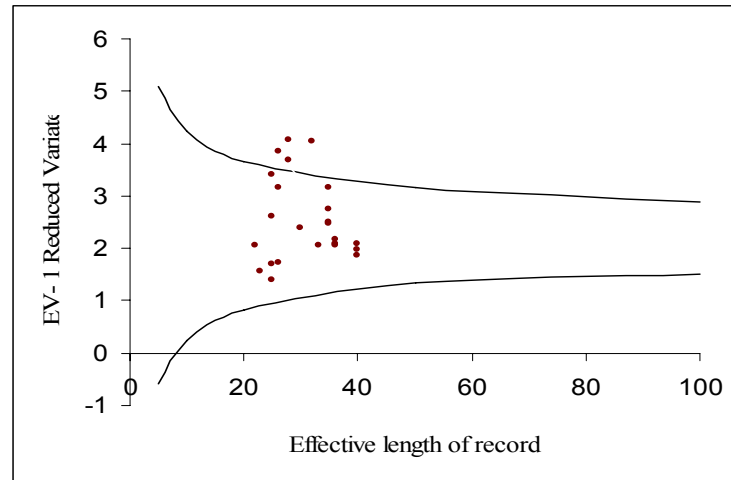
Fig 2 : USGS Homogeneity plot for option A (Entire catchment)

Table 3 : Results of USGS Homogeneity tests

Opt No.	Option details	No of sites considered in analysis	Hydrologically Nonhomogeneous sites (No.)
A-1	All CWC sites	24	04
B-1	CWC sites with Catchment area >5000 sqkm.	11	02
B-2	CWC sites with Catchment area < 5000 sqkm.	13	01
C-1	CWC sites with runoff > 0.29 cumecs / sqkm.	11	--
C-2	CWC sites with runoff < 0.29 cumecs / sqkm.	13	02
D-1	Proper Krishna River basin (only CWC sites)	14	--
D-2	Proper Bhima River Basin (only CWC sites)	10	--
E-1	Proper Krishna River basin with HDUG sites	28	--
E-2	Proper Bhima River Basin	10	--

DEVELOPMENT OF REGIONAL FREQUENCY CURVES

Following the index flood procedure and using at site flood frequency curves, the regional flood frequency curve is obtained. The form of this curve is as below-

$$Q_T/Q_{2.33} = u + \propto (-\ln (-\ln (1-1/T)))$$ Eq.(1)

where, Q_T is estimated flood for T year return period and

   $Q_{2.33}$ is mean annual flood

   u and $\propto$ are scale and location parameters respectively and are calculated using index-flood procedure.

The regional flood frequency curves for different options are given below in Table 4. The growth factors determined for different options are also given in Table 5.

RELATIONSHIP BETWEEN REGIONAL MEAN ANNUAL FLOOD PEAK AND CATCHMENT AREA

The Relationship between regional mean annual flood peak and catchment area can be written in its natural form $Q = c A^a$

   The relationship can be written as

   $\log Q_{2.33} = \log c + a \log A$ Eq. (2)

where, $Q_{2.33}$ is the mean annual flood (cumecs)

A is the drainage area (sq. km.)

c and a are the constants of regression.

The relationship between Mean Annual Flood and Catchment Area obtained considering the different delineation options is given below in Table 4.

Table 4 : Summary of RFF curve and regression equation for different options

Opt No	Regional Flood Frequency Curve	Regression equation	Correl Coeff	SEE (cumecs)
A	$Q_T/ Q_{2.33} = 0.7589 + 0.4166\, Y_T$	$Q_{2.33} = 18.7145* A^{0.4889}$	0.7486	1133.978
B-1	$Q_T/ Q_{2.33} = 0.7855+0.3707Y_T$	$Q_{2.33} = 145.4016* A^{0.2969}$	0.5904	1492.306
B-2	$Q_T/ Q_{2.33} = 0.7183 +0.4868\, Y_T$	$Q_{2.33} = 37.0401* A^{0.3664}$	0.4158	568.324
C-1	$Q_T/ Q_{2.33} = 0.8008+0.3452Y_T$	$Q_{2.33} = 22.2891* A^{0.5445}$	0.9763	170.130
C-2	$Q_T/ Q_{2.33} = 0.7101+0.5011Y_T$	$Q_{2.33} = 0.6409* A^{0.8136}$	0.9521	577.832
D-1	$Q_T/ Q_{2.33} = 0.8269+0.2992Y_T$	$Q_{2.33} = 62.2775* A^{0.4042}$	0.8541	1008.422
D-2	$Q_T/ Q_{2.33} = 0.7047+0.5105Y_T$	$Q_{2.33} = 0.6139* A^{0.8285}$	0.9323	1035.054
E-1	$Q_T/ Q_{2.33} = 0.8214+0.3086Y_T$	$Q_{2.33} = 55.5065* A^{0.4000}$	0.8627	872.581
E-2	$Q_T/ Q_{2.33} = 0.7047+0.5105Y_T$	$Q_{2.33} = 0.6139* A^{0.8285}$	0.9323	1035.054

Table 5 : Summary of Growth Factors

Return Period (Yrs) Option No.	2	5	10	20	50	100	200	500	1000
A-1	0.91	1.38	1.70	2.00	2.38	2.68	2.97	3.35	3.64
B-1	0.92	1.34	1.62	1.89	2.23	2.49	2.75	3.09	3.35
B-2	0.90	1.45	1.81	2.16	2.62	2.96	3.30	3.74	4.08
C-1	0.93	1.32	1.58	1.83	2.15	2.39	2.63	2.95	3.19
C-2	0.89	1.46	1.84	2.20	2.67	3.02	3.36	3.82	4.17
D-1	0.94	1.28	1.50	1.72	1.99	2.20	2.41	2.69	2.89
D-2	0.89	1.47	1.85	2.22	2.70	3.05	3.41	3.88	4.23
E-1	0.93	1.28	1.52	1.74	2.03	2.24	2.46	2.74	2.95
E-2	0.89	1.47	1.85	2.22	2.70	3.05	3.41	3.88	4.23

Above Table 4 indicates that the correlation coefficient is considerably improved in option C and option D and also the SEE values are also lower down. A more homogeneous region is possible when delineation is based on runoff producing capacity. However, the regions obtained based on this option may not be geographically contiguous. The results are also satisfactory when the riverbasinwise delineation is attempted. Thus we can think of this option as a better criterion to delineate the Krishna river basin into two regions instead of considering the entire catchment as a whole.

The delineation based on catchment area (option B) doesn't result in better regionalization as can be seen by reduced correlation coefficient and associated high degree of standard error in estimation of regional mean annual flood. This indicates that the regional mean annual flood doesn't depend only on catchment area but few more geomorphologic parameters viz. slope of main river, slope of catchment, mean elevation of catchment, average annual runoff, drainage density, stream density, soil type, landuse and land cover etc.

The plots of observed mean annual peak flood series versus regional mean annual flood values estimated using the relations mentioned above are shown in Fig. 3
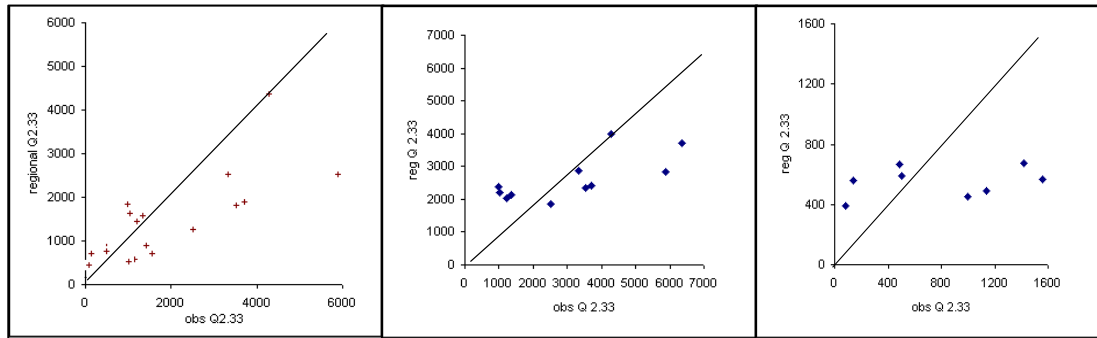
Option A (All CWC sites)   Option B-1 (large catchment area)   Option B-2 (small catchment area)
C.R.= 0.7486   C.R.=0.5904   C.R.=0.4158
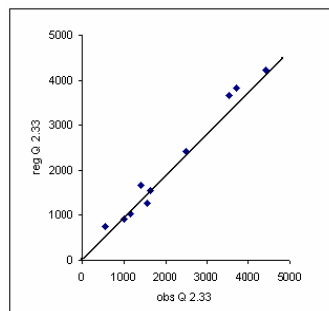
Option C-1 (High Runoff/ sqkm)   Option C-2 (Low Runoff/ sqkm)
C.R. = 0.9763   C.R. = 0.9521
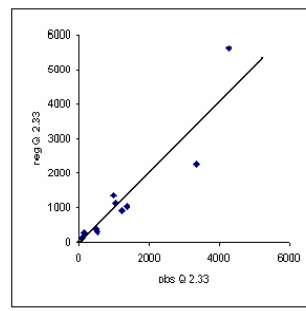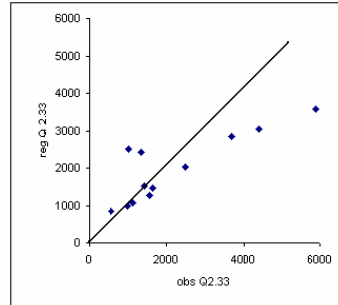
Option D-1 Proper Krishna Basin   Option D-2 Proper Bhima Basin
(All CWC sites)   C.R. =0.8541   (All CWC sites) C.R. = 0.9323
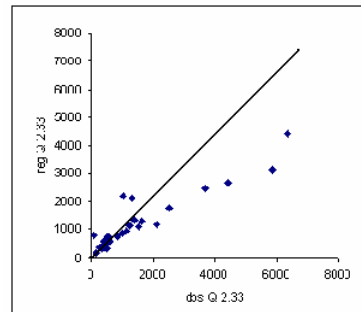
Option E-1 Proper Krishna Basin   Option E-2 Proper Bhima Basin
(CWC & HDUG sites) C.R. = 0.8627   (CWC & HDUG sites) C.R. = 0.9323

Fig. 3 : Relationship between observed Q2.33 and regional $Q_{2.33}$

VALIDATION

Following two CWC RG sites are used as test sites –

1. Takali which lies in proper Bhima river basin having catchment area more than 5000 sqkm and runoff less than 0.29 cumecs per sq.km.
2. Gotur which lies in proper Krishna river basin having catchment area less than 5000 sqkm and runoff more than 0.29 cumecs per sq.km.

The Gauging records of these two test sites were not used in the regional flood frequency analysis. The flood values for these test sites for different return periods are obtained from Index flood method using at site parameters. These flood quantiles are compared with those flood values computed using regional flood formulae using different delineation options.

The flood estimation at test sites is validated based on following approaches-

1. Comparison of average percentage absolute error in flood estimation using actual parameters and observed mean annual flood peak with flood estimation using regional parameters and observed mean annual flood peak.
2. Comparison of average percentage absolute error in flood estimation using actual parameters and observed mean annual flood peak with flood estimation using regional parameters and regional mean annual flood peak.

The results are summarized in following Table 6.

Table 6 : Comparison of percentage absolute error in flood estimation for test sites

Option	with regional parameters and at site mean		with regional parameters and regional mean	
	Takali	Gotur	Takali	Gotur
A	0.1257	0.0646	0.2474	0.1984
B	0.1738	0.1568	0.2518	0.2711
C	0.0372	0.0304	0.1648	0.2880
D	0.0273	0.0895	0.0564	0.2774
E	0.0273	0.0772	0.0564	0.1120

REGIONAL FLOOD FREQUENCY ANALYSIS FOR HDUG VALIDATION SITES

Instead of relaying on validation through one test site only , it was decided to validate the RFF analysis by applying it to 14 HDUG validation sites. Also an attempt is tried to check the effect of sample size on regional flood frequency analysis by adding these HDUG validation sites in the original data set and thus increasing the sample data size.

 The result of USGS homogeneity test for HDUG validation sites indicate that Sarud RG site and Patryachi wadi RG site donot lie within hydrologically homogeneous region. The record length available for Ambavade RG site is only of 8 years and the record at Wadange RG site is intermittent. Hence, these 4 sites are not included in a set of validation sites.

It should be noted that all the HDUG validation sites are with catchment area less than 5000 sq km and with a runoff producing capacity more than 0.29 cumecs per sq.km. All of them are from Proper Krishna Basin.

The regional flood frequency analysis results are applied to these 10 HDUG validation sites considering delineation option D and E as these options give better results as compared to other options considered in RFF analysis. The percentage absolute error is compared with the results obtained from option A i.e. considering the entire catchment as a whole. The results are summarized in Table 7.

Table 7 : Comparison of % absolute error in flood estimation for validation sites

R.G. Site	Opt A	Opt D-1	Opt. E-1
Ajara	0.2410	0.3448	0.1871
Ambale	0.3102	0.3092	0.1579
Belwade	0.5781	0.1913	0.2831
Gudhe	0.4046	0.0975	0.1016
Jambare	0.3717	0.3586	0.2102
Mandukali	0.3456	0.2546	0.1112
Nitwade	0.3810	0.0271	0.0970
Parali	0.7282	0.4646	0.5266
Shigaon	0.3359	0.0075	0.1207
Tarewadi	0.3617	0.1140	0.0182
Average	**0.4064**	**0.2169**	**0.1814**

RESULTS AND DISCUSSIONS

1. For both the test sites the average percentage absolute error is increased in all possible delineation options when regional parameters are used with regional mean annual flood. This indicates that the better results can be possible with improved regional mean annual flood. Hence, along with catchment area alone few more geomorphologic parameters can be used in regression equation used for estimation of regional mean annual flood.

2. For a test site Takali, the average absolute percentage error is reduced considerably when delineation is based on runoff producing capacity (option C) and least when delineation is based on riverbasin criteria (option D). Whereas, the delineation based on catchment area results in increase in average percentage absolute error.

3. From the results obtained for test site Gotur, it canot be definitely concluded that which delineation option performs better. However, the option D i.e. a riverbasin criteria can be considered for delineation as it performs satisfactorily. This is also supported by reduced standard error of estimation and improved correlation coefficient in the regression analysis between catchment area and regional mean annual flood.

4. However, this is also confirmed when the results are applied to 10 HDUG validation sites. The results also show that the hydrologic regionalization can further be improved by increasing the number of sites in data set.

CONCLUSIONS AND RECOMMENDATIONS

The regional flood frequency analysis is carried out using annual peak discharge data of 24 CWC R. G. sites and 14 HDUG RG sites in upper Krishna basin under three different delineation options and validated through two test sites and in particular option D through 10 additional validation sites. Conclusions of the analysis of hydrologic regionalization for study area are as below -

1. The study area can be delineated into two regions viz. proper Krishna river basin and proper Bhima river basin.

2. In all the delineation options, the estimated percentage absolute error in determining the flood quantiles for desired return period is increased when estimated regional mean annual flood is used instead of observed mean annual flood. Whereas the estimated percentage absolute error using regional parameters and observed mean annual flood is in good comparison with estimation of flood quantiles using at site parameters and observed mean annual flood.

3. As such we can conclude that determination of regional mean annual flood is a most crucial and decisive factor. Better results are expected with improved regional mean annual flood.

4. Although the size of catchment plays an important role in developing the regional flood formula, the high standard errors associated with estimated mean annual flood in regression analysis indicate that the mean annual flood may also depend on other physiographic characteristics.

5. Hence, it is recommended to carry out a further study to develop regional flood formulae based on the various physiographic characteristics of a catchment viz. slope of main channel and catchment relief, drainage density, drainage frequency, average annual rainfall, land use and land cover etc. including the catchment area.

6. The above formulae developed are from single realization and with a comparatively less number of sites. Hence, it is recommended to adopt a simulation study to decide the robust flood frequency analysis method.

7. It is also recommended to carry out the RFF analysis using other higher order probability distributions viz. EV-1, GEV, GL, P-III, LP-III, wakeby and kappa etc. with advanced techniques of parameter estimation such as probability weighted moments and L-moments.

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Chemical Weathering in Central Himalaya: Focus on Dissolved Silica Dynamics in Glacier Meltwaters

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ABSTRACT

Major ion chemistry of glacier meltwater draining from Lirung Glacier in the Himalaya Mountains of Nepal studied to investigate weathering processes and the diurnal variation of major solutes. Weathering at our study site was primarily fueled by sulfide oxidation, with the dissolution of carbonate and aluminosilicates suggested by the high calcium and sodium concentrations in Lirung Glacier meltwater. Anorthite and albite appear to be the dominant primary minerals undergoing weathering, with bisiallitization the dominant weathering pathway throughout the seasons. Snow samples showed slightly higher concentrations at depth than in shallower samples, suggesting the influence of contact with underlying geologic strata or the effects of sublimation in the older, deeper snow. Major solute concentrations were slightly higher in pre-monsoon than the post-monsoon period in diel samples. The highest discharge of major solutes was observed in the evening (with highest meltwater volume) and lowest in the morning in both sets of samples; patterns in concentration were reversed. The high discharge of weathering products from Lirung Glacier reflected the intense chemical weathering of aluminosilicates and carbonates in the central Himalaya. Biotite and plagioclase were dominant reactants and K-feldspar and muscovite were minor reactants within the Lirung drainage basin. Kaolinite and smectite were the dominant clay minerals produced during the chemical weathering processes within the catchments.

Key words : Chemical weathering, Central Himalaya, Major solutes, Glacier meltwater, Aluminosilicates, Carbonates, Lirung glacier

1. INTRODUCTION

Snow and glaciers store vast amounts of freshwater in the Himalayas. Glacial meltwaters from the Himalayas contribute base flow to mountain streams throughout the year, which are very important for the water resources management of Nepal. The chemistry of the Brahmaputra, Ganga and Indus Rivers, which together contribute about 6.7% of the total global flux of dissolved solutes to the global ocean, reflects the intense chemical erosion occurring in the Himalayas (Meybeck 1976). Physical erosion is substantially greater in alpine glaciers than Mountain Rivers (Hallet et al. 1996). Solute flux in meltwaters from glaciated catchments is higher than the global mean (Reynolds and Johnson 1972; Eyles et al 1982; Collins 1983; Sharp et al. 1995) and is particularly high in the tectonically active Himalayan region (Sarin et al 1989; Collins et al. 1996; Collins 1998; Galy and France-Lanord 1999; Hasnain and Thayyen 1999; Bhatt et al. 2000). Tectonic uplift of the central Himalayan region may have led to cooling of the global climate by accelerating weathering and thus the consumption of atmospheric CO_2 (Raymo and Ruddiman 1992). Bernard et al. (2006) observed high rates of denudation in central Nepal Himalaya due to tectonic uplift, glacial fluctuations and an active monsoon climate in the region.

The chemistry of river systems originating from the Himalaya has received more attention in the literature in recent decades due to interest in chemical weathering processes. Various authors have documented weathering-related phenomena in studies in the river systems that originate from the Himalaya (Sarin et al. 1992; Bartarya 1993; Jenkins et al. 1995; Collins and Jenkins 1996; Gardner and Walsh 1996; Blum et al. 1998; Harris et al. 1998; Krishnaswami and Sing 1998; Galy and France-Lanord 1999; Hasnain and Thayyen 1999; Pandey et al. 1999; Bhatt et al. 2000; Dalai et al. 2002; West et al. 2002; Das and Dhiman 2003; France-Lanord et al. 2003; Chakrapani 2005; Krishnaswami and Sing 2005).

Chemical weathering rates mainly depend on the amount of carbon dioxide present in the solution (White and Blum 1995; Gaillardet et al. 1999; Millot et al. 2002) as well as bedrock types of the basin through which water drains (Drever 1988; Gibbs 1970; Stallard and Edmond 1983) and temperature (Krishnaswami and Singh, 2005; McDowell and Asbury, 1994; Velbel, 1993).

Climate plays a major role in the rates of chemical weathering of silicate minerals and has received considerable attention in the literature (Lasaga et al. 1994; Dorn and Brady 1995; White and Blum 1995; Gaillardet et al. 1999; White et al. 1999; Millot et al. 2002). This interest stems largely from the observation that weathering of silicate rocks consumes higher amounts of carbon dioxide than weathering of other rocks (Brady 1991; Velbel 1993; Ludwig et al. 1998; Gaillardet et al. 1999) and the global budget of CO_2 is considered to be an important driver of weathering rates over geologic time (Walker et al. 1981; Brady and Carroll 1994; White and Blum 1995). The Ganga-Brahmaputra draining through the Himalayan front has higher CO_2 consumption rates by silicates rocks during chemical weathering than the large Huang river system and the global average (Amiotte Suchet et al. 2003; Krishnaswami and Singh 2005; Wu et al. 2005).

Numerous authors have highlighted the role of physical erosion in controlling surface water chemistry (Stallard and Edmond 1983; Drever 1988; Edmond and Huh 1997; Harris et al. 1998; Gaillardet et al. 1999; Dalai et al. 2002; Millot et al. 2002; Das and Dhiman 2003; Dupre et al. 2003; West et al. 2005).

Glaciological and meteorological observations on glaciers in the Nepal Himalaya have been carried out since 1973, and the Langtang valley has been under observation since 1989 through the Glaciological Expedition of Nepal (GEN; Higuchi et al. 1982). The chemistry of glacier meltwater, pond water and ice cores from Nepal Himalaya have been documented by various authors (Kamiyama 1984; Watanabe et al. 1984; Reynolds et al. 1995; Harris et al. 1998; Bhatt et al. 2000; West et al. 2002; Quade et al. 2003; Tipper et al. 2006; Bhatt et al. 2007; Bhatt et al. 2008). The aim of this paper is to evaluate diurnal changes in the fluxes of major solutes with the emphasis on dissolved silica in glacier meltwater from the debris-covered Lirung glacier and to investigate the mechanisms of aluminosilicate weathering within the Lirung glacier basin in central Himalaya.

2. STUDY AREA

The Lirung glacier (28°12.9'N, 86°39.9'E) is located in the southern front of the Great Himalaya. This glacier is about 60 km north of Kathmandu and is the headwater area of the Langtang - Narayani river system that joins the Ganga River in India and finally enters into the Bay of Bengal. Figure 1 shows the topography of Lirung glacier basin showing the observation site and the debris area. The area of Langtang glacier watershed is 333 km² of which 127 km² is covered with glaciers (Ohata et al. 1987). The highest point of this watershed is 7234 m above sea level (asl). The total area of the drainage basin is 13.8 km², of which 33% is steep bedrock walls, 16% debris covered glacier and the remaining 51% debris free ice (Fukushima et al. 1987). Lirung outlet is vegetation -free area although there is a small seasonal settlement supported by subsistence farming.

2.1 Geologic Setting

The Langtang Lirung area lies in a complex transition zone between the high Himalayan metasediments (south) and Tethyan sedimentary series (north). The lithology consists entirely of

high grade metamorphic rocks with traces of igneous rocks including migmatites, gneisses, schists, phyllites and granites (Inger and Harris 1992). Analytical results by X – ray florescence analysis of rock samples from the debris area of Lirung glacier are tabulated in Table 1a and mineralogical compositions are examined for thin sections of rock samples in Table 1b. The bedrock consists of biotite, quartz, and plagioclase with minor muscovite, alkali feldspar, ilmenite and sillimanite. Biotite, quartz and plagioclase are the dominant silicates in the bedrock with lesser amounts of muscovite, alkali feldspar, ilmenite and sillimanite. Sulfide bearing minerals including pyrite, galena, sphalerite and pchalco pyrite are also present in the region (Bhatt et al. 2007; Bhatt et al. 2008).
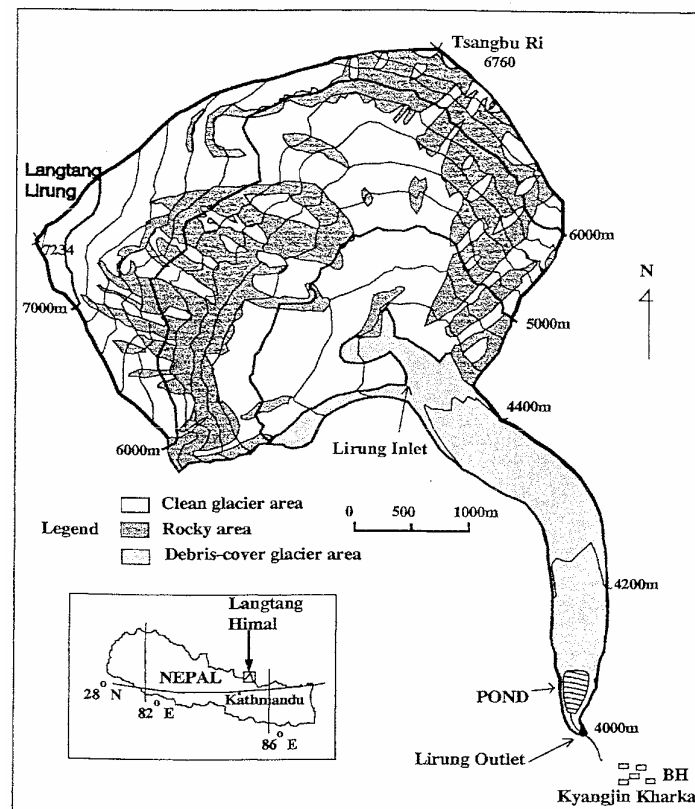
Figure 1. Topographic map of Lirung Glacier basin in the central Nepal Himalaya showing sampling point Lirung outlet (After Sakai et al. 1997).

3. MATERIALS AND METHODS

3.1 Sample Collection

Discharge waters at the Lirung outlet were sampled at nearly weekly intervals from pre-monsoon to post-monsoon in 1996 as a part of the Cryosphere Research Expedition in the Himalaya (Fujita et al. 1997; Nakawo et al. 1997; Sakai et al. 1997; Bhatt et al. 2000). Glacier meltwater samples were also collected every three hours for 30h on 30-31 May and 29-30 September 1996 at the outlet point to examine diurnal changes. Rock samples were collected within the debris area of Lirung glacier. Snow samples from Yala glacier (5450 m a. s. l.) were collected at different depths during 1996. Discharge was measured at the outlet from 8 May to 25 October 1996 (Sakai et al. 1997). Metrological variables were measured from the pre-monsoon to post-monsoon period in 1996 (Fujita et al. 1997). Sampling methods are described in detail by Bhatt et al. 2000.

3.2 Analytical Methods

Rock samples were collected within the debris area of Lirung glacier and examined under a microscope after preparation of thin sections. A part of each rock sample was powdered and analyzed by a Shimadzu SFX -1200 by the method of Morishita and Suzuki (1993). Electrical conductivity (EC) and pH were measured at the time of sampling using a Horiba B-173 and Horiba B-212 respectively. Dissolved silica (SiO_2) and $PO_4 - P$ were analyzed spectrophotometrically (Hitachi 124) with the standard molybdenum blue methods. Suspended sediments (SS) were measured gravimetrically on 47mm GELMAN Super polyethersulfone filter after drying in a vacuum oven at 60°C for 48hr. Alkalinity was determined by acid titration. Detection limits for SS and alkalinity were 1 mg L^{-1} and 1 micro equivalent (μeq L^{-1}), respectively. Major cations (Na^+, K^+, Mg^{2+}, Ca^{2+}, and NH_4^+) and anions (Cl^-, NO_2^-, NO_3^-, and SO_4^{2-}) were determined by cation (Dionex DX-100) and anion (Dionex QIC) chromatography, respectively, relative to IAPSO International Standard seawater as well as relative to standard solutions prepared from analytical reagents. Analytical errors were <2% for Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, and SiO_2, < 4% for NH_4^+ and <5% for $PO_4 - P$.

The authors used chloride concentration as a reference species to correct the contribution of sea-salt in glacier meltwater at Lirung outlet for Na^+, K^+, Mg^{2+}, Ca^{2+} and SO_4^{2-}, and present the sea-salt corrected chemical species with an asterisk. Various authors have used molar ratios of various elements relative to marine aerosols to correct the sea-salt contribution in earlier studies (Keene et al. 1986; McDowell et al. 1990; Bhatt and McDowell 2007).

4. RESULTS

4.1 Physical parameters

Maximum discharge was observed in the evening (6 pm) and minimum in the morning (9 am) during intensive sampling of both pre-monsoon and post-monsoon meltwater from the outlet of Lirung glacier. The highest temperature in the meltwater was observed at noon. Melted water passed through the debris area where it interacted with the rock floor and its residence time within the debris area was higher than in other parts of the drainage basin. We estimate that Lirung glacier meltwater probably took 5-6 hr to pass through the debris area. The observed temperature of meltwaters varied from -3°C to 7°C. Post-monsoon water temperature was lower than pre-monsoon. The water temperature remained negative during night in the post-monsoon sampling series. The pH values observed ranged between 7.1 and 8.2. The average pH in both seasons remained slightly alkaline. The pH of the snow sample was 6.4. The electrical conductivity (EC) in these glacier meltwaters ranged between 27-47 μS cm^{-1}, with the highest values during the periods with lowest discharge. Suspended sediment concentrations were inversely related to EC, with highest values during periods of high flow. Snow sample showed very low EC value (2.5 μS cm^{-1}). The average suspended sediment during pre-monsoon and post-monsoon seasons was 98 and 61 mgL^{-1} respectively at the Lirung outlet (Table 2).

4.2 Chemical parameters

4.2.1 Rock Analysis

Analysis of rock samples from the debris area of the Lirung glacier by X - ray fluorescence showed the dominance of silica and alumina, chemical composition occurred in the following order: SiO_2 > Al_2O_3 > FeO > K_2O > Na_2O > MgO > CaO > TiO_2 > P_2O_5. Gneiss and Schist are the main bedrock types within the basin. The bedrock consists of biotite, quartz and plagioclase as the dominant silicates and muscovite, alkali feldspar, ilmenite and sillimanite as the minor minerals within the basin. The analytical results of the rock samples and mineralogical composition of the thin sections of the rocks are given in Table 1a and Table1b respectively.

Table 1a. Analytical results by X-ray fluorescence analysis for rock samples from the debris area of the Lirung Glacier.

Chemical compositions	Sample I	Sample II	Sample III
SiO_2	71.83	69.30	70.08
TiO_2	0.44	0.85	0.86
Al_2O_3	12.98	13.96	13.60
FeO*	4.89	4.54	4.83
MnO	0.19	0.06	0.07
MgO	1.28	1.83	2.00
CaO	0.93	1.99	3.11
Na_2O	2.16	2.53	2.01
K_2O	4.00	3.43	2.28
P_2O_5	0.25	0.17	0.16
Total	98.95	98.66	99.00

*Total Fe as FeO

4.2.2 Chemistry of Snow

Snow samples were collected at depths of 158, 245, and 200 cm during pre-monsoon, monsoon and post-monsoon seasons. The electrical conductivity of all the post-monsoon samples was less than $1\mu S\ cm^{-1}$ and pH value ranged from 5.9 to 6.8. The cationic concentrations of these samples were very low. Magnesium and potassium were not detected in most of the samples while sodium and calcium were detected at very low concentrations. Cationic and anionic species were not detected in samples collected during the post-monsoon season. Nitrate was slightly higher than sulfate indicating the result of atmospheric deposition. Almost all samples contained very low concentration of dissolved silica, ranging from 0.05 to 0.14 $\mu eq\ L^{-1}$ with an average value of $0.1\mu eq\ L^{-1}$ (Table 2).

Table 1b. Mineralogical compositions examined for thin sections of rock samples from the debris area of the Lirung Glacier.

	Sample I	Sample II	Sample III
Rock	Gneiss	Schist	Schist
Minerals	Biotite	Biotite	Biotite
	Muscovite (tr.)	Muscovite	Muscovite (rare)
	Quartz	Quartz	Quartz
	Plagioclase	Plagioclase	Plagioclase (An* rich)
	K-feldspar (ab.)	K-feldspar (ab.)	K-feldspar (rare)
	Ilmenite		
	Sillimanite		

*Anorthite

4.2.3 Diel variation in discharge water chemistry at Lirung outlet

The average chemical composition of discharge waters during the pre-monsoon and post-monsoon season at the outlet of Lirung glacier and snow samples from Yala glacier is compiled in Table 2. Calcium was the dominant cation in both seasons and accounted for 76% of the total cations. Sodium, potassium and magnesium comprised 8%, 6%, and 10% of the total cations respectively. Alkalinity (mainly as bicarbonate) was the dominant anion and accounted for 56% of the total anions. Discharge at the glacier outlet was highest at 6 pm and lowest at 6 am in both seasons and such variation could be directly related to variation in temperature (Figure 2). The highest glacier

melt appeared at noon and it takes about 5-6 hrs to reach the discharge point through the debris area. During the middle of the night temperature was lowest and hence discharge was lowest in the morning at the outlet point. The silicon concentration was highest at noon and low in the evening to late evening in both seasons and concentration was higher in pre-monsoon season than the post-monsoon season (Figure 3). The high concentration of silicon at noon is probably due to the high dissolution rates of aluminosilicate due to high temperature. The sum of base cations after sea-salt correction showed a very strong relationship with discharge in both the seasons (Figure 4). The concentration trend appeared decreasing from pre-monsoon to post-monsoon season probably due to dilution effect. Furthermore, major aluminosilicate weathering products such as alkalinity and dissolved silica showed very clear seasonal variation trends at the Lirung outlet based on the samples taken from May to October 1996 (Figure 5). During the monsoon season concentrations of both species decreased sharply, probably due to the effects of dilution. Highest dissolved silica flux was observed at 6 pm in the pre-monsoon season and 3 pm in the post-monsoon season and lowest at 6 am in both seasons (Figure 6). Flux appeared much higher in the post-monsoon season than the pre-monsoon season. The concentration of silica was lower and its flux was higher during the post-monsoon season compared to the pre-monsoon.

Table 2 Chemistry of discharge water at the Lirung outlet suring pre-monsoon and post-monsoon and snow samples during pre-monsoon to post-monsoon at different depth in 1996. All chemical values represent the average volume weighted concentration. Asterisks represent seasalt corrected values.

Measured parameters	Discharge at Lirung glacier outlet		Snow		
	Pre-monsoon	Post-monsoon	Pre-monsoon 245cm	Monsoon 158cm	Post-monsoon 200cm
N	11	11	25	16	22
Water flux (m^3/d^{-1})	2893	5623	14.5	74.5	34.5
Water temp (ºC)	2.61	-0.03	nd	nd	nd
pH	7.43	7.86	nd	nd	6.44
EC (µS/cm)	36	40	nd	0	2.5
SS (mg/L)	98	61	nd	nd	nd
Na (µeq/L)	30	28	0.55	0.72	0.07
*Na (µeq/L)	26	24	<0.1	0.203	<0.1
K (µeq/L)	23	18	0.27	0.24	0.06
*K (µeq/L)	22	18	0.251	0.229	0.052
Mg (µeq/L)	34	29	0.16	0.04	0.02
*Mg (µeq/L)	33	28	<0.20	<0.20	<0.20
Ca (µeq/L)	253	229	2.47	0.43	0.04
*Ca (µeq/L)	253	229	2.43	0.41	0.02
NH4 - N (µeq/L)	1.9	0.2	12.2	6.3	0.17
HCO_3 (µeq/L)	158	156	<1	<1	<1
SiO_2 (µeq/L)	155	144	0.14	0.07	0.05
SO_4 - S (µeq/L)	108	99	0.67	0.04	0.1
*SO4 -S (µeq/L)	107	98	0.563	<0.60	0.058
NO_3 - N (µeq/L)	25	12	2.12	0.17	0.72
PO4 - P (µeq/L)	0.12	0.22	0.054	<0.090	<0.090
Cl (µeq/L)	4.8	4.6	1.03	0.68	0.4
CBE (%)	7.2	5.6			
Si/*Na+*K	3.23	3.43	0.56	0.16	0.96
*K/*Na	0.85	0.75	2.51	1.13	0.52
SiO_2/Al_2O_3	4.45	4.47	4.58	4.69	4.67

N is sample number, nd = no data.

The dominance of Ca^{2+}, bicarbonate and SO_4^{2-} in glacier meltwaters and the correlations between them (Table 3) suggest that carbonate dissolution coupled with pyrite oxidation was the main chemical weathering processes within the Lirung Glacier drainage system, as widely observed in other glacierized basins (Tranter and Raiswell 1991; Tranter et al. 1993; Hasnain and Thayyen 1999)

and observed previously in the Lirung Glacier basin by Bhatt et al. (2000); Bhatt et al. (2007). Furthermore, the tight relationship between the sum of sea-salt corrected calcium and magnesium with sea-salt corrected sulfate suggests that pyrite oxidation and carbonate dissolution are the dominant weathering process within the drainage basin (Figure7). The strong relationships among concentrations of silica, bicarbonate and sulfate strongly suggest that these species are released during the course of chemical weathering. It is also possible that weathering is enhanced by pyrite dissolution due to the abundant supply of protons produced during the dissolution of sulfides and their subsequent oxidation to sulfuric acid (Table 3).
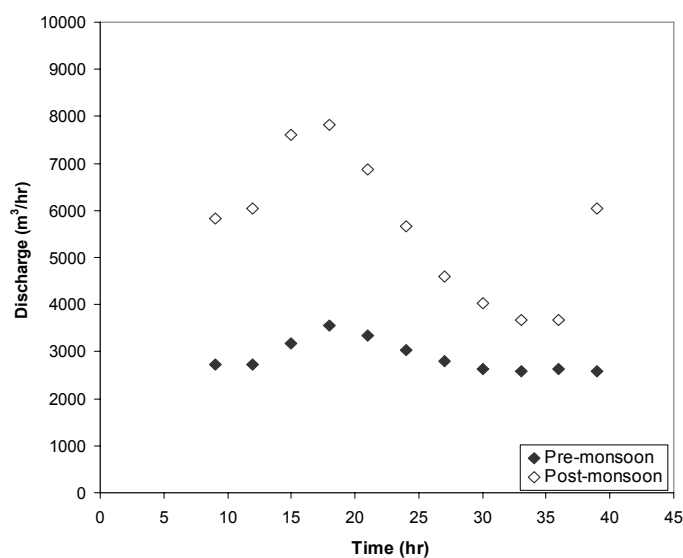
Figure 2. Variation of water discharge with time at Lirung outlet during pre-monsoon and post-

monsoon seasons in 1996
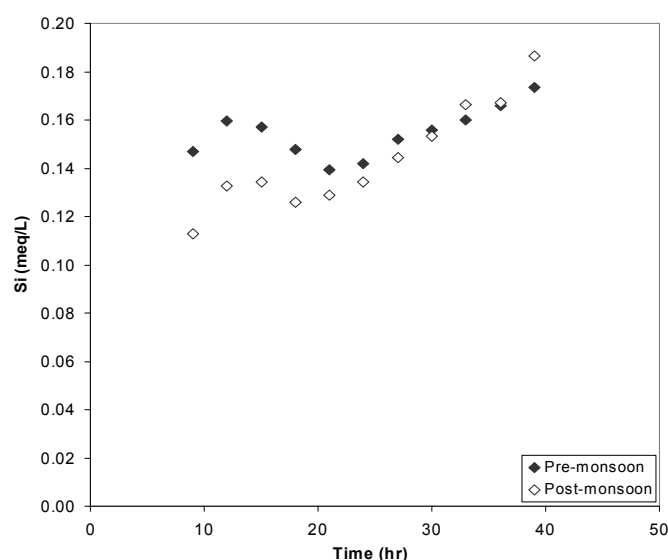
Figure 3. Variation of silicon with time at Lirung outlet during pre-monsoon and post-monsoon season in 1996

Table 3. Pearson correlation matrix and matrix of probabilities among some major chemical parameters in the water samples of the Lirung glacier meltwater at the outlet of Lirung glacier sampled tri-hourly on 30-31 May and 29-30 September in 1996.

Parameters	Na	K	Mg	Ca	Cl	NO_3	SO_4	HCO_3	SiO_2
Na	1.00								
K	0.68**	1.00							
Mg	0.75**	0.93**	1.00						
Ca	0.78**	0.89**	0.98**	1.00					
Cl	0.74**	0.32	0.30	0.26	1.00				
NO_3	0.30	0.89**	0.77**	0.69**	0.05	1.00			
SO_4	0.85**	0.84**	0.96**	0.97**	0.37	0.59**	1.00		
HCO_3	0.85**	0.52*	0.67**	0.76**	0.42	0.15	0.80**	1.00	
SiO_2	0.97**	0.71**	0.80**	0.84**	0.61**	0.35	0.91**	0.86**	1.00

** indicates $p<0.001$ for individual comparison

The average concentrations of these species appeared higher during pre-monsoon than the post-monsoon season. The hourly discharge of sea-salt corrected sulfate and sea-salt corrected calcium was very strongly correlated in both pre-monsoon and post-monsoon seasons with correlation coefficient and probability of $R^2 = 0.99$ and $p< 0.0001$, respectively, at the Lirung outlet (Figure 8). The average flux of both species in the post-monsoon season was nearly double that of the pre-monsoon season; similar trends in both seasons suggest the same geochemical processes are responsible for mobilizing these species throughout the year. The concentrations of all analyzed chemical parameters were lower during periods of high discharge than periods of lower discharge.

Figure 4. Relationship between sum of base cations after sea-salt correction and discharge at Lirung outlet during pre-monsoon and post-monsoon season in 1996
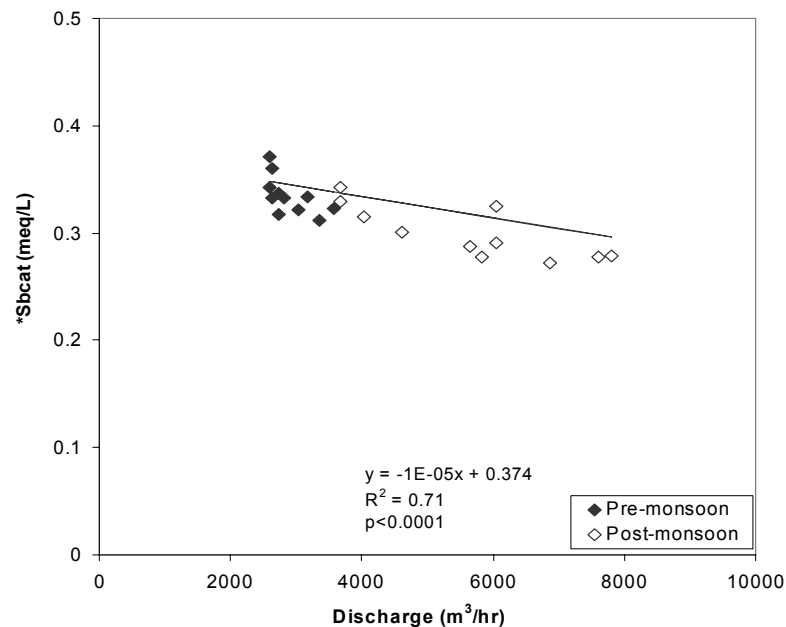
5. DISCUSSION

5.1 Evidence of Chemical Weathering

The major ionic species of the glacier meltwater reflect the rapid silicate weathering rates in the glacial system relative to temperate watershed (Johnson et al. 1981). Dissolved silica concentration at the Lirung outlet was higher than the non-glacier White Mountains Hubbard Brook Experimental Forest, New Hampshire, USA (Johnson et al. 1981) and rivers of the slave province of the Canadian Shield (Millot et al. 2002). Silicate weathering rate are enhanced because of the increased runoff production in the basin as a result of the glacier melt (Anderson et al. 1997). Calcium was the dominant cation, accounting for about 76% of the total cations when expressed as equivalents. Bicarbonate and sulfate are the dominant anions and comprised about 56% and 36% respectively of the total anions. Many chemical parameters in the glacier meltwater showed strong relationships with each other (Table 3). Basic cations were highly correlated with bicarbonate, sulfate and dissolved silica. Bicarbonate showed a strong relationship with sulfate. The oxidation of pyrite was the main proton source to accelerate the aluminosilicate weathering and can be written as (Drever 1988).

$$FeS_2 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_3\downarrow + 4H^+ + 2SO_4^{2-} \tag{1}$$
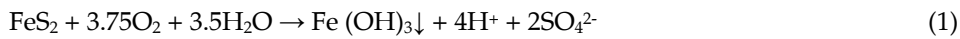
The dissolution of calcium carbonate takes place as,

$$CaCO_3 + CO_2 (aq) + H_2O \rightarrow Ca^{2+} + 2HCO_3^- \tag{2}$$
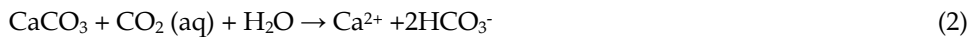
Sodium was the second dominant cation in Lirung meltwater, and the Na:Cl ratio was greater than 4, indicating that the sodium found in glacial meltwater came from the weathering of aluminosilicate rocks. After the sea-salt correction sodium alone accounted for about 8% and (*Na + *K) comprised ~15% of the total cations. Previous work suggests that initial cation release from biotite is significantly faster than cation release from plagioclase at lower temperatures, based on the high (*K/*Na) ratios in cold glacial watersheds relative to warmer environments (White et al. 1999). Discharge water at Lirung glacier in Nepal shows high average ratios of potassium to sodium after sea-salt correction (*K/*Na = 0.80) relative to a tropical watershed (*K/*Na = 0.06) in Puerto Rico (McDowell and Asbury 1994) which has the fastest documented weathering rate of any silicate terrain in the world (White et al. 1998; Millot et al. 2002; Turner et al. 2003; Braun et al. 2005; Buss et al. 2005; Fletcher et al. 2006). The release of potassium was rapid but less temperature-sensitive than silicon and sodium.

Dissolved silica showed strong relationships with all major base cations, which suggests that these cations were derived from aluminosilicate weathering. Furthermore, mineralogical composition of rock samples from the debris area of Lirung glacier indicated the presence of gneiss and schist, both of which contain biotite, muscovite, quartz, plagioclase and K-feldspar as major components (Tables 1a and 1b). Based on these mineralogical observations, the major aluminosilicate weathering reactions occurring within the Lirung glacier basin can be reconstructed based on the chemistry of discharge water at Lirung outlet according to the model of Garrels and Mackenzie (1967) are as follows:

Dissolution of Biotite to Kaolinite:

$$KMg_3AlSi_3O_{10}(OH)_2 + 7CO_2 + 3.5 H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 3Mg^{2+} + K^+ + 2SiO_2 + 7HCO_3^- \tag{3}$$
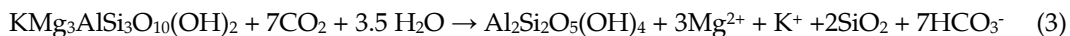
Dissolution of Plagioclase to Smectite:

$$0.846Na_{0.62}Ca_{0.38}Al_{0.38}Si_{2.62}O_8 + CO_2 + H_2O \rightarrow 0.5Ca_{0.17}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 0.52Na^+ + 0.24Ca^{2+} + 0.377SiO_2 + HCO_3^- \tag{4}$$
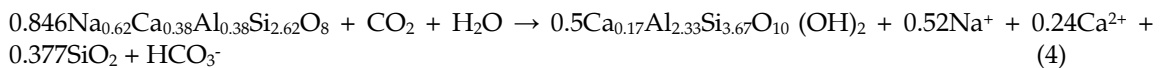
Dissolution of K-feldspar to Kaolinite:

$$KAlSi_3O_8 + CO_2 + 1.5H_2O \rightarrow 0.5Al_2Si_2O_5(OH)_4 + K^+ + HCO_3^- + 2SiO_2 \tag{5}$$
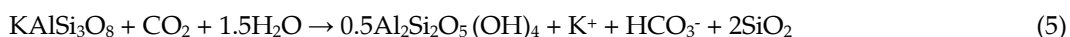
Dissolution of Muscovite to Kaolinite:

$$KAl_3Si_3O_{10}(OH)_2 + CO_2 + H_2O \rightarrow 1.5Al_2Si_2O_5(OH)_4 + K^+ + HCO_3^- \tag{6}$$
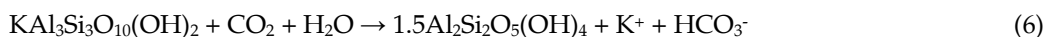
Biotite is assumed to be the main source of magnesium, bicarbonate, dissolved silica and a small amount of potassium (Eq. 3). Plagioclase is thought to be the main source of sodium, which changes to smectite with the release of Na, Ca, SiO_2 and bicarbonate (Eq. 4). K-feldspar is the primary source of K and changes to kaolinite with the release of K, bicarbonate and dissolved silica (Eq. 5). Muscovite changes to kaolinite with the release of K and bicarbonate (Eq. 6). All released aluminosilicate minerals contribute larger amounts in the post-monsoon season than those in pre-monsoon season. The contribution of plagioclase was highest during the post-monsoon season. Higher amounts of kaolinite were formed in the post-monsoon season than pre-monsoon season during the weathering processes within the Lirung glacier basin. This result suggests that the higher discharge of all dissolved species during the post-monsoon season were due to the rapid dissolution of minerals as high runoff accelerates the silicate weathering rate (Anderson et al. 1997; France-Lannord et al. 2003). Biotite and plagioclase are the major reactants and K-feldspar and muscovite are minor reactants. Kaolinite and smectite were the major clay minerals produced during the chemical weathering process. Lirung glacier meltwater contains higher amounts of dissolved solutes than those of debris-free Khymjung glacier in the same area reflecting the importance of debris for global solute yields. Thus, we suspect that there may be faster weathering rates within the debris area due to abundant availability of fresh reactive minerals and high contact time with the water in comparison to a non-debris glacier. Debris covered areas may be a more favorable environment beyond the glacier margin to play a significant role in increasing global solute yield (Anderson et al. 1997). Dissolution of calcites contributed the highest amount of base cations followed by the weathering of aluminosilicates in glacier meltwater at the central Himalaya.
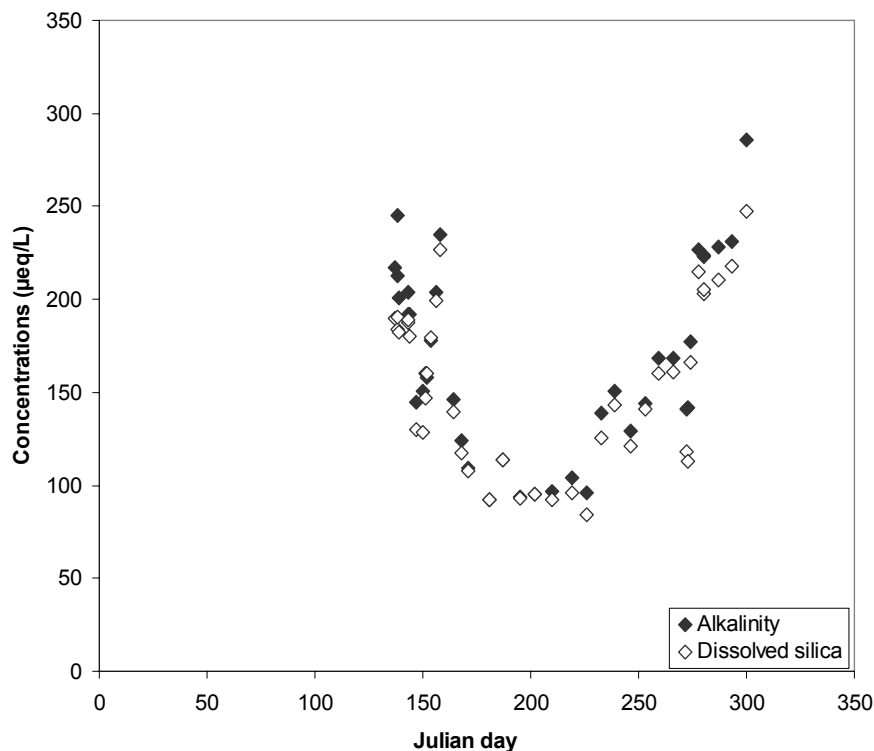
Figure 5. Seasonal variation of dissolved silica and alkalinity at the outlet of Lirung glacier meltwater from May to October in 1996 (Data from Bhatt et al. 2000)

5.2 Dial Variation of chemical species in discharge water at Lirung outlet

Dissolved silica, bicarbonate and base cations are byproducts of the dissolution of aluminosilicate minerals during the chemical weathering processes. Base cations such as calcium and magnesium and bicarbonate also are released as a result of dissolution of carbonates. The concentrations of major solutes such as the sum of base cations after sea-salt correction, silica, and bicarbonate were lower and their fluxes were higher during the post-monsoon season compared to the pre-monsoon season for both the diel and seasonal samples (Bhatt et al. 2000). This could be due to either a dissolution effect or enhanced chemical weathering at the time of high discharge. The flux of weathering products appeared highest in the evening and lowest in the morning for both sets of diel samples suggesting the role of temperature, runoff, and the presence of debris are primarily responsible for variation of chemical species at the discharge point.
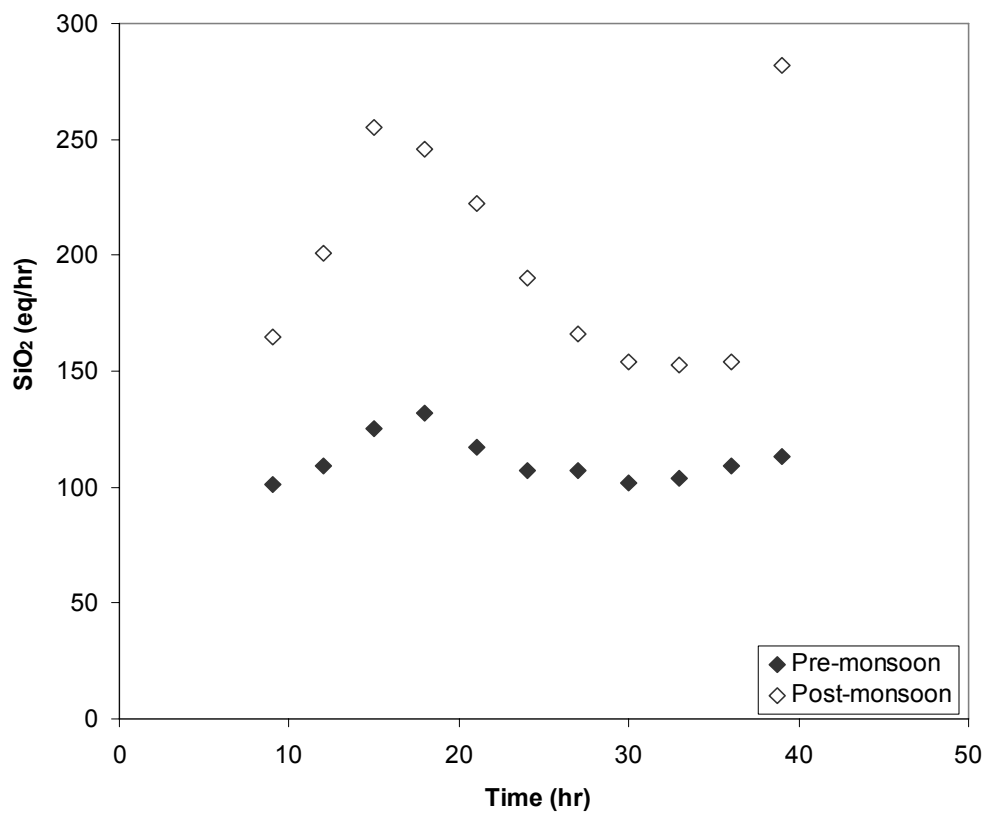
Figure 6. Hourly discharge of dissolved silica at Lirung outlet during pre-monsoon and post-monsoon seasons in 1996

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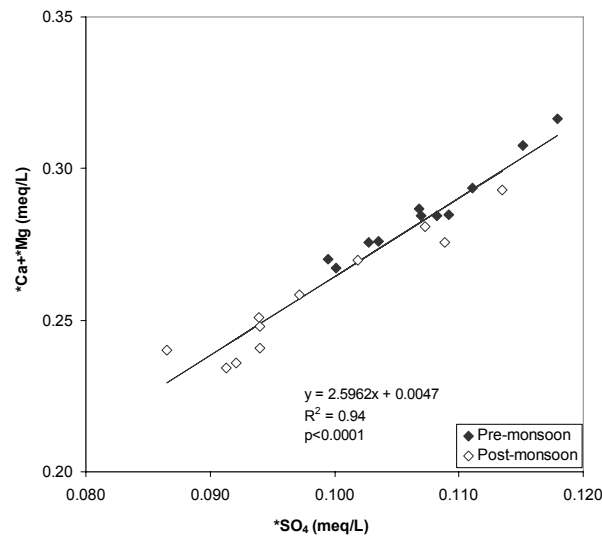
Figure 7. Relationship between sea-salt corrected sum of calcium and magnesium and sea-salt corrected sulfate at Lirung outlet during pre-monsoon and post-monsoon season in 1996

The principal weathering type was characterized based on the geochemistry of glacier meltwaters (Tardy 1971; Semhi et al. 2000). The ratio of silica to alumina was 4.5 at the outlet of Lirung glacier, reflecting that bisiallitization was the pre-dominant type of weathering occurring within the basin. Bisiallitization corresponds to the neoformation of minerals with two silica layers per alumina layer yielding a silica to alumina ratio of two or higher. In this predominant weathering type, base cations are completely released while a portion of the silica remains in situ (Tardy 1971). There is no seasonal effect observed in the weathering type (silica to alumina ratio) in the glacier meltwater at the Lirung outlet reflecting that the principal weathering mechanism remains the same in pre-monsoon and post-monsoon season (Table 2).
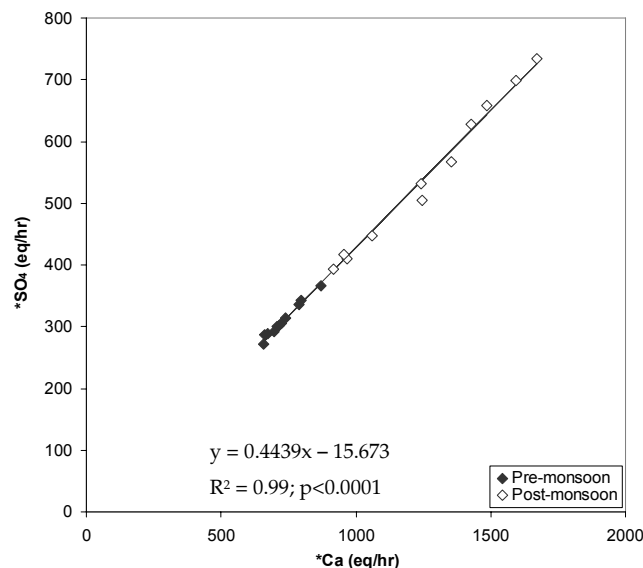
Figure 8. Relationship between hourly discharges of sea-salt corrected sulfate and calcium at Lirung outlet during pre-monsoon and post-monsoon season in 1996

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5.3 Chemical flux in the Himalaya

The total dissolved solid content of glacier meltwaters is almost completely dependent on the rate of chemical weathering processes, as the snow that forms the glacial ice is exceedingly low in solutes (Table 2). Chemical denudation rates are generally low at high altitude due to low temperature (Drever and Zobrist 1992), but the physical erosion by alpine glaciers results in an enhanced rate of erosion (Hallet et al. 1996) which could accelerate the weathering processes and as a result increase the rates of cationic denudation. The cationic denudation rate (CDR) in the Lirung glacier basin is 740 meq m^{-2} a^{-1} (Bhatt et al. 2000), which is similar to the range observed in other glaciers (676 meq m^{-2} a^{-1} in the South Cascade glacier, USA (Axtmann and Stallard 1995); 640-685 meq m^{-2} a^{-1} in Haut glacier d'Arolla, Switzerland, (Sharp et al. 1995). The higher fluxes of weathering products indicate that the high rates of chemical weathering in the central Himalaya are probably due to tectonic uplift. The aluminosilicates (biotite, plagioclase, K-feldspar, and muscovite) in the Lirung glacier basin are weathered at higher rates during post-monsoon than pre-monsoon season and the resultant clays (kaolinite and smectite) are produced at the same rates and pattern. Lirung Glacier meltwater carrying high amounts of dissolved materials mix into the Ganga River, one of the world's largest river system and ultimately to the Bay of Bengal.

6. CONCLUSIONS

Chemical weathering processes as a result of pyrite oxidation dominated the chemistry of glacier meltwater. Pyrite oxidation produced high proton concentrations and hence accelerated the carbonate dissolution and weathering of silicate minerals. Biotite and plagioclase were the major reactants and K-feldspar and muscovite were the minor reactants within the Lirung glacier drainage basin and contributed about 35% of the total cations into the meltwater. Clay minerals kaolinite and smectite were produced during the chemical weathering reactions as major products. Bisiallitization was the principal weathering type and ratios of silica to alumina remained the same for both seasons, suggesting that the principal weathering mechanism remained the same throughout the year within the Lirung glacier basin. Dissolution processes were more rapid during post-monsoon than pre-monsoon season probably due to high runoff. The highest flux of chemical species was observed in the evening and lowest in the morning. Snow samples collected from highest depth showed slightly higher concentrations of major solutes than shallower samples reflecting either geologic influence or the effects of sublimation. The higher discharge of weathering products at the Lirung outlet suggests that the high rates of weathering in the central Himalaya are probably due to the rapid tectonic uplift in the region.

7. ACKNOWLEDGEMENTS

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ABSTRACTS

Ev-K2-CNR climatic studies at CEOP Reference sites in Himalaya and Karakorum regions

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Himalaya and Karakorum Regions include the highest mountain ranges and they lie in the climate area characterized by the monsoon regime influencing a wide areas of the Asian continent with consequent and remarkable repercussions on the worldwide economy.

The Ev-K2-CNR's monsoon study started in Himalaya in nineties with the installation in the high Khumbu Valley of an Automatic Weather Station (AWS) near the Pyramid Laboratory (5050 m, Lobuche, Nepal). The first results have allowed to reach a deep comprehension of the monsoon local characteristics, pointing out the importance of the long period of observations carried out at the Pyramid. The importance of these results have suggested the installation of two news AWSs (implemented with new sensors) near the Pyramid Laboratory, and other three AWSs in Lukla (2260 m), Namche Bazaar (3570 m) and Pheriche (4260 m).

Recently (2004 and 2005) the investigated area extended also to the Karakorum range, with the installation of two AWSs in the Baltoro Glacier areas, Pakistan, near Urdukas (4000 m) and at Askole (3000 m).

The activities performed by Ev-K2-CNR in Himalaya and Karakorum are a part of the SHARE-Asia (Stations at High Altitude for Research on the Environment) Integrated Project that aims to study the complex mechanisms of interaction between the local and synoptic atmospheric circulation. Since 2001 the activities in Himalayas are included in CEOP (Coordinated Energy and water-cycle Observation Project, formerly Coordinated Enhanced Observed Period) and the Pyramid station is a reference station. CEOP has the objective to study the water and energy budgets connected to climatic variability. These activities are linked with ABC/UNEP (Atmospheric Brown Cloud/United Nations Environmental Program), which aims to study the impact of tropospheric pollution on the regional and global physical-climate system. In the framework of the SHARE-Asia and UNEP-ABC projects, the remote monitoring station ABC-Pyramid Observatory has been installed in the Khumbu valley at 5079 m a.s.l., near the Ev-K2-CNR International Pyramid Laboratory to monitoring and sampling of atmospheric compounds (atmospheric aerosol and trace gases) at high altitude in Eastern Himalaya.

The main results obtained within these activities permitted to highlight the weak rise of temperature over more than 10 years of measurements carried out at 5000 m and the monsoon onset mechanism using multiple AWSs installed in the Khumbu Valley along 2300 m of altitude gradient. The low increasing of temperature, according with another station located in the Khumbu Valley (Syangboche, DHM), indicates a complex effect of global change on high altitude areas and will be very carefully studied.

Important effect of air mass transport processes on Himalayan atmospheric composition appeared from the first year of atmospheric aerosols and trace gas measurements at the ABC-Pyramid station.

These high altitude activities performed in Himalaya can provide important information about the complex interaction among monsoon regimes, atmospheric composition and circulation as well as high mountain ranges, an issue that, in the next future, will require more attention in the framework of general studies on global change.

Key words : Khumbu valley, monsoon

Disasters Associated with Climate Change and Hydrological Extremes in the Western Ghats Mountain Region of Kerala

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ABSTRACT

Increasing vulnerability to natural hazards associated with hydrological extremes as a result of climate change has become a serious issue in the State of Kerala in India. Orography of the Western Ghats Mountain that borders the eastern side of Kerala produces heavy and intense rainfall. Because of the steep slopes, the water flows fast down, creating floods in lowlands. As the topography makes conservation measures difficult, the State experience serious water shortage and drought condition during non-rainy months. Recent changes in rainfall amount and seasonality has worsened the condition creating social, environmental and economic problems. Water related disputes are worsening with decreasing water availability. Water is becoming a rare and costly commodity in a region that receives 3000 to 4000mm of rainfall annually. Increased intensity of rainfall leads to erosion and sedimentation, affecting river runoff and storage capacity of dams. Erosion and sedimentation have considerably reduced the river runoff and has made some of the once perennial rivers seasonal. Landslides and flash floods are becoming more common, causing casualties. Human interference in the mountain environment adds to the climate related disasters. Deforestation and introduction of plantation crops replacing the natural vegetation has affect the topography and water holding capacity of soil, reducing summer water flow in the rivers and storage capacity of reservoirs. Construction of a number of dams and large-scale sand and rock quarrying in the mountain region further degrade the environment. A comprehensive study of the climate related disasters in the Western Ghats Mountain region is made in this paper. Hydrological conditions during the last 100 years and the impact of hydrological extremes have been analysed. An assessment of the existing policies and strategies has been made. The State lacks an efficient disaster management programme and a policy for climate change impact mitigation. The rules and regulations to protect the forests and environment are not properly implemented because of various social and political reasons. Guidelines for a climate change adaptation policy and an appropriate environment policy to face the new challenges have been provided. Suggestions to minimise the impact of natural hazards and the proper implementation of policies and strategies have been provided, taking into consideration the environmental, political, social and economic situations in the State.

Key words : climate change, disasters, rainfall

Green Energy solutions for Climate Change Impacts

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ABSTRACT

Water Resources Conservation is closely linked with ecological disturbance and climate change. Water Cycle presents water in different forms: ocean, vapour, rainy clouds, rivers and their man-made reservoirs, lakes and ponds, ground water storage and most importantly, as glaciers on high mountains like the Himalayas which have been contributed to the perennial rivers. Rainfall that replenishes these water bodies is unevenly distributed globally - in any particular region for that matter. The numerous huge reservoirs and canals are results of human attempts to distribute the available water. These activities in agriculture industry resulting in ecological disturbances and climate changes are, in fact, the origin of global warming phenomenon. But this is negligible as very minor and human survival- centric.

Subsequent industrial explosion, particularly the fossil-fuel and carbon based green house gas emissions, phenomenal growth of automobile and aviation industry, invasion into space that triggered off a nuclear explosion race etc., however, have taken the global warming to such a high threshold that it has become the prime concern of the entire world community - except perhaps the commercial one having a vested interest in fossil fuel based carbon economy. The scientific community has been raising loud alarms against such human activity-released gases like CO_2, non-CO_2 gases like methane, nitrous oxide, halocarbons etc. and their contribution to global warming and consequent climate change. The crux of the issue is, the climate change cannot be managed post- facto.

In 1800, at the start of the industrial revolution the CO_2 level in the atmosphere was 280 ppm and the recent estimate puts it at 380 ppm. Therefore, the subject of Global warming and climate change has moved into the main stream of the political debate, which has given birth to Kyoto Protocol, the implementation phase of which (i.e, 2008-2012) is drawing very close now.

The biggest threat of the Global warming is perhaps to the glaciers of the Himalayas, facing a reduction or total ablation. The general temperature of the region has risen by 1 degree Celsius, which is almost double the rise (0.6 Celsius) measured just 30 years ago. The Himalayas bordering / seating on it many a State is an international entity and in the event of such a situation the catastrophe can be better imagined than stated. The Himalayan Glacial cover is 500,000 sqkm, releasing 8.6M.m^3 of glacial melt every year. The annual per capita fresh water supply available now is 1900m^3, which is estimated to fall down to almost half (1000 cubic meter)!

The paper deals with the devastating consequences to India with three perennial rivers: Indus, Ganga & Bhramaputra fed by these Glaciers and the drastic measures needed, like, moving away from a Fossil fuel economy to one of solar energy where lies its possible survival.

Key words : climate change, global warming, glaciers, rainfall

Impact of climate change in Afghanistan

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ABSTRACT

Afghanistan is a mountainous country with an arid and semi arid conditions and which experiences extremes of climate and weather. Winters are cold and snowy, and summers hot and dry. The wet season generally runs from winter through early spring, but the country on the whole is dry, falling within the Desert or Desert Steppe climate classification. Very little snow falls in the lowland deserts of the southwest, but the snow season averages roughly October-April in the mountains and varies considerably with <u>elevation</u>. Observational evidence and future climate change scenarios suggest an amplification of climatic contrasts across the Afghanistan. This is seen most prominently in the marked increase in notable flood events and drought episodes and may profoundly affect water resource systems in vulnerable areas, as exemplified by the 1997-2001 in south, south west and north west of Afghanistan partly affected more but in north and north west relatively not so sever. Improved weather during the 2002/03 winter and summer seasons contributed to a <u>recovery</u> in Afghanistan's grain output in key growing areas, following three years of drought. The 2003/04 crop season began with planting of winter grains in October. Early indications point to continued improvement of growing conditions in the northern provinces. The southern and southeastern provinces reflect very dry conditions, similar to the start of 2001year's winter grain The 1997-2001drought resulted in severe stress to the Afghanistan water supply, most of the river during summer dry and most of glaciers reduced and caused problem in long term, and the growing season in all provinces changed by the 15 -20 days later or earlier. This research is an investigation for all Afghanistan and partly and for Kabul River basin as a model we choose Logar valley ,so in this case the result shows natural climatic variability and possible much future climate change in Logar valley and all over Afghanistan. The temperature increased by 2-5 degrees if we compare to pre ware situation or before 1980.

Key words : climate change, flood, drought

Climate change and its impact on crop production in Jammu and Kashmir

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ABSTRACT

The pollutants or aerosols, resulting from combustion of fossil fuels, biomass burning and other activities have led to change in earth's radiation balance. These changes in atmospheric composition are likely to alter temperature, precipitation pattern, extreme events and other aspects of climate on which the natural environment and human system depend. Climate change will impact various regions and sectors differently based on their sensitivity and adaptive capacity and therefore vulnerability.

In recent years the potentially countervailing influence of aerosol forcing and increased greenhouse gas forcing on the atmosphere has become a new focus of attention. Aerosols in the atmosphere influence the radiation balance of earth directly through scattering and absorption and indirectly by altering cloud properties. A study of climate characterization was carried out by Agro-meteorological Research Centre, SK University of Agricultural Sciences and Technology, Jammu for two major cities Jammu and Srinagar of Jammu and Kashmir State (India) representing low altitude subtropical region and temperate region, respectively. The data revealed that the day temperature in Jammu has decreased by 0.70 ^{o}C from last two decades while night temperature has gone up by 0.60^o C during this period. On the other hand in Srinagar city, both maximum and minimum temperatures have gone up by 1.0^{o}C and 0.40 ^{o}C respectively. Similarly the rainfall in these cities has also changed with increasing trend of 2.0 mm per year in Jammu and decreasing trend of 8.0 mm per year in Srinagar which is alarming. Pollutants resulting from steep industrialization, vehicular pollution, biomass burning, dust storms etc might increase the Aerosol Optical Depth (AOD).This results in variation in radiation balance, alter in the ecosystem thereby change the scenario of the crop production which is being discussed in this paper.

Key words **:** Climate change, temperature, rainfall, crop production and Jammu & Kashmir

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Future Water Availability Scenario of the Kangsabati River under the Threat of Climate Change Using HEC HMS

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ABSTRACT

This study attempts to provide a future water availability scenario for the Kangsabati River in Puruliya, West Bengal under the climate change conditions. The climate change impact assessment on water resources can best be handled through simulation of the hydrological conditions that shall prevail under the projected weather conditions in that area. Climate change is likely to worsen the existing situation by further limiting water availability. Under a changed climatic regime for any given region, the combined effect of lower rainfall and more evaporation would have dire consequences. Both these would lead to less runoff, substantially changing the availability of freshwater in the watersheds.

Agricultural demand, particularly for irrigation water, which is a major share of total water demand of the country, is considered more sensitive to climate change. An attempt has been made to quantify the impact of climate change on the water resources of the Kangsabati river catchment, using a distributed hydrological model HEC – HMS after due calibration using historical data.

A very well calibrated Hydrological Engineering Centre, Hydrological Modeling System (HEC HMS) will be used to generate a future water availability scenario for the year 2050 using statistical data from IITM, Pune as input.

Under the threat of global climate change, sustainable development of the Kangsabati basin is very necessary for proper water resources management for future generations.

Key words : Future Water Availability, Kangsabati River, Hydrological Modeling, Climate Change Impacts, HEC HMS Model, Water Resources Development.

Recent trends in rainfall, discharge and temperature for Satluj basin (India)

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ABSTRACT

Indian mountain glaciers and weather system are key variables for early detection strategies in regional climate-related observations. In the present study, trends of rainfall, discharge and temperature have been evaluated for the Satluj basin. The Satluj river originates from the lakes of Mansarover and Rakastal in the Tibetan Plateau and covers an area of about 22,305 km^2 up to Bhakra in India. The elevation of the catchment varies from about 500 to 7000m. For evaluating the effect of climate change, attempts have been made to identify trends in time series of rainfall, discharge and temperature data by studying the anomalies with time and application of trend identification techniques. Trends for both low altitude and high altitude stations have been investigated. Three non-parametric tests, i.e., Kendall's rank correlation test, Mann-Kendall test and Spearman's Rho test were applied to detect monotonic trends in each of the series. The results indicate an increasing trend in temperature, rainfall and discharge at 95% confidence level.

Key words : rainfall, discharge, temperature

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Identifying the Climate Extremeties and the Geographical Areas

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ABSTRACT

The climate change in general is change in rainfall and temperature pattern in specific areas which has affects various sectors such as agriculture and water resources. For this very purpose comprehensive analysis of the key meteorological parameters of Nepal has been conducted to identify the climate extremities and geographical locations. The spatial pattern of mean maximum annual temperature trends shows the increasing trend in almost all over the entire country. The inter-annual variation of rainfall is quite large that no significant trend in temperature has been observed. The general tendency towards increasing or decreasing trend is more significant in rainfall. Most of the Eastern, Central and Western Development Regions shows increasing trend in pre-monsoon rainfall, while Mid-western and far western Development Regions shows the decreasing trend. Siwalik and the Terai belt which generally receive less total seasonal rainfall receive the highest 24 hour rainfall. These regions are therefore prone to flash flood and inundation. Especially, the southern parts of Central and Western Development Regions are more susceptible to the floods in comp0arison to the other regions.

Key words : monsoon, extremities, annual variation, climate.

Climate Change in Nepal: Impacts and Challenges

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ABSTRACT

Nepal is a mountainous country with an area of 147,18 km² and population of 27.1 million. Nepal possesses different climatic zones that are mainly determined by the topography, location, and monsoon precipitation. Due to active tectonics, steep slopes and highly concentrated monsoon precipitation, the country is extremely vulnerable to different types of natural disasters such as earthquakes, landslides and floods.

Accelerated process in Green House Gas (GHG) emission has gravely influenced the natural climate change process in Nepal. Nepal shares only 0.025% of global emission but it is one of the greatly climate change affected countries of the world. In Nepal, water resources, agriculture, forest, biodiversity, health and livelihood are some of the major vulnerable sectors in the context of climate change. Analyses of the temperature of last few decades show that the average temperature in Nepal is rising at a rate of 0.06° C per year. This has resulted in the expansion of glacial lakes to a highly dangerous scale. Tsho Rolpa, Imja glacial lakes are some of the examples. Studies show that an increase in temperature by 0.06° C per year, the theoretical hydropower potential of Nepal will rise by 5.7% by 2030 AD but will decreased by 28% by the end of this century. An increase in temperature by 3° C would cause an increase in annual irrigation water demand by 11%, while other parameters of water demand keeping constant. Nepal is already experiencing water deficit during 4-5 months in non-monsoon season. Further warming may worsen the situation.

Studies also show that ELA has been shifting up by 25-79m (1959-1992), retreat of majority of glaciers by 30-60m (1970s-1989) and thinning of the glacier surface by nearly 12m (1978-1989). The rate of retreat has accelerated in recent years. Fast increase in glacier-melting process has caused creation of many new glacier lakes and expansion of existing ones. As a result, the risk of GLOF has bee increasing.

Analysis of precipitation data from station records all over Nepal does not reveal any significant trends. The models predict almost no change in the western part and 5 to 10% increase in the eastern part of the country in winter season. During summer, however, the whole country is expected to experience increase in precipitation in the range of 15 to 20%.

Nepal is also rich in biodiversity. Nearly 7,000 species of higher plants are found in Nepal, out which 5% are endemic to Nepal and 30% endemic to the Himalayas. There are more that 75 types of vegetation. There exist 118 types of ecosystems in the country. Such rich biodiversity is likely to be adversely affected due to climate change.

The impact of climate change has put forward serious scientific and socio-economic changes to Nepal which are needed to be addressed through the proper identification of suitable climate models, vulnerable areas, adaptation and mitigation measures. Selection of proper climate-friendly technologies and creation of public awareness are equally important.

Key words : climate change, Nepal, glacier

Hydraulic modeling of sediment transport and fluvial processes in mountain-piedmont rivers

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The long-term experience of the laboratory-field studies and
Hydraulic modeling of sediment transport and fluvial processes in the
mountain-piedmont rivers, made at the State Hydrological Institute
(St. Petersburg, Russia) is presented in this paper.

ABSTRACT

General laws and peculiarities of forming and dynamics of river channels and flood planes composed of pebbles and gravels are outlined and discussed. River channel morphological types, mesoforms (channel middle and side bars) and microforms (dunes) are described and corresponding design dependences are presented for their geometric and dynamic characteristics.

Examples of the Hydraulic modeling of sediment transport and fluvial processes in the mountain-piedmont river reaches on undistorted mobile physical models are given (Laba, Khara-Murin, Utulik and Anosovka river case-studies). The scale model studies provided the most effective design decisions for the bridge crossings after-floods reconstruction on the Khara-Murin, Utulik and Anosovka rivers and the most admissible and rational way for the gravel excavation from the Laba river bed.

Some results and findings of the studies on the problem of bedload discharge and yield assessment in mountain-piedmont rivers are discussed and recommendations are made on the selection of several suitable formulae for their application in the mountain-piedmont river conditions both in case of structural (dune) and nonstructural movement of bedload.

Experimental studies of the flow turbulent structure and characteristics in the Hydraulic flume with the heightened roughness bed, typical for the mountain rivers, revealed the peculiarities of forming the turbulent patterns and flow characteristics in mountain-piedmont rivers, depending on the size and granulometric composition of the bed material.

Key words : hydraulic modeling, mountain-piedmont rivers, sediment

Application of remote sensing technique for the assessment of sedimentation in Bhakra Reservoir in the western Himalayan region

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ABSTRACT

The entire Himalayan region is afflicted with a serious problem of soil erosion and therefore the rivers flowing through this region transport a heavy load of sediment. Sediment deposition into storage reservoirs built for hydropower generation has several major detrimental effects which include loss of storage capacity, damage to or impairment of hydro-equipment, bank erosion and instabilities, upstream aggradations, and effect on water quality. Conventional methods, such as hydrographic survey and inflow-outflow approaches, are used for estimation of sediment deposition in a reservoir, but these methods are cumbersome, time consuming and expensive. There is a need for developing simple methods, which require less time and are cost effective.

The present study deals with an assessment of sediment deposition in the Bhakhra Reservoir located on the Satluj River in the foothills of the Himalayas using the remote sensing data. Multi data remote sensing data (IRS-1C, LISS III) provided the information on the water-spread area of the reservoir which was used for computing the sedimentation rate. The revised capacity of the reservoir between observed maximum and minimum levels was computed using the trapezoidal formula. The loss in reservoir capacity (live zone) due to deposition of sediments for a period of 41 years (1965–2006) was determined to be 821.27 Mm^3, which gives an average sedimentation rate of 20.07 Mm^3 $year^{-1}$. The original designed live storage capacity of the reservoir was 7436.034 Mm^3. The average rate of sedimentation using hydrographic survey data for the period (1965-2001) as per Bhakra Beas Management Board (BBMB) report was 20.03 Mm^3 $year^{-1}$ for live zone. A comparison of the results shows that the rate of sedimentation assessed using the remote sensing based approach was close to the results obtained from the hydrographic survey.

Key words : Remote Sensing, Bhakra Reservoir, Sedimentation

Forecast of the Mountain Nurek Reservoir Sedimentation

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ABSTRACT

The Construction of the dam of Nurek HPS has started in 1961. At the period of 1972-1989 years sediment flow of the Vakhsh River was measured in 1977, 1980-1982 on Komsomolabad and in 1978, 1985 on Kishrog Hydropost. In 1977 and 1985 years sediment flow, measured on Komsomolabad station changed in accordance with change of wateriness year from 55,2 up to 38,3 mln. t, on the station of Kishrog from 86 up to 59 mln. t.

On the estimation of the Institute of Mathematics of AS of Tajikistan additional value of tributary sediment from Komsomolabad up to Nurek reservoir is 4 mln. t.

Thereby, the sediment flow Vakhsh River at the input in Nurek reservoir in condition average on wateriness of year can be evaluated in 60-65 mln. t. The calculation carry out with take into consideration above estimation demonstrated that by the sixth year of constant exploitation useful volume of the reservoir will decrease to 200 mln. m^3 and to 11th year - to 650 mln. m^3.

This paper presents the initial forecast sedimentation of Nurek reservoir. Under its formation was accepted that the process of sedimentation will conditionally begin in 1978, and its intensity at the first five years was 40 mln. m^3 per annum, but in all following years - 90 mln. m^3 per annum.

Key words : Reservoir, Sedimentation

Climate Change and River Sediment - A Case in Kali Gandaki River near Lete-Ghansa, Mustang of Nepal

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ABSTRACT

The study area is a part the fragile mountains and lies in the head watershed of Kali Gandaki river. The geology of the basin is of Tibetan – Tethys sedimentary rocks of Paleaeozoic and Mesoic ages. Part of area is probably overlain by the sediments of Neogene to Quaternary age Ground based observation is relatively poor in Nepalese Himalayas. No glacial monitoring networks lie in Mustang area. The paper based on short term observation of temperature, rainfall, river flow and river sediment and, limited historical data related to river morphology.

The spatial trend of temperature follows the altitude variations. Fourth Assessment Report (AR4) of the Inter Governmental Panel on Climate Change warns that the warming of the climate system is unequivocal and finds evidences of increase in global average air and ocean temperatures resulting widespread melting of snow and ice. Due to temperature increasing, the impacts are experienced in the Himalayan glaciers

The spatial pattern of mean maximum temperature trend showed increasing trend in almost the entire Nepal which is higher in the North (high altitude). The study area fall in the region where the mean minimum annual temperature is in decreasing trend. The area receives lowest rainfall in Nepal. The highest rainfall observed is in Mustang at Lomanthang is 143.6 mm only.It is observed that the increasing trend in extreme rainfall results in increasing wash loads to the rivers in the area having watershed morphology like Mustang. Retreating glaciers, melting of permafrost and annual fluctuation of snow cover of the area in the context of rising temperature due to accelerating global and local warming are also the causes of sediment yield.

Key words : Kali Gandaki, Mustang, Permafrost, River sediment, Local warming

Sedimentation is one of the major challenge for sustainable hydropower development in Nepal - A case study in the Kulekhani Hydropower Project.

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ABSTRACT

Sustainable development is the development that meets the needs of the people today without compromising the ability of future generations to meet their own needs. Water resources development is sustainable when it dose not significantly or progressively diminish the resources quantity or quality over the long term, and maintains the diversity of natural habitats and ecosystems. Sedimentation are generally considered as an undesirable but unavoidable challenge for sustainability of hydropower projects.

Despite adequate availability of surface water, several hydropower projects have not been yielding expected output primarily due to sedimentation problems, which were underestimated at design stage in most of the cases. Sediment production in Nepalese watersheds has generally been acknowledged to be the highest in the world and little reliable data of actual sediment production is available.

The Kulekhani Hydropower system in Makawanpur District is located in the Middle Mountain Zone of the Central Development Region of Nepal. The Kulekhani I with installed capacity of 60 MW was commissioned in May 1982. Kulekhani II Power Station with installed capacity 32 MW utilizes water from the tailrace of Kulekhani I and was commissioned in December 1996. So far, this is the only project offering seasonal water storage in Nepal. Unfortunately, it has lost more than 25% of its total storage capacity during its 22 years of operation (1982-2004). This paper highlights the sediment issues and its management mostly focusing on the Kulekhani Hydropower Project.

Key words : Sedimentation in Himalaya, Kulekhani Reservoir, sediment management and sustainability of hydropower projects.

Long-term fluctuations and trends in water discharge and suspended material transport in the Polish part of Carpathian Mountains in the 20th century (Central Europe)

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ABSTRACT

Regular measurements of river discharge in the northern part of the Western and Eastern Carpathian Mountains (Southern Poland) drained by Vistula river, were started in 1930, whereas the measurements of the suspended material transport were started in 1945. The first conclusions concerning the trends of changes of river discharge in this area related to long-term precipitation variation and human impact became were formulated in the 1960s and 1970s. There were even contradictory opinions indicating the increase or decrease of water discharge. Not earlier than in the 1990s, having long enough series of measurement results, was it possible to notice true changes in trends of water discharge and suspended material transport. Until now and since 1930 there has been one full 40 year- long cycle in water discharge, with a maximum in about 1970 and minimums in the 1940s and in about 1990. These fluctuations of water discharge are shown by the changes of average annual river discharges and by variable in time frequency of large high water stages. The frequency of large high-water stages increased again in the mid 1990s. There are also visible 10-year fluctuations of rivers discharge caused by clustering of large high-water stages in several-year long periods. The distinguished cycles of Carpathian rivers' discharges refer to fluctuations of the Vistula river discharge known from the literature, which are approximately 24,0 – 36,5 years long or 53,0 – 57,0 years long, as well as to the cycles 12,5 – 14,0 years long. They refer also to the discharge cycles recorded in other European rivers. The fluctuations are still noticeable, despite the increasing number of large dams. Increasing or decreasing trends in water discharge of the rivers are also indicated in earlier papers, referred to the time period before and after 1970, and therefore were assumed as not representative for a long term period. The present data series, even longer than 70 years, are more credible, but still not suitable enough for the prognosis of the changes of water discharge of the Carpathian rivers in the period longer than at least half of a 40 year- long cycle. In the transport of suspended material, despite its decreasing trend due to forestation and influence of dams, still over 10-year long fluctuations are noticeable. In this case, due to the overlapping of climatic and anthropogenic factors, the prognosis of changes is also difficult.

Key words : water discharge, suspended material transport

Computing and Analyzing Selected Meteorological Parameters and Major Components of Heat balance : A Case of Langtang Hmalaya

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ABSTRACT

Snow capped areas in the Himalyas are most vulnerable to global warming and are among the least studied area with connection to the climate change phenomenon. In order to explore different aspects of glacier retreat, this research admits some facts on energy balance and mass balance of snow and glacier in the Langtang region of Nepalese Himalaya with respect to turbulent heat flux, i.e.; sensible heat flux and latent heat flux. Kyangjin meteorological station in the Langtang valley was chosen for this purpose, where meteorological information was available for six months.

Energy Balance method was used to derive the heat flux components. It was observed that the variation in heat flux trend was consistent to the meteorological parameters and its contribution was high for the energy balance. The latent heat flux (-90W/m2) was about five times higher than the sensible heat flux (-20W/m2).

As the contribution of the heat flux to the energy balance is high, it is recommended that these components should not be ignored when dealing with mass and energy balance.

Key words **:** glacier, mass balance energy balance, turbulent heat flux, Himalaya, Nepal.

Chemical W eathering in Central Himalaya: Focus in Dissolved Silica: Dynamics in Glacier Meltwaters

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ABSTRACT

Major ion chemistry of glacier meltwater draining from Lirung Glacier in the Himalaya Mountains of Nepal studied to investigate weathering processes and the diurnal variation of major solutes. Weathering at study site was primarily fueled by sulfide oxidation, with the dissolution of carbonate and aluminosilicates as suggested by the high calcium and sodium concentrations in Lirung Glacier meltwater. Anorthite and albite appear to be the dominant primary minerals undergoing weathering, with bisiallitization the dominant weathering pathway throughout the seasons. Snow samples showed slightly higher concentrations at depth than in shallower samples, suggesting the influence of contact with underlying geologic strata or the effects of sublimation in the older, deeper snow. Major solute concentrations were slightly higher in pre-monsoon than the post-monsoon period in diel samples. The highest discharge of major solutes was observed in the evening (with highest meltwater volume) and lowest in the morning in both sets of samples; patterns in concentration were reversed. The high discharge of weathering products from Lirung Glacier reflected the intense chemical weathering of aluminosilicates and carbonates in the central Himalaya. Biotite and plagioclase were dominant reactants and K-feldspar and muscovite were minor reactants within the Lirung drainage basin. Kaolinite and smectite were the dominant clay minerals produced during the chemical weathering processes within the catchments.

Key words **:** Chemical weathering, Central Himalaya, Major solutes, Glacier meltwater, Aluminosilicates, Carbonates, Lirung glacier

Impact of variations of large-scale atmospheric circulation on snow cover spatial-temporal changes in Central Asia mountains

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ABSTRACT

Time series (since 1940s) of snow depth in the mountain systems of Tien Shan and Pamir are analyzed together with routine meteorological data and indices of the dominant large-scale modes of extratropical atmospheric circulation. Advanced multi-dimensional statistics has been used for the study.

The analysis allowed us to reveal main peculiarities of interannual spatial-temporal variations of the snow depth. Mostly increase of the snow amount correlates with more intensive cyclonic circulation on the polar front during the cold season. Usually the air temperature also increases with more intense cyclonic circulation in the region. Under anticyclonic conditions, colder weather with lower precipitation prevails in the Central Asia mountains due to more frequent cold invasions from the north. The spatial distribution of the snow cover is also dependent on the atmospheric circulation. On the windward (with regard to the main tropospheric flow) slopes in a particular year, one usually can see heavier snow cover, while on the leeward slopes snow depth in this season tends to decrease.

Number of melting events during winter is also an important characteristic for the snow cover seasonal evolution. This parameter turns out to be dependent on certain circulation mechanisms. Depending on the location and altitude, certain mechanisms and indices demonstrate significant correlation to the number of melting events in the Central Asian mountains.

Key words : snow, Central Asian Mountains, circulation

Evaluation of snow cover area using MODIS and NOAA images in western Himalayan region

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ABSTRACT

Information on snow cover area (SCA) is very essential for wide range of hydrological studies. The ground based estimation of SCA is a vital parameter in various snowmelt runoff modeling. In rugged and climatically complex terrain like Himalaya, the estimation of this parameter is extremely difficult and expensive. The emergence of remote sensing technique has provided a reliable and economic technique to map SCA. Until now NOAA data were widely and effectively used for SCA estimation in several Himalayan basins. The suit of snow cover products produced from MODIS data were not yet been used in SCA estimation and snowmelt runoff modeling in any Himalayan basin. The present study was conducted with an aim to estimate SCA using NOAA-AVHRR data and AQUA/TERRA MODIS data and access the accuracy. The total SCA was estimated from the separate images for fifteen dates spread over a period of four years. The results were compared with the ground based estimation of SCA and very good results were observed. Snow mapping accuracy with respect to elevation was tested and it was observed that in higher elevation MODIS sensed more snow and proved better in mapping snow under mountain shadow condition. MODIS data product has an automated snow-mapping algorithm, which reduces the time and errors incorporated during processing satellite data manually. Considering all these factors it was concluded that MODIS data could be effectively used for SCA estimation under Himalayan condition which is a vital parameter for snowmelt runoff estimation.

Mathematical methods for determination of main Characteristic of the Mountain Glaciers

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ABSTRACT

For conditions of Tajikistan whose territory basically is presented by mountains, data on temperature, precipitation and other characteristics in remote mountain tops have great value. It is a problem it became actual after disintegration of the USSR when the national states yet in a condition to rehabilitate meteorological stations existing earlier. Now in conditions of global climate change the monitoring and the control of a condition upstream of river formation very important. For example, discharge of the rivers originating from glaciers essentially depends on temperature of district of glacier location at different heights, and observation posts are located at the bases of mountains at low heights. For definition of some basic meteorological characteristics of heights mountain glaciers on the basis of corresponding meteorological data from observation post located at the around of glaciers on more low heights we offer method corresponding to assumed that the investigated district in three-dimensional system of coordinates.

Key words : Mountain, glacier, temperature, precipitation

Evapotranspiration and water balance in mountain regions: lessons from the Tibetan Himalaya

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ABSTRACT

Water availability is one of the most pressing issues in global change related mountain research. While mountains are recognized as water towers for the surrounding lowlands there is only unconsolidated knowledge about the individual water balance components precipitation and evapotranspiration (ET), disregarding glaciers and permafrost as water sources, in mountains. Most studies focus entirely on the spatial distribution of precipitation neglecting the variability of ET. While this may be permissible in arid water-limited environments, in humid energy-limited environments (where precipitation > ET) run-off, plant growth, erosion and water availability in general depend mainly on ET rates. Published ET estimates however often rely on temperature-based estimates like the Thornthwaite or Hargreaves method that are extremely unreliable and underestimate ET in the Tibetan Himalayas by up to 100%.

ET rates from the Tibetan Himalayas (~ 90° - 102° E, 27° - 32° N) show that at altitudes of ~ 4000 m annual ET rates of ~ 1200mm are comparable to those of subtropical lowlands at similar latitudes in China and that ET rates do not necessarily diminish with altitude. Results presented illustrate the importance of

AET estimates made with a physical combination method (Penman-Monteith method) as the only reliable estimator in mountain regions

Key words **:** Evapotranspiration, water balance, Tibetan Himalayan

Heat Invades the glaciated tops of HKH Ranges

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ABSTRACT

The analysis of daily climatological data of 10 meteorological stations (at elevation 1500m to 2500m a.m.s.l) for the period of 25 years (1981-2005) on pentade basis revealed the dynamics of thermal regime along the southern slopes of HKH region. The results show that 30° C isotherm has moved northward at about 350 m above its existence in early 1980s. Frequency analysis of moderate (Maximum Temperature > 35° C) and severe (Maximum Temperature > 40° C) heat waves shows that they have not only been increased in number but also their continuous persisting duration has almost been doubled as compared to 1981-85. Longer the persistence of heat wave greater the melting rate and hence more the volume of melt water. It is reflected in simultaneous rise in stream flows. The pentad ending with 2005 had been the hottest one which thermally influenced the snow and glacier reserves of HKH. A centurion extreme event of snowmelt flood occurred in June 2005 in the Indus River and its tributaries. The increasing thermal build has caused the general reduction in precipitation amount on the southern slopes of HKH ranges. Invading upward thermal flux and decline of precipitation may be attributed to the anthropogenic activities. Depletion of Siachen glacier is a glaring example of warming due to human activities.

Key words **:** snow, glacier, heat

Snow Monitoring in Pakistan Using Landsat Data

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ABSTRACT

Snow cover is important feature both for global climate predication and water resource management. Due to inaccessibility in mountainous terrain and very limited in-situ data acquisition and availability, satellite remote sensing technique is utilized to monitor the snow and glaciers in Northern Pakistan. This research demonstrates the assessment of snow volume using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) imageries. However, the data collected by the satellites contain the undesirable atmospheric effects. In addition, the presence of cloud cover in a satellite image impedes the accurate land cover mapping. First, the atmospheric model is used on the images to rectify the atmospheric contribution. Second, Automated Cloud Cover Assessment (ACCA) algorithm is applied to detect, assess and remove the cloud cover in the satellite imageries. Finally, snow albedo is estimated over the snow cover region. The results show that satellite remote sensing can be successfully used for the retrieval of snow pack parameters.

Key words **:** ACCA, TM, ETM+

Modern condition of Mountain glaciers of Tajikistan and adaptation of economic activities in conditions of global warming

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ABSTRACT

The summer of 2006 Agency on hydrometeorology of Republic of Tajikistan had been organized expedition for studying glaciers of Hissar mountains and Northwest Pamir. Thus topographical shooting of the ends of glaciers, their cross-section structures, photographing from different points, the description of all changes which were having place on glaciers for the last years was carried out. Glacier of Hissar mountains - Yakarcha locate in high Maykhura Rivers, the right making Varzob river which are flowing down from a southern slope of Hissar Mountains. Varzob is right inflow of Kofarnigan. Yakarcha glacier is northeast exposition in length of 1,5 km and the area 0,9 km². Height of the tongue is 3800 m, firn lines - 3940 m, the maximum part of glacier - 4160 m; volume of a glacier 23 million m³. As appeared, for 18 years (the previous shooting was in 1988) the glacier has not changed almost. Global warming was not reflected almost in it. All glacier including the tongue in July has been still covered with a dense layer of a snow in height up to 0,5 m because of that it was not possible to make topographical shooting. This testifies that thawing of Yakarcha glacier began only at the end of July - for a month later than the norm. The second expedition surveyed glaciers in Zarafshan Karatag pools. Karoviy glacier GGP (received the name in honor of the Hydrographic party} lies on northern slope of Hissar mountains in the river basin of Saritag (Iskandarkul lake). The length of a glacier of 1,16 km, average width of 0,47 km, the area 0,54 km², begins it at height of 3820 m, comes to an end at height of 3520 m above sea level. For last 16 years (1990 - 2006) a glacier has receded on 35-55 m annually the average its speed has made about 3 meters per year though in the eightieth years of the last century it has made about 8 meters annually. Shooting of a cross-section structure has shown that the glacier has not changed almost, and recedes only from a final part.

Key words : global warming, glacier

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Impact of climate change on the runoff from a highly glacierised catchment in Nepal Himalaya

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ABSTRACT

The large river basins of South Asia are dependent on water supplied by the melting of Himalayan glaciers and snowfields. The snow and glacier melt is particularly important during winter and pre-monsoon seasons, when the contribution of precipitation to the runoff is low. A daily time-step degree-day runoff model was used to simulate the snow and glacier melt from Langtang, a highly glacierised catchment in the Nepal Himalaya. The simulation was validated using observed runoff data for 7 years. next, the runoff scenarios for projected climate change scenarios for 2070-2100. Runoff scenarios were also generated for a hypothetical scenario of 50% reduction in the glacier are in the catchment. The results although preliminary, provide important insights into the variations in the runoff regime from the catchment and could be important for water resources planning in **the downstream areas.**

Key words : catchment, glaciers

Processes Controlling Snow Hydrology in the Canadian Rocky Mountains

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ABSTRACT

Field and modeling studies in the Canadian Rocky Mountain have been directed to advance the understanding of snow processes and to improve hydro meteorological models of stream flow and related atmospheric variables. Modeling studies of blowing snow over alpine terrain are showing promise in the prediction of the spatial distributions of snow water equivalent in complex environments. The model includes a complex terrain wind flow algorithm coupled to a two-phase flow snow transport and sublimation algorithm. It calculates snow accumulation as a residual of the snow redistribution and sublimation processes. An important new feature is the application of the model to aggregated landscape units having common physiographic and aerodynamic characteristics, these landscape units require much less physiographic information than do fully spatially distributed applications of the model and area suitable to application in remote alpine regions. Comparisons of model outputs to snow surveys suggest that this level of spatial resolution and physically based simulation can produce reliable snow accumulation estimates in alpine catchments. Snow ablation studies have focused on application of energy balance to estimate snowmelt over landscape units with consideration of sub-unit depletion of snow covered area. In this case hydrological response units are segregated based on snow accumulation and applied melt energy fluxes in complexes terrain. The calculated depletion of snow covered area and melt rate at a point agree well with observations from oblique time-lapse digital photography, LiDAR and snow surveys. Improved algorithms resulting from this application of field technology are being used to update a modular, object-oriented computer simulation of the cold regions hydrological cycle, the Cold Regions Hydrological Model (CRHM). CRHM can be easily and frequently updated as improved algorithms become available and used to predict both snow dynamics and stream flow from high mountains areas.

Key words : snow, Cold Regions Hydrological Model.

The Role of Watershed Management in Watershed Basin Management with Emphasis on Water Affair.

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ABSTRACT

The strategies of watershed management are permanent on three axis, "reparation and reconstruction, Keeping and prevention, extension and exploitation"

In as much as all of the activities result from water and then managing of this resource with emphasis to climatic conditions must be given special importance.

Water as an important element in sustainable development, has a main and serious role to influence human existence.

Watershed management with different practices (mechanical, biological, biomechanical and managing) makes positive effect in conservation of water and water resources management.

This paper tries to introduce this new knowledge and particularly the science of watershed management and suitable method for prevention of water induced disaster.

Key words : water_ watershed management_ Basin and water managements- water disaster.

Turning a hydrological disaster into opportunity: A case study of catchment management to improve livelihood in Rampur village in Okhaldhunga Nepal

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ABSTRACT

Mountain communities of Nepal struggle hard to cope with extreme climatic events and water-hazards mainly floods, landslides and erosion during summer monsoon from June to September and long drought leading to severe water shortages from December to May in a cyclic fashion. Every year about three hundred people are killed; thousands of families are affected as they loose properties or precious farm lands on which they depend for living and public infrastructures such as irrigation canal, trails, roads and bridges are damaged(Ref…). Some of the affected communities have been successful not only to recover from the shock of disaster and rebuild their capacity back to normal but also to improve their living standard through their collective efforts. The community of Rampur village of Okhaldhunga District in eastern Nepal is one such example that has served as model to many others for bringing a change in their living standard by employing local techniques innovatively to harvest water, diversify farming practices, enhance productivity in terrace lands and conserve forest. The remote mountain village was severely affected by landslides, floods and debris flow in July 1993 when half of the settlement went under debris that killed 23 people; lost most productive farm lands and forced many households to leave village for alternative source of livelihoods (Dahal, 1998). For centuries, indigenous techniques of watershed protection are common among mountain communities. The techniques include turning slope land into terrace farm land (khet), building ponds and slope stabilization activities like building small check dams and diversion to prevent erosion. The uniqueness of Rampur community is its motivation to enrich their traditional practices of managing the small catchment head with modern managerial skills and low-cost technologies aimed at conserving water, forest and land in an integrated approach. Therefore after 15 years of the great disaster, the village finds itself in a better position when the location has been the most preferred place for migration among the neighboring hill dwellers for easy access to water supply, electricity, effective erosion control on hillsides and enhanced forest cover and land productivity.

This paper explores and analyses the process and causative factors behind the motivation to work collectively through application of improved technologies and participatory management approaches to rebuild their villages after the 1993 flood disaster. The paper also draws lessons that can be used elsewhere in the hills to address similar problems.

Key words **:** floods, landslides, catchment

Flood forecasting system development for Carpathian Mountains area using Remote Sensing and GIS

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ABSTRACT

In contribution to Carpathian rivers flood forecasting system development for the Ministry of Emergency of Ukraine, the pilot project was conducted. The aims of the project were to develop methods for automate image processing and to develop interpolation methods for data from water observation stations.

On the first stage of the project the following data was gathered:

- digital relief (izoline vector layer) for Zakarpatsky region
- digital settlements map (vector layer)
- settlement population data (tables)
- multitemporal satellite images for pilot territory (ERS SAR, ENVISAT SAR, ENVISAT MERIS, Landsat-5 images)
- water observation station data (river level probability)

On the second stage the advantages and challenges for remote sensing data implementation to forecasting system was studied. The available Synthetic Aperture Radar and multispectral images were tested. As a result SAR images were proposed to use for automation of flood area detection, and SAR image classification method was developed using ERDAS Imagine 9.1.

On the third stage the methods of interpolation of river level probability data from water observation stations to river outfall on the pilot territory were developed. Geostatistical analyst and Spatial Analyst extensions of ESRI ArcInfo were used.

Key words **:** Carpathian Mountains, flood forecasting system

Monitoring and Management of River System Dynamics Using Geographical Information System

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ABSTRACT

In early days, monitoring and management of natural resources was a complex job. Extensive field visits, mapping, manual analysis were few of important activities. With the emergence of remote sensing technologies and Geographical Information Systems (GIS), the monitoring and management of resources became an easy job. Simple software techniques are capable of performing the complex analysis.

Rivers in their evolutionary stages present a dynamic system. They keep changing their course from time to time. The water and sand ratio also varies from time to time. The satellite remote sensing techniques provide an efficient tool in obtaining periodic information for monitoring the dynamics of the river systems and also in the assessment of the extent of migrations. Multidate satellite data in conjunction with the topographical sheets help in monitoring the dynamics of river system. All the temporal data can be overlaid on a GIS software and the analysis can be done in order to achieve the results using some GIS specific tools.

The changes in volume of water and total surface area covered by sand may predict the chances of flooding in a particular area. Inadequate sediment accumulation and monsoon downpour in an area may create expulsion of water from the surface thus causing floods. Other possible reasons for this flooding could be flood peak synchronization, Subsidence and compaction of sediments, Riverbed aggradation, Deforestation in upstream region, Soil erosion, Excessive development and Seismic & neotectonic activities in the area. The possibilities of flooding can be calculated using GIS and preventive measures can be formulated in order to avoid loss of organisms and property.

Key words **:** Geographical Information System, natural resources

Statistical Characteristics of Shower Precipitation in Mountain Regions

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ABSTRACT

Elaboration of methods for estimating maximal water discharges is an actual problem of hydrology. The traditional approach is the one based on the correlation between the runoff characteristics and those of shower precipitation. In the conditions of sparse observational network and short samples, which are typical for mountain regions, the results of the estimations of the rare events' probability turn out unreliable. More stable result can be obtained using the regionalization method, consisting in combining of independent observation data within the limits of a homogeneous region into one sample.

 Layers of precipitation in Mongolia for different time intervals were subjected to joint analysis using the method of combination of sets offered by S.N. Krytsky and M.F. Menkel. As the result, the regionalization of the Mongolia's territory was carried out. Eight homogeneous regions were distinguished for which combining observations within their limits leaded to reliable results. For five homogeneous regions including eight and more stations probability curves of probabilities and distribution curves for individual estimations of the variation coefficient were constructed

The reduction curves were improved based on joint analysis of the observations using method of G.A. Alekseev for the construction of integrated curves of precipitation. Parameters of the distribution of precipitation layers for the time intervals up to 2880 minutes and their dispersions were obtained by individual statistical processing. Four types of the precipitation reduction in time were distinguished on the Mongolia's territory.

Reduction of the rain floods maximal specific runoff under the conditions when a runoff scattering zone was presented within a river basin was investigated. The dependence suitable for the calculation purposes can be derived in this case by modification of the reduction formula.

Key words **:** precipitation, water discharges

Mesoscale Modeling & Flood Forecasting for Early Warning System

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ABSTRACT

Flash flood caused by heavy rainfall events is one of the major hydro-meteorological disasters faced by many south Asian countries annually. In 2006, Bangladesh, India, Nepal and Afghanistan all experienced flooding or landslides following the monsoon. In 2007, the flooding was some of the worst experienced in living memory, in addition to which the cyclones in Pakistan and Bangladesh placed considerable strain on resources at all levels.

Intense rainfall often leads to floods and landslides in the Himalayan region even with rainfall amounts that are considered comparatively moderate over the plains; for example, 'cloudbursts', which are devastating convective phenomena producing sudden high-intensity rainfall (10 cm per hour) over a small area. Early prediction and warning of such severe local weather systems is crucial to mitigate societal impact arising from the accompanying flash floods. A cloudburst event in the Himalayan region at Shillagarh village in the early hours of 16 July 2003 is examined. The storm lasted for less than half an hour, followed by flash floods that affected hundreds of people. The fidelity of MM5 configured with multiple-nested domains (81, 27, 9 and 3 km grid resolution) for predicting a cloudburst event is examined with attention to horizontal resolution and the cloud microphysics parameterization. The MM5 model predicts the rainfall amount 24 hours in advance. However, the location of the cloudburst is displaced by tens of kilometers.

Key words : Mesoscale Modeling, floods, landslides

Statistical Methods to Estimate Extreme Quantiles Values of Hydrological Data- A Case Study of Kali Gandaki River

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ABSTRACT

Some of the important elements to be considered by the designer in the field of water defenses and hydraulic structures with mechanical devices include the total determination of the maximum environmental loads: such as flood, maximum water level and extreme water discharges at the locations of particular interest. The specified variables are usually described by statistical distribution functions are normally used in Nepalese river for hydroelectricity design.

The design parameter of these distribution functions, various methods for hydropower generation with Medium Irrigation Method (MIP), Hydest Method as well as Catchment Area Ratio (CAR) Methods based upon available datasets. The main points of interest are the behavior of each method for predicting the extreme values with probably distribution functions. It is desirable that its expected values should be nearly equal to the true values and its uncertainty should be as small as possible. Though in civil engineering practice efficient estimation should be unbiased and fruitful for design structures.

In this paper, an overview is delineated for data management with trend analysis subsequently, the methods to predict the probability of occurrences with extreme values are presented. Application is made for design structures of small as well as medium dams of hydropower generations.

Koshi Disaster: A Lesson Learned Event in South Asia in General and Particularly in Nepal and India

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ABSTRACT

Koshi disaster caused by breaching of the eastern embankment of Koshi River at Kushuwa in Sunsari district of Nepal on 18th October 2008 displaced about 57,500 people and damaged about 4350 ha. of agriculture lands and physical properties equivalent to millions of Rupees in Nepal. Thousands of people from the most affected five districts of Bihar were also displaced by this event in India. The actual damages including social, economical, physical and environmental aspects is yet to be formally come out in both the countries. This paper highlights the causes and effects of the event and also appraises the situation of the event during and aftermath the disaster. The published and unpublished documents and data related to hydro-meteorological situation during the event, reports of emergency management assessment of the event, and other documents related to Koshi project agreement and the documents dealing governance addressing the event were reviewed in the paper. A field visit was also made in getting the primary information and the data regarding the situation of the event. The study finds that the cause of the event is a failure of hydrological structure. The structure failure was not significantly contributed to hydro-meteorological situation but it is extensively due to the lacking of good governance. So far as the concern in responding the disaster, the real practices in the preparedness to respond such type of structural failure disaster in a massive scale is almost the first in Nepal. The work carried out by the rescue teams was a successful task whereas the relief works during the emergency were not much more satisfactory especially in settlements and health components. The political support at grass root level was not a remarkable efforts aftermath the disaster. The lesson learned by the Koshi event is certainly made aware to communities, decision makers and political bodies of both the countries about the consciousness of man made disaster.

Key words **:** Koshi, disaster, Nepal

Regional Flood Frequency Modeling for Predictions in Ungauged Basins of Upper Krishna Basin of India.

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ABSTRACT

Extreme environmental events such as floods cause a lot of damage to life and property of human society. A reliable estimation of magnitude and frequency of occurrence of such extreme events is of great significance in minimizing damages by facilitating proper planning and design of civil engineering structures.

The problem of estimating flood frequency at an ungauged catchment has often been approached through regionalization techniques. In the present study, the Index flood procedure is used for regional flood frequency modeling of Upper Krishna Basin. Annual flood series of 8 to 41 years of 38 sites in the basin have been used for the study. Different delineation options are considered and the homogeneity has been verified using USGS homogeneity test. For each option the percentage absolute error in flood estimation using regional parameter is compared with flood estimation using at site parameters for two test sites. The results are further validated through 10 more validation sites and an attempt is made to check the effect of sample size on accuracy of flood predictions.

Key words : Regionalization, Homogeneity, Return period, Index flood,

Snowmelt Runoff Modelling in a Western Himalayan Basin using Remote Sensing Data and GIS.

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ABSTRACT

Snow cover in mountain regions provides critical water supply, serving nearly one-sixth of the global population with freshwater for domestic, agricultural and industrial uses. Snowmelt driven water resources are crucial for generation of hydroelectric power, particularly in the Himalayan region. The Himalayan basins have runoff contribution from rainfall as well as from snow and ice. In the present study a conceptual snowmelt runoff model has been applied for Satluj basuin located in western Himalayan region. This model employs direct input of remotely sensed snow cover extent data for calibration and simulation of the model. Snow covered area in the basin was determined using remote sensing data from IRS-WiFS and MODIS satellite data. Beside this data daily precipitation and temperature as well as Digital Elevation Model have been taken as input for the model. DEM was used subsequently to prepare the area elevation curves. The snowmelt has been computed using the degree-day approach and rain induced melting was also considered. The model was first calibrated using the dataset for a period of three years (1996-1997 to 1998-1999) and model parameters for stream flow routing were optimized. Using the optimized parameters, simulations of daily stream flow were made for a period of three years (2000-2001 to 2002-2003) and for one year 2004-2005. The stream flow verification was determined using different criteria such as shape of the outflow hydrograph, efficiency, and difference in volume. In all the cases (calibration and simulation), model successfully simulated the observed flow.

Geospatial Streamflow Model of Bagmati Basin: Nepal

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ABSTRACT

The impact of floods is an increasing problem in Nepal as has been illustrated by the 2007 floods and the recent Kosi disaster. However, there still is a lack of reliable and timely warning to evacuate people and save lives and property for which availability of hydrometeorological stations is mainly concentrated in the accessible middle mountain understanding of the hydrological processes which leads to widespread inundation in the Terai area of the country. An operational flood forecasting system is yet to be in place for informed decision making to warn communities in a timely manner. Timely availability of data and utilization of Satellite based rainfall estimates in hydrologic models could provide reliable information about flows which can be used for flood forecasting. The USGS Geospatial Streamflow (GeoSFM) model which is a spatially distributed, physically based hydrologic model has been used to calculate streamflow of the Bagmati Basin at Pandhara Dovan. To determine the hydrologic connectivity we have used the Hydro 1k DEM dataset. The model was forced by daily estimates of rainfall and evapotranspiration derived from weather model data. The rainfall estimates used for modeling are those produced by the National Oceanic and Atmospheric Administration Climate Prediction Centre (NOAA/CPC) and ground stations. The model parameters were estimated from globally available soil and landcover datasets – the Digital Soil Map of the World by FAO and the USGS Global Landcover dataset. The model predicted the streamflow at Pandhara Dovan gauging station. The comparison of the simulated and observed flows at Pandhara Dovan showd that the GeoSFM model performed well in simulating the flows of the Bagmati basin. Further comparison of the results of the Bagmati Basin with GeoSFM has been made with those using the Integrated Flood Alert System (IFAS) developed by the International Cente for Hazard Management, Japan.

Key words **:** Floos, Nepal, GeoSFM modelling, Satellite Rainfall Estimate.

Flood Hazard Modelling of
Lower West Rapti River Basin of Nepal

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ABSTRACT

Flood is found to be a recurrent phenomenon in Nepal, especially in the Terai region. The flood damages life and properties including the physical infrastructures as well as productive agriculture land, and livestock. Floods have caused difficulty in mobility, increased risk for living at houses, trends of fear and trauma, and erosion of social assets such as neighborhood, brotherhood, and strong bondage of kinship.

This study has aimed at investigating the flood disaster problem focusing Matehiya and Gangapur Village Development Committees of Banke District of Nepal as case. The study area lies in the West Rapti River Basin. HEC-RAS model was developed and used to simulate various scenarios of flooding. Floods of 2, 5, 10, 20, 50 and 100 years were considered in the flow analysis. Impact of torrential rainfall, constructed Kalkaluwa bandh (dyke) and Laxmanpur Barrage on Indian side were considered to assess the flood hazard in the study area. Based on the gradually varied steady flow analysis a number of inundation maps were prepared for various return periods of floods, and the settlements under high hazard zones were identified. It was found that both the dyke and the barrage built in India resulted in the increase in the depth and area of flooding. However the effect of Kalkaluwa bandh was found to be more pronounced than that of Laxmanpur Barrage.

Key words : Flood hazard, flood modeling, HEC-RAS.

Seasonal snow modeling in Tien Shan mountains, Central Asia: role of stratigraphy and metamorphism

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ABSTRACT

A model of snow cover has been developed and tested against data observed at several experimental sites. The model includes layer-by-layer snow accumulation, metamorphism of snow crystals, snow densening and/or loosening, evaporation and melting, changes in albedo and liquid water holding capacity. The snow cover model is combined with a model of heat/water transfer between soil, vegetation and atmosphere. The model complex reproduces full cycle of heat and water transformations at the land surface with a time step of several hours. The model has been tested against data obtained at several sites in mountains of Eurasia, specifically western Tien Shan in Uzbekistan. Comparison with a single-layer snow model shows that inclusion of the multi-layer structure allows significant improvement of the model quality. Uncertainties of calculations resulting from meteorological parameters, snow properties, as well as vegetation and soil features, can lead to significant scatter of evaluated variables.

Key words : Snow cover, numerical modeling, snow metamorphism, Central Asia

Impact of Hydropower Damming in Aquatic Bio-diversity of River System

Surya Gubhaju

ABSTRACT

A proper utilization of vast water resources for hydropower generation will contribute greatly to the economy of Nepal, so far, less than 1% of nation hydropower potential is exploited when there is prospect for profitable utilization of about 44,000mw (almost 50% of total hydropower potential). At the present infant stage, experience of Kali Gandaki and Kulekhani hydropower project have shown the tremendous alteration in aquatic environment, creating direct effect on water volume and velocity with impact on aquatic bio- diversity and fish migration. In Kali Gandaki, 18.0 km dry zone is created in dry season which has tremendous effect on water table, surrounding vegetation and micro climate. Similarly, huge reservoir created in Kulekhani area by blocking the course of Kulekhani river has changed free flowing riverine condition into impounded condition with changed water quality, stratification of temperature and dissolved gases, like oxygen and carbon dioxide along with the replacement of riverine aquatic biota by biota of impounded condition. These projects have, so far, not followed the basic guidelines of Environment Impact Assessment (EIA) like release of 10% compensation flow, conservation and management of soil, forest, effluents and agro-chemical discharges from the catchment areas. Development works must be given due attention to the maintenance of the environment, micro climate and aquatic bio-diversity. Otherwise this will affect the aquatic environment through heavy siltation and chemical discharges affecting the turbine, tunnel, reservoir, machinery parts and finally the life of a hydropower project. Exploitation of hydropower in Nepal has just started and has to go far ahead in future. The success of project lie in proper management of water resources at this initial stage before being late, for sustainable economic development of nation.

Key words : hydropower, Kulekhani, bio- diversity

Possible impacts of climate change on ecosystems and agriculture in the Pamirs

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ABSTRACT

Global environmental change which comprises more than climate change, but which is strongly controlled by the effects of global warming is an unarguable fact. In the presentation some relevant aspects of climate change which is a major global driver are considered with main focus on temperature, precipitation and drought. The latter constitutes a main restriction for agricultural land use and food security, drinking water supply and hydropower generation. However, since climate change is closely linked with different regional uncertainties as far as magnitude of changes is concerned, regional climatic prognoses over given time spans are extremely difficult. This is according to the actual report of the Intergovernmental Panel on Climate Change (IPCC) also the case in South and Central Asia (IPCC 2007, 2008).

After characterising the present climates and eco-zonal situation of Central Asia and the region under consideration on the basis of different methodical approaches, it is informed about biodiversity and plant productivity. The complexity of the eco-systematic driving system is demonstrated, and is finally reduced to climatic and hydrologic driving forces of environmental conditions and change.

Starting with the pattern of global temperature and precipitation trends for different time spans, the predicted continental Asian and regional Central und South Asian conditions are discussed. Special emphasis is put on drought with its diverse and sometimes severe environmental and socio-economic effects. As a result, drought will most probably intensify in the future in the region. In this context, satellite-based observations of plant health conditions and related parameters like Vegetation Health Index (VHI) which is based on reflection of visible light by vegetation canopy, are helpful for evaluating drought conditions on the continental and regional scales. The consequences of changing climates for runoff and groundwater recharge, i.e. for water availability as for example for irrigation purposes is another aspect discussed here.

The following impacts of climate change which are relevant for the region are mentioned and explained with diagrams and maps:

Natural ecosystems and biodiversity, hydrology and water resources as well as agriculture and food security will be strongly affected after findings in IPCC (2007). Accordingly, it is absolutely sure that average temperatures will rise by at least 3-5 °C within the next hundred years depending on simulation (prediction) model for double CO_2 scenario, precipitation will most probably slightly diminish, and droughts become more frequent, durable and severe. As a consequence, total biodiversity is at risk in the Pamir region including the forelands. Grassland coverage is projected to decline, and desertification to increase. Climate change related melting of glaciers could seriously affect millions of people depending on glacier melt for water supplies, with unfavourable effects for downstream agriculture relying on glacier melt for irrigation water. Since climate change does not only influence crop yield but also the area of crop production, there may result substantial decreases in cereal production potential, because most arable land suitable for cultivation is already in use. However, losses in crop potential are most obvious in rain-fed crop production areas of South and Southeast Asia as crop simulation modelling shows for realistic future scenarios.

Key words : climate change, ecosystems, agriculture

Mutual Rainfall and Biophysical Changes across the Judean Mountains Gradients: A Synergie of Remote Sensing and Field Studies

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ABSTRACT

The peak of the Judean Mountains reach only 700 meters above sea level, however on their Eastern side it slope down to the Dead Sea of 420 meters below sea level, within horizontal distance of less than 25 Kilometers. Mean annual rainfall decrease along this transect from 650 mm/year to 70 mm/year, thus representing steep transition from typical Mediterranean climate to extreme arid regime. Studying mutual changes of rainfall and vegetation across this transition zone is crucial for the understanding of the extent and magnitude of desertification in the Eastern Mediterranean. For this purpose data were collected from existing phyto-geographical maps, from local field surveys and from remote sensing imagery. Since rainfall decreases both along the North to South and west to East slopes of the Judean Mountains it was found instrumental to compare the results from these two transects. Correlation levels between vegetation cover and biomass with precipitation were found to be significant, revealing the non-linearity of these relationships. Differences in the modes of rainfall-biomass change between the North to South and West to East transects are meaningful in terms of the interpretation of desertification processes taking place. These interpretations concern both the spread of dwarf shrubs of low biomass productivity and anthropogenic disturbances which are characteristic of wide regions undergoing land degradation.

Planning Urban River Conservation in the Himalaya: Learning from Bagamati River Action Plan

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ABSTRACT

Bagmati River in the Kathmandu Valley represents a picture of Nepal's rivers in urban setting. Though the river and its tributaries were instrumental to develop the Kathmandu civilization, they are no more in position to sustain it for severe degradation since three decades. At present, the Bagmati River with its tributaries has been heavily abused particularly in the city area of Kathmandu. Dumping of all types of raw wastes, uncontrolled sand extraction, land encroachment, etc are only a few examples. Bagmati river and its tributaries serve as the sources of water supply to the nearly 2 million populations living in the rich fertile plain of the Kathmandu Valley. Within the last few decades, this valley has undergone rapid urbanization and influx of immigrants.

The pollution of Bagmati river system has deeper impacts on overall urban environment as it passes through the major settlement of the city with its wider application. Deteriorating condition of the river has become so critical that it no longer is an environmental problem alone but one that has wider socio-cultural implications requiring strong political, administrative and socio-cultural interventions to address these problems. The National Trust for Nature Conservation together with government agencies is developing a comprehensive and scientific action plan by synthesizing past studies and plans, documenting efforts made by various organizations over the river environment and assessment of appropriate technologies to address the main problem. To improve the Bagmati River environment, following objectives have been set for:

- o Document major roles and efforts of key actors of the Bagmati River System with the prime aim to asses their initiatives and strength;
- o Develop some pilot demonstration projects with viable technological options and assess their replicability and
- o Synthesis all the available studies and plans into a single comprehensive, scientific and practical plan.

NTNC has taken this as opportunity to use its two decades of experiences, expertise and resources for management of the urban river ecosystem. NTNC will carry out the responsibility of formulating the Bagmati River Action Plan in collaboration and consultation with all the key stakeholders. Formulation of the Bagmati River Action Plan is one of the key activities of the Bagmati River Conservation Project on the NTNC management. A team of experts is visiting field sites, reviewing and analysing various documents and literatures, consultation with key stakeholders and drafting an Action Plan. The proposed plan will cover all the major river systems of the Kathmandu valley and will consider both upstream and downstream issues of these river systems. The Bagmati River Action Plan will be a major guiding document for systematic and scientific interventions in the future. Further details of the project may be obtained from the address given at the end of this page.

ANNEXES

Annex -1

PRESS RELEASE

A Three-Day (15 to 17 November, 2008) International Conference on Hydrology and Climate Change in Mountainous Areas, jointly organized by Society of Hydrologist and Meteorologists-Nepal (SOHAM-Nepal), Department of Hydrology and Meteorology /Government of Nepal and United Nations Educational, Scientific and Cultural Organization (UNESCO), is being inaugurated by Honorable minister Mr. Bishnu prasad Paudel, Water Resources, on November 15, 2008 at Hotel Everest in Kathmandu. The program will be concluded on 17 November. The closing remarks will be given by the Honorable minister Mr. Ganesh Shah, Ministry for Environment, Science and Technology. Honorable minister Mr. Shah will be the chief guest for the closing ceremony of the conference and he also chair one of the sessions, most probably Koshi flood, in the program.

The key note speakers of the conference are………………………..

The SOHAM-Nepal, a professional society of Hydrologists and Meteorologists, and Water resources Specialists, has been leading a key role in the promotion and development of hydrology, meteorology and water resources in the nation's development since its establishment in 2001.

A global change in the physical environment has been made a sober concern to the scientific communities, planners, policy makers including political bodies, and developers. As we have been aware that the developing country like Nepal is at high risk to climate change. Snow and glaciers, hydro-meteorological processes in watersheds, people's livelihoods are the sensitive areas to climate change impacts in the country. It means, the impacts of climate change on the natural processes are the non-political challenges for the prosperous of the country. Updating and sharing the knowledge on how to address such impacts to make people's resiliency efficient among the concerned stakeholders is a major significant of the conference. This approach is one of the opportunities to deal with the challenges. All the papers are relevant to the objectives of the conference in their respective aspects. Hydrological extremes, early warning system, hydrological modeling system, hydro-climatic disasters, climate change and its impacts on hydrological systems, river sedimentation, water resources, snow and glacier and biodiversity are the major sessions of the conference.

The conference is almost the first in the country in the context of highlights climate change impacts on the hydro-meteorological processes. The experts from different countries like Nepal India, Japan, Germany, Pakistan, Iran, Russia, Bangladesh, Poland, Canada and Thailand are being participated in the conference. Similarly, 54 technical papers including 10 papers from international specialists are being presented in the program.

Released by
SOHAM Nepal

Annex -2

Opening remarks by the Chief Guest
of the opening session

Mr. Bishnu Prasad Paudel,
Minister, Water Resources, Government of Nepal.

Chairperson,

Distinguished guests in the dash,

International participants, Nepalese participants, Guests, ladies and gentlemen,

Since the beginning of 21st century climate change is the subject of worldwide concerned. Today I am very much pleased to find me amongst scientists, and experts working on climate change, hydrology, meteorology and related fields.

The streams and rivers originating from the Himalayas provide sufficient fresh water in Nepal. Global warming has been enhancing ice-melting processes, and so the perennial nature of these resources is altered and threatened. This is one of the new challenges added by climate changes to the economic development of the countries. Therefore, this **"International Conference on Hydrology and Climate Change on Mountainous Areas"** and its **themes** are pertinent and timely.

The Himalayas is also called the third pole. The countries lying at the sea level are concerned from sea level rise due to melting of polar ice. Similarly, Nepal, a country in mountainous areas is concerned about the dangers of changing of year round snow-covered mountains to the bare rocky mountains due to increase in global warming. Nepal like other countries is also concerned to the threat of excessive rainfall and drought and it's the consequences to water resources, agriculture and other life cycles due to increase of green house emissions globally.

In the 19th century, research in the Polar Regions was initiated with the launch of the first International Polar Year. In Nepal, data collection and research on hydrology and water resources started institutionally only after 1960 A.D. It is also crucial that the findings of researches on climate change and know how of adaptation measures need to be reached to the community level as well. I hope conferences like this will provide encouragement and create opportunities for Nepali scientists and professionals to share knowledge and conduct collaborative research with international scientists and experts.

Nepal had ratified the Kyoto Protocol and had also prepared National Communication Report under the UNFCCC. The Ministry for Environment, Science and Technology is drafting policy regarding the climate change. As the government of Nepal has many other priority areas, especially the poverty alleviation and so the government might not be able to provide sufficient resources to the research on climate change. However, the government will always encourage and support your efforts to tape international resources.

The floods in Nepal and its surrounding areas are causing substantial adverse impacts. Even after almost half a century after the institutionalization of research on hydrology, expected progress has not been made in the area of flood forecasting and warning. The discussion on "Floods in Nepal" in one of the sessions in this conference has a great relevance. The special session in conservation programs for the rivers in the cities to be implemented is also timely. I am hopeful that concrete suggestion and recommendations will be gathered that would be helpful to the government to formulate policies and to implement programs for the benefit of the country and the region.

Finally I would like to wish our international participants an enjoyable stay and thank the organizers and supporters of the conferences.

Thank you

Annex - 3

Chairperson: Kiran Shankar Yogacharya

(Chairman: Society of Hydrologists and Meteorologists-Nepal)

Chairperson's Remarks

Hon'ble Chief Guest Minister Bishnu Prasad Paudel, Ministry of Water Resources, Dr. Siegfried Demuth, Dr. G. Kesar, and Dr. Bhanu Neupane from UNESCO, … , Respected Experts and representatives from various organizations and countries, Ladies and Gentlemen, and Colleagues,

It is a well known fact that existence of life is being mobilized by five essential natural factors of solid, liquid, luminous, aerial and ethereal out of which liquid and aerial factors are of prime importance in the hydrological cycle. In Sanskrit, the liquidity or the liquid factor is generally known as "*Jal*" and the mobility or aerial factor is known as "*Vaayu*." When combined, these two factors give rise to what we generally call "*Jal-Vaayu*" or climate. Hence, the role and importance of climate and hydrology for the existence of life in this planet cannot be ignored. Any disturbance in the climate must have corresponding impact in the hydrological cycle, and for that matter, corresponding impacts in everything upon which life is depending. So, we must be careful with what we do with the climate. We have two options: improve it for better living or destroy it. Naturally then, you will agree with me in opting for better living not only for the present, but also for betterment for the future generations. If so, then we must do something for improving the climatic conditions of this planet, which has been tampered with towards global warming through the increase in greenhouse gases like CO_2, CH_4, N_2O, and others because of uncontrolled human activities.

As is evident, the climate change scenario will have a major impact especially on regional water resources. Hence, we need to understand and materialize the concept of integrated water resources management in the present context of climate change. We need to understand the effects of climate change on the hydrological regimes. Then we need to understand the inevitable role of both mitigation and adaptation measures. Whatever the measures are taken, we must understand that they are achievable. The sharing of knowledge and expertise is very much needed; and hence, along these lines we have the themes of the present 3-day conference that have been highlighted already by one of the previous speakers.

In Nepal, based on the data from the Department of Hydrology and Meteorology, during the 32 year long period from 1975 to 2006, there has been an increase of 1.8^o C that means 0.056^oC increase per year. Number of days with precipitation of 100 mm or more is increasing. Even changes in the time and period of precipitation are being noticed. According to the climate change study that was started from 1994 in Nepal, a shift in the peak discharge was noticed from August to July. Due to warming effect, snow and glacier melt is taking place, thereby increasing the sizes of glacier lakes, thus increasing the possible dangers of glacier lake outburst floods known as GLOFs. Thus, the adverse effects of climate change are being noticed in Nepal as well.

Hence, preventive measures need to be taken through timely monitoring and reporting and other mitigation measures along with other corrective measures including management and adaptation. Moreover, collaboration and cooperation are needed among all countries both in sharing knowledge and implementing suitable practices. In the context of Nepal, the mountainous areas are vulnerable to the climate change impacts. I hope the present conference would address these problems of vulnerability to climate change so as to enable the countries concerned to take up the appropriate preventive/mitigation and adaptation measures.

The honourable minister of water resources, Mr. Bishnu Prasad Paudel had already highlighted the importance of this present conference by stating that the water resources are being impacted by global warming, creating challenges for economic development.

Our Keynote speaker Dr. Siegfried Demuth had already highlighted various aspects of climate change issues in hydrological regimes with reference to the mountainous areas, including critical issues of climate change and roles and activities of International Hydrological Programmes (IHP).

Among others, there will be two special highlights in this conference. One will be on the Floods in Nepal under the broader framework of Hindu Kush – Himalayas FRIEND Project. Another one will be presentation on Planning Urban River Conservation in the Himalaya: Learning from Bagmati River Action Plan under the auspices of the National Trust on Nature Conservation in Nepal.

I believe that your active participation and deliberation will make this international conference successful in achieving its goal; and I am confident that we can come up with some fruitful summaries and constructive output in the matters of climate change issues in relation to the hydrological regimes in the most fragile mountainous areas. On behalf of the organizers consisting of the Society of Hydrologists and Meteorologists – Nepal, Department of Hydrology and Meteorology, Government of Nepal, and the United Nations Educational, Scientific and Cultural Organization, and also on behalf of the support and collaboration from Nepal National Committee for International Hydrological Programme, National Trust on Nature Conservation, Real Time Solution P. Ltd., RECHAM, and the Small Earth Nepal, I wish you a grand success in this conference, and wish our international participants and presenters from UNESCO, Bangladesh, Germany, Malaysia, Poland, Russia, and Thailand an enjoyable stay in Nepal!

Thank you!

Annex - 4

Closing remarks by the Chief Guest of the Closing Session

Er. Ganesh Shah,
Minister for Environment, Science and Technology.

Good afternoon, Ladies and gentleman,

I am not a climatologist or practicing hydrologist like many of you are, but I have worked on water sector for a long time and so I do understand that the management of water resources is becoming increasingly complex in the changing global climatic situation. Often competing range of domestic, agricultural, and environmental demands makes it more complex. Many factors - especially climate, determine the quantity and quality of available water.

I also understand that there has been a growing concern over watershed degradation and its implications to water resources and ecosystems sustainability. Flood is one phenomenon that is directly linked to how we manage our watersheds.

In order to understand these better, we require scientific investigation and knowledge base. This requires creating new knowledge and evaluating old ones for their benefits and uses. We have to network amongst us, both to learn from each other and to create a condition for synergies. Scientific knowledge of interactions between climate and hydrological processes is of the paramount importance for effective design and implementation of adaptation strategies. This is also important for developing rational land and water management strategies. Despite this the coupling mechanisms of climate and hydrological processes across multiple scales have not yet been explored properly.

I would like, however, to remind you that this is not because of complacency. We are very worried about how our climate is changing. Climate change is expected to exacerbate current stresses on water resources. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water availability, hydropower potential, and the changing seasonality of flows in the Himalayan region. We are also concerned that the change will trigger several hydrological extreme events and complicate our preparedness to deal with them. We are fully aware that this requires adequate evaluation and improvement to keep pace with our strategy for flood risk reduction.

Lest us however, not forget that there is also a big "human" dimension attached to the whole issue. Our livelihood is intricately linked to climate and thus its increasing uncertainties is also linked to uncertain future that awaits millions of Nepalese, especially those who are underprivileged and poor.

Ladies and Gentlemen,

I am confident that by an active participation of the people and through a concerted effort of all concerned we have been able to provide an all new thinking in the area of interrelationships between hydrology and climatic processes. However, I emphatically note that we are just at the beginning of a long battle that awaits us.

I would like to note that the Government of Nepal, and especially my ministry is fully committed to work with the international community to better understand the climatic processes and adapt to increasing uncertainties. However, we need your advice and support on this. We are in a process to build a "New Nepal" for which there are several actions that we would like to see implemented. We are banking on our vast water resources potentials for our New Nepal. Thus we wish to receive

international community's support in developing and nurturing new understanding on hydrology and climate change. You all have deliberated in the last 3 days and resolved that Nepal needs to scientifically assess the impacts of climate change, identify the most vulnerable sector and develop key initiatives and programs on adaptation. I concur that and request the international community to assist in building capacity of key institutions, like Department of Hydrology and Meteorology. I wish to work with you to devise a set of concerted efforts to build institutional capacity and to enhance capacity of staff there in.

Data gap in the mountainous area is excruciatingly visible. There is a need to enhance the existing hydrological and meteorological stations to comply with the international standards. This requires initiation at both the fronts. In one extreme to opt for sophisticated hydrological and meteorological stations with telemetry facilities, simultaneously, there is a need, at the other extreme, to initiate efforts to create pool of "barefoot hydrologist". Our government has already taken initiatives in identifying the cryospheric elements, in particular the major glaciers in Nepal, however, your support will be fundamental to undertake ground-truthing verification. I look forward to receive any assistance in undertaking such exercises. I am already aware of your initiation to strengthen the mass balance measurements in key glaciers. I will be willing to provide all types of support for this program's smooth implementation.

Improving scientific understanding of watersheds vis-à-vis flood is critical need for the region. Thus there is a need to initiate a pilot project in integrated watershed management. There is an urgent need to review existing flood disaster reduction initiatives in the country. In that, there is a need to assess the readiness of the early warning, flood forecasting, and flood management facilities currently installed in the country. In order to implement this, I would like to invite the Flood research group of the HKH FRIEND and International Flood Initiative of IHP to spearhead an international collaboration to support Nepal. I am very thankful to UNESCO for already taking steps toward the scientific assessment of the recent floods in Koshi River. I hope that we can soon implement the project on a consortium mode.

We are also aware of the institutional support that will be needed to undertake such a gigantic task. As per our National Water Plan, we are already taking action to establish a "Climate Center" to take into account the climatic process in the Himalayan region of Nepal.

I am very delighted to acknowledge the commitment on the part of UNESCO, which has timely come forward to help us deal with the future uncertainties. My sincere thanks to UNESCO's team, who has been collaborating with the Government of Nepal.

I have taken note of the benefits to Nepal for being active in the International Hydrological Programme of UNESCO. I have realized that there is a need to strengthen the National Committee of the International Hydrological Program in Nepal. I will soon be directing my staff to provide a suitable working environment to the committee to function flawlessly.

Finally, I wish to thank the organizers of the conference. I once again commit myself and my ministry to implement the recommendations and guidance derived from this conference in this country and in the region.

Thank you

Annex - 5

Chairperson: Convener-Chairperson, Kiran Shankar Yogacharya, Organizing Committee

Chairman: Society of Hydrologists and Meteorologists-Nepal

Chairperson's Remarks

Hon'ble Chief Guest Minister Ganesh Shah, Ministry of Environment, Science and Technology, Dr. Siegfried Demuth, and Dr. Bhanu Neupane from UNESCO, Distinguished Experts, guests and representatives from various organizations and countries, Ladies and Gentlemen, and Collegues,

From the past 3 day deliberation with fruitful and extended discussions, it is clear that climate change impact is tending towards an intensification of the global hydrological cycle, with a major impact on regional water resources.

I am very happy to note here that our Honorable Minister Ganesh Shah of Environment, Scence and Technology, in his address, has emphatically given importance to the area of interrelationships between hydrology and climatic processes; and it is very gratifying to note that the Ministry of Environment, Science and Technology is fully committed to work with the international community to better understand the climatic processes and adapt to increasing uncertainties. I am very encouraged by the commitment of the Honorable Minister to foster international cooperation in developing and nurturing new understanding on hydrology and climate change.

As an important outcome of this present conference, the Kathmandu Declaration has definitely emphasized the need of holding such international conferences to advance the science of hydrology and climate change in the mountainous areas, once in every two years. This declaration has also come up with an important agenda for establishing Regional Center of Excellence on Climate Change and Cryospheric Research in Himalayan Region in Kathmandu.

I do not need to repeat whatever has been expressed by our Hon. Chief Guest and the Kathmandu Declaration, but I would like to further highlight on the need of strengthening the readiness of the early warning, flood forecasting, and flood management facilities currently installed in the country. In this regard, the role of the Flood research group of the HKH FRIEND and International Flood Initiative of IHP is necessary in order to realize the international collaboration to support Nepal. With respect to water resources in general and floods in particular, I would like to quote a part of a verse from the Mahabharata: "*Andham balam jalam cha aahu, pranetavyam vichakshanaih.*" This means water is only a blind force, it needs to be properly assessed, systematically harnessed, and rationally utilized and managed by the related experts, scientists, engineers, and managers. Managed properly, water becomes a boon to our life. Hence, as per the ancient Sanskrit literature, "*aapo naaraah*" meaning simply: "Water is life." Moreover, we assert the importance of water by stating: "*Aapo Shaantih*" which simple means: May the hydrosphere be beneficial to all. This very statement is a warning signal to all of us not to disturb the sanctity of water resources by disturbing the atmosphere creating unwanted greenhouse gases. But the climate change is gradually taking place adversely affecting every aspect of our life, and hence we need to assert the importance of atmosphere by stating: "*Vaayu shaantih*" that is, May the atmosphere be beneficial to all. And, let us all hope that preventive, mitigative and adaptive measures be taken in time in order to avoid the harmful effects of climate change impacts.

I am very much indebted to the Hon Minister Ganesh Shah for his invaluable time given to us and by blessing us with his kind presence at various sessions as well. I am also grateful to UNESCO for kindly supporting the activities like this conference, which is responsible for generating and highlighting the awareness towards the impacts of climate change, inducing the related agencies to take up the necessary measures to fight against such adversities that might occur in course of time if the present trend of GHG emission continues. In this context, I am hopeful that the recommendations made in the Kathmandu Declaration 2008 as an outcome of this conference be implemented.

Finally, I wish to whole-heartedly express my thankfulness to your active participation and deliberation that have made this international conference successful in achieving its goal.

Hope our international participants and presenters have had their enjoyable stay in Nepal!

Thank you !

Annex - 6

Vote of Thanks

Jagat Kumar Bhusal,

Member Secretary Organizing Committee

Chief Guest Hon"ble Minister Ganesh Shah, Ministry of Environment, Science and Technology, Chairman of this Closing Session, Mr. Kiran Shankar Yogacharya, Convener of the Conference, Mr. Adarsha Prasad Pokhrel, Chairman IHP-Nepal, NATCOM, Mr. Nirmal Hari Rajbhandari, Director General, DHM, Dr. Siegfried Demuith, Dr. Bhanu R. Neupane, Participants, Journalists, Ladies, and Gentlemen.

It is indeed a great pleasure for me to stand in front of you to deliver the vote of thanks in this closing ceremony of the conference. Mr. Chairman, let me allow to speak a few words about background of the conference.

The Society of Hydrologist and Meteorologist –Nepal is a professional society carrying out its activities with voluntary support of its members and its well-wishers. Nearly two years before, SOHAM-Nepal decided to open a forum to gather international and national scientists and engineers and experts to address on the very emerging issue of climate change on hydrological processes and mountain ecosystems.

SOHAM Nepal made a preliminary announcement of this "International Conference on Hydrology and Climate Change in Mountainous Areas" including its major themes in 2006. SOHAM Nepal received encouraging support from Mr. Nirmal Hari Rajbhandari, Director General, DHM and Dr. Madan Lall Shrestha Academician, NAST, Senior national and international experts agreed to support as the chairperson, co-chairpersons and members of Organizing Committee, Scientific Committee and Advisory committee.

It is indeed Dr. Bhanu R. Neupane, who supported DHM and SOHAM-Nepal to proceed ahead with assurance on behalf of UNESCO to support the conference. Without UNESCO support, the conference would not have achieved so success. Continuous support of Mr. Suresh Marahatta, Dr. L. P Devkota, and Mr. Dharmendra Rajbhandari is very praiseworthy. Seven – 24 work of Mr. Kiran Shankar Yogacharya for the last two months had contributed a lot the smooth going of all sessions of the conferences. Well-experienced advisory support of Mr. Adarsha P. Pokhrel, advisor of SOHAM-Nepal, Nepal and guidance of Dr. J. L Nayava and Prof. Bidur Prasad Uphadhaya, both ex chairman of SOHAM Nepal with whom I worked as general secretary of SOHAM Nepal had contributed to the conference.

The Conference received financial support from United Nations Educational, Scientific and Cultural Organization, Department of Hydrology and Meteorology, Ministry of Environment Science and Technology, Government of Nepal, NESCO, DHM, National Trust for Nature Conservation, Realtime Solution and Secretariat support of RECHAM Consult Pvt. Ltd. and the Center Department of Hydrology and Meteorology TU.

I would like to express my sincere thanks to Chief Guest of this closing session: Hon"ble. Minister Ganesh Shah, Minister, Science and Technology, for inspiring speech and commitment to support Kathamndu Declaration and in spite of his very tight schedule, sparing some time with us on 15 Nov. and 16 Nov. as well.

Sincere appreciation goes to Hon"ble. Minister Bishnu Prasad Paudel, Ministry of the Water Resources, the Chief Guest of Inaugural session, who spare his valuable time in inaugurating the Conference and Delivering the importance and relevancy of conference.

Member of Constituent Assembly of Nepal, Hon'ble Usha Kala Rai, for chairing a very important session –Koshi flood in Nepal, Hon'ble Navodita Chaudary, for her presence and remarks in the same session and Hon'ble Sunil Babu Pant papers delivered in the conference, do all deserve our appreciation.

I would like to thank to all key speakers Dr. Siegfried Demuth,UNESCO Dr. Bhanu Neupane, UNESCO, and Dr. Georg Kaser, UNESCO, for their valuable key speeches, for chairing the technical sessions as well as for participation.

My sincere thanks also go to Prof. N. Alekseevskiy, Dr. G. Tartari, Dr. Madan Lall Shrestha, Prof. Dr. P. K. Jha, Dr. Laxmi Prasad Devkota for chairing the technical session and Mr. Mani Ratna Shakya, Mr. Om R. Bajracharya Mr. Bhuwan Dhakal, Ms. Sarojani Pradhan, Dr. Rijan Bhakta Kayastha, Dr. Sunil Adhikari, Dr. Maya P Bhatt, Dr. Khada Nanda Dulal, Mr. Mahendra Gurung and Prof. Susie N. David Asen , Dr. Dilip K. Gautam, Mr. Tech Bahadur Thapa Ms. Mandira Shrestha, Dr. N. Frolova and Mr. Ram Gopal Kharbuja.

Now I would like to express my sincere appreciation for all paper presenters and all participants. Special thanks goes to participants from abroad without whose participation this conference would have been only a national conference.

I would also like to thank Chairperson, Co-Chairpersons and Members of Organizing Committee; Chairperson, Co-Chairpersons and Members of Scientific Committee; Chairperson, Co-Chairpersons and Members of Advisory Committee; Mr, Dhiraj Pradhandhanga and all SOHAM- Nepal executive members and Life members for their valuable support in bringing the conference to the success.

Thanks to Mr. Saraju Vaidya and Mr. Pancha Ratna Shakya and Kumar Rajbhandari and their team for providing excellent services at the conference.

Thanks to Miss. Kanchan Shrestha, the master of ceremony of this three days conference for providing invaluable time in conduction sessions.

Thanks TIKA travel for preparing enjoyable post conference tour package to our foreign participants.

Finally, thanks goes to management of Hotel Everest for providing excellent facilities, logistics, as well as comfortable stay of our foreign delegates.

Once again, thanks to DHM, UNESCO, NTNC, MOWR, NEA, DOI, DWIDP, WECS, DOED, Dept of Livestock Dev. services, RECHAM , The Small Earth and other agencies for providing support directly and indirectly.

Thank you

Annex - 7

International Conference on Hydrology and Climate Change
in Mountainous Areas
November 15-17, Kathmandu, Nepal

Conference Programme

Opening Session : November 15, 2008, Saturday

08:30 – 09:30   **Registration and Tea**

09:40   **Arrival of the Chief Guest**

Chairperson: Kiran S. Yogacharya
Chairman, Society of Hydrologists and Meteorologists – Nepal (SOHAM - Nepal)

09:40 – 09:50   **Welcome Address:** Mr. Adarsha P. Pokhrel, Chairman, Nepal National Committee
for International Hydrological Programme (IHP)

09:50 – 10:00   **Inauguration:** Chief Guest, Hon. Minister Bishnu Prasad Paudel, Ministry of the
Water Resources

10:00 – 10:20   **Keynote Address:** Dr. Siegfried Demuth, UNESCO

10:20 – 10:30   **Inaugural Address:** Chief Guest

10:30 – 10:40   **Address** by the Chairperson

10:40 – 10:45   **Vote of Thanks:** Mr. Nirmal Hari Rajbhandari, Director General, Department of
Hydrology and Meteorology, Government of Nepal

10:45 – 11:30   *Tea Break*

Technical Session-1 : Climate Change Impacts and Adaptations

Chairperson: Dr. Bhanu R. Neupane, UNESCO
Rapporteurs: Mr. Mani Ratna Shakya and Mr. Om R. Bajracharya

11:30 – 11:50   **Climate Change in Nepal – Impacts and Challenges**: Mr. Adarsha P. Pokhrel

11:50 – 12:10   **Spatial Distribution of Water Resources in the Tatra Mts. (Central Europe) on
the Background of Other Mountains:** Dr. Adam Lajczak (Poland)
12:10 – 12:30   **Ev-K2-CNR Climatic Studies at CEOP Reference Sites in Himalaya and
Karakorum Regions:** Dr. G. Tartari (Italy)
12:30 – 13:00   **Discussion and Chairperson's Remark**

13:00 – 14:00   Lunch Break

Technical Session - 1 Contd.

14:00 – 14:20   **Impact of Climate, Climate Change and Modern Technology on Wheat Production in Nepal 1970/71-2006/2007:** Dr. Janak Lal Nayava (Nepal)

14:20 – 14:40   **Exploring the Potential Economic Impacts of Climate Change in Nepal:**
Sunil Babu Pant, Member of Constituent Assembly, Nepal, and Clare Shakya, Senior Regional Environment and Water Advisor, South Asia Policy Team, DFID Nepal

14:40 – 15:10   Discussion and Chairperson's Remarks

15:10 – 15:40   *Tea Break*

Technical Session-2 : Sedimentation and Mass Wasting
Chairperson: Prof. N. Alekseevskiy
Rapporteurs: Mr. Bhuwan Dhakal and Ms. Sarojani Pradhan

15:40 – 16:00   **Correlations between Mass Transport Processes and Ion Concentration Distributions in Loei River and Mekong River, Thailand:** Sarunya Promkotra (Thailand)

16:00 – 16:20   **Sedimentation - One of the Major Challenges for Sustainable Hydropower Development in Nepal - A Case Study in the Kulekhani Hydropower Project** - Dr. Durga Prasad Sangroula (TU, Nepal)

16:20 – 16:40   Contemporary flood frequency, fluctuations and trends of changes in water discharge in the piedmont course of the Vistula River, Southern Poland (Central Europe) - Adam Lajczak (Poland)

16:40 – 17:00   **Bed Roughness Estimation for High Gradient Rivers in Malaysia -** Susie N. David Asen, Shanker K. Sinnakaudan , , And Mohd. Sofiyan Sulaiman

17:00 – 17:30   **Discussion and Chairperson's Remarks**

November 16, 2008, Sunday
Technical Session-3 : Snow and Glacier Hydrology

Chairperson: Dr. Georg Kaser
Rapporteurs: Rijan Bhakta Kayastha and Sunil Adhikari

09:00 – 09:20   **Keynote Address**: Dr. Georg Kaser, UNESCO

09:20 – 09:40   **IHP-VII:** Dr. Siegfried Demuth, UNESCO

09:40 – 10:00   **Chemical Weathering in Central Himalaya: Focus in Dissolved Silica Dynamics in Glacier Meltwaters** - Maya P Bhatt (Nepal), Toshiyuki Masuzawa, Mineko Yamamota and William H. McDowell

10:00 – 10:20   **Climate Change Impact on Dangerous Hydrological Processes for Mountain River Basins of the Big Caucasus (Case Study of the Terek River):** N. Alekseevskiy, N.Frolova, and V.Zhuk (Russia)

10:20 – 10:40   **Evapotranspiration and Water Balance in Mountain Regions: Lessons from the Tibetan Himalayas:** Dr. Axel Thomas (Germany)

10:40 – 11:00   Discussion and Chairpersons Remarks

11:00 – 11:30   *Tea Break*

Technical Session-4 : Floods in Nepal
(Within the broader framework of HKH FRIEND Project)

Chairperson: Hon'ble Usha Kala Rai, Member of Constituent Assembly, Nepal
Chief Guest: Hon'ble Minister Ganesh Shah, Ministry of Environment, Science and Technology
Guest: Hon'ble Navodita Chaudhary, Member of Constituent Assembly, Nepal
Moderator: Mr. Adarsha P. Pokhrel
Rapporteurs: Mr. Jagat Bhusal and Dr. Ram Gopal Kharbuja

11:30 – 11:50   **Keynote Address:** Dr. Bhanu Neupane, UNESCO

11:50 – 12:10   **Floods: Genesis, Magnitude and Frequency:** Kiran S. Yogacharya and Dr. Dilip Gautam (Nepal)

12:10 - 12:30   **Floods: Disaster and Management Aspect:** Mahendra Gurung/DoI, Vasistha Adhikary/DWIDP and Dr. Laxmi P. Devkota/Member, SOHAM-Nepal

12:30 – 12:50   **Floods: Socio-Economic Dimension:** Dr. Narendra Khanal (Nepal)

12:50 – 13:10   **2008 Koshi Embankment Breach Floods – A Cross Border Implications:** Dr. Ajaya Mani Dixit (Nepal)

13:10 – 13:40   **Discussion**

13:40 – 14:00   **Summary and Recommendation:** Adarsha P. Pokhrel

14:00 – 15:00   *Lunch Break*

Technical Session-3 (contd…) : Snow and Glacier Hydrology

Chairperson: Dr. G. Tartari
Rapporteurs: Dr. M. P. Bhatt and Dr. K. N. Dulal

15:00 – 15:20   **Impact of Climate Change on the Runoff from a Highly Glacierized Catchment in Nepal Himalaya:** Arun B. Shrestha, Sharad Joshi, Sudip Pradhan, Rajesh Thapa and Ludwig Braun, ICIMOD

15:20 – 15:40   **Atmospheric and Land-surface Conditions Responsible for Seasonal Change of Evaporation Rate in Langtang Valley, Nepal Himalaya, 2008:** T. B. Chettri (TU, Nepal)

15:40 – 16:00   **Estimation of Turbulent Heat Flux in the Langtang Valley of Nepal Himalaya:** Dinkar Kayastha (TU, Nepal)

16:00 – 16:20   **Discussion and Chairperson's Remarks**

16:20 – 16:50   *Tea Break*

Technical Session-5 : Water Induced Disaster Management

Chairperson: Dr. Madan Lall Shrestha
Rapporteurs: Mr. Mahendra Gurung and Prof. Susie N. David Asen

16:50 – 17:10   **Altitude Zoning of River Runoff in Mountainous Areas (on an Example of Mongolia)** - Bolgov M.V., Trubetskova M.D. (Russia)

17:10 – 17:30   **Koshi Disaster: A Lesson Learned Event in South Asia in General and Particularly in Nepal and India – Mr. Deepak Paudel**

17:30 - 18:00   **Discussion and Chairperson's Remarks**

18:30 – 20:30   **Reception Dinner**

November 17, 2008, Monday
Technical Session-6: Hydrological Extremes and Early Warning Systems

Chairperson: Dr. Siegfried Demuth, UNESCO

Rapporteurs: Mr. Jagat Bhusal and Mr. Ram Gopal Kharbuja

09:00 – 09:20   **Flood Estimate in Ungauged River Basins of Nepal:** Prem Chandra Jha (TU, Nepal)

09:20 – 09:40   **Statistical Characteristics of Shower Precipitation in Mountain Regions** - Bolgov M.V., and Trubetskova M.D. (Russia)

09:40 – 10:00   **Mesoscale Modeling & Flood Forecasting for Early Warning System** - Someshwar Das (Bangladesh)

10:00 – 10:20   **Real Time Data Acquisition System for Flood Forecasting Using CDMA Wireless Technology –** Dilip K. Gautam (Nepal)

10:20 – 11:00   **Discussion and Chairperson's Remarks**

11:00 – 11:30   *Tea Break*

Technical Session-7 : Hydrological Modeling

Chairperson: Dr. Laxmi Prasad Devkota
Rapporteurs: Dr. Dilip K. Gautam and Mr. Pradeep Man Dangol

11:30 – 11:50   **Application of the Hydrological Modeling System in the Jhikhu Khola Watershed, Nepal, for the study of Hydrograph Characteristics:** Tirtha Raj Adhikari (TU, Nepal)

11:50 – 12:10   **Hydrological Modeling of Upper Trishuli 3 A Catchment, Nepal Comparison of Lumped and Distributed Models:** Netra Timilsina (Nepal)

12:10 - 12:30   **Geospatial Streamflow Model of Bagmati Basin, Nepal:** Mandira Shrestha, ICIMOD

12:30 – 12:50   **Flood Hazard Modeling in Lower West Rapti River Basin of Nepal:** Utsav Bhattarai, Mahesh Raj Gautam, Rabindra Osti, and Laxmi P. Devkota (Nepal)

12:50 – 13:20   **Discussion and Chairperson's Remarks**

13:20 – 14:30   *Lunch Break*

Technical Session-8 : Climate Change & Biodiversity

Chairperson: Prof. Dr. P. K. Jha
Rapporteurs: Ms. Mandira Shrestha and Dr. N. Frolova

14:30 – 14:50   **Possible Impacts of Climate Change on Ecosystems and Agriculture in the Pamirs:** Andreas Herrmann (Germany)

14:50 – 15:10   **Mutual Rainfall and Bio-Physical Changes across the Judean Mountains' Gradients: A Synergy of Remote Sensing and Field Studies:** M. Shoshany

15:10 –15:40   **Discussion and Chairperson's Remarks**

Special Presentation

Chairperson: Mr. Kiran Shankar Yogacharya, Chairman, SOHAM-Nepal

15:40 – 16:40   **Planning Urban River Conservation in the Himalaya: Learning from Bagamati River Action Plan**: Dr. Siddhartha B. Bajracharya and Ngamindra Dahal, NTNC (Nepal)

16:40 – 16:50   **Discussion**

Closing Session

November 17, 2008
17:00 – 18:00

Chairperson: Mr. Kiran Shankar Yogacharya, Chairman, SOHAM-Nepal

Chief Guest: Hon. Minister Ganesh Shah, Ministry of Environment, Science and Technology

- o **Conference Summary**: Mr. Dhiraj Pradhananga, General Secreatary, SOHAM - Nepal

- o **Remarks from Participants**:

  - ▪ Dr. M. Shoshany, Geo-Information Engineering, Faculty of Civil & Environmental Engineering, Israel Institute of Technology, Israel
  - ▪ Dr. P. C. Jha, Institute of Engineering, TU

- o **Remarks**: Chief Guest Hon. Minister Ganesh Shah, Ministry of Environment, Science and Technology

- o
- o **Kathmandu Declaration 2008:** Mr. A. P. Pokhrel, Chairman, IHP-Nepal National Committee

- o **Closing Remarks**: Chairperson Mr. Kiran Shankar Yogacharya, Chairman, SOHAM-Nepal

- o **Vote of Thanks**: Mr. Jagat Kumar Bhusal, Member Secretary, Organizing Committee and Vice-Chairman, SOHAM-Nepal

Tea

Annex - 8

KEY NOTE SPEAKERS

Opening Session: November 15, 2008, Saturday, 09:00 – 11:00

Dr. Siegfried Demuth, Chief, SC/HYD/HPC, UNESCO
Dr. Gorg Kaser, UNESCO
Dr. Bhanu Neupane, UNESCO, DEHLI

Annex - 9

International Conference on Hydrology & Climate Change in the Mountainous Areas
November 15-17, 2008, Kathmandu, Nepal

Chairperson and Rapporteurs ofTechnical Sessions

Session	Chairperson	Rapporteur-1	Rapporteur-2
Opening Session	Kiran S. Yogacharya		
Technical Session-1: Climate Change Impacts and Adaptations	Dr. Bhanu Neupane	Mr. Mani R. Shakya	Mr. Om Ratna Bajracharya
Technical Session-2: Sedimentation and Mass Wasting	Prof. Alekseevskiy	Mr. Bhuvan Dhakal	Mr. Sarojini Shrestha
Technical Session-3: Snow and Glacier Hydrology	Dr. Georg Kaser	Dr. Rijan B. Kayastha	Dr. Sunil Adhikari
Technical Session - 3: (Cond.)	Dr. G. Tartari	Dr. M.P. Bhatta	Dr. K. N. Dulal
Technical Session-4: Floods in Nepal (Within the broader framework of HKH FRIEND Project)	Hon'ble Minister Ganesh Shah, Ministry of Environment, Science and Technology	**Moderator:** Mr. Adarsha P Pokharel **Rapporteur:** Mr. Jagat Bhusal	Dr. Ram Gopal Kharbuja
Technical Session-5: Water Induced Disaster Management	Dr. M.L. Shrestha	Ms. Suse	Mahendra Gurung
Technical Session-6: Hydrological Extremes and Early Warning Systems	Dr. Siegfried Demuth	Mr. Jagat Bhusal	Dr. Ram Gopal Kharbuja
Technical Session-7: Hydrological Modeling	Dr. Laxmi Prasad Devkota	Dr. Dilip K. Gautam	Mr. Tek Bdr. Thapa
Technical Session-8: **Climate Change and Biodiversity**	Prof. Dr. P. K. Jha	Ms. Mandira Shrestha	Dr. N. Frolova
Closing Session	Mr. Kiran S. Yogacharya		

Annex - 10

List of Participants – International Conference on Hydrology and CC in Mountainous areas 15-17 November, 2008

International

UNESCO	1.	Dr. Bhanu Neupane
UNESCO	2.	Dr. Demath Segfried
UNESCO	3.	Dr. G. Kaiser
Germany	4.	Dr. Axel Thomas
Russia	5.	Dr. Marina Trubetsrova
Russia	6.	Prof. Dr. Alekeesevisky
Russia	7.	Dr. Bulgov
Russia	8.	Dr. Natalia
Poland	9.	Dr. Adam Lajezak
Malaysia	10.	Dr. Ms. Susie N.D.
Haiti	11.	Dr. Gianni Tartari
Israel	12.	Dr. Maxinu Shoshany
Thailand	13.	Dr. Sarunya Premkotra
Thailand	14.	Dr. Tawiwan Kangsadan
Germany	15.	Prof. Andreas Herman

National

Bangladesh	16.	Dr. Someshor Das	DHM	82.	Niraj Sapkota
DHM	17.	Mr. Nirmal Hari Rajbhandari	DHM	83.	Ram Chandra Khatri
DHM	18.	Dr. Keshav Pd. Sharma	DHM	84.	Shanta Panta
DHM	19.	Mr. Jagat K. Bhusal	DHM	85.	Sudeep Kayestha
DHM	20.	Mr. Om R. Bajracharya	DHM	86.	Sujan Subedi
DHM	21.	Mr. Mani Ratna Shakya	DOED	87.	Ram Gopal Kharbuja
DHM	22.	Mr. Rajendra Pd. Shakya	EOI	88.	Vikas Kumar Agrawal
DHM	23.	Mr. Kawal Prakash Budhathoki	ICIMOD	89.	Dr. Arun Bhakta Shrestha
DHM	24.	Mr. Sarju Kumar Baidya	ICIMOD	90.	Finu Shrestha
DHM	25.	Mr. Pancha R. Shakya	ICIMOD	91.	Madhav Dhakal
DHM	26.	Mr. Keshav D. Shrestha	ICIMOD	92.	Mandira Shrestha
DHM	27.	Mr. Jagadishor Karmacharya	ICIMOD	93.	Pradeep Dongol
DHM	28.	Mr. Indra Kumari Manandhar	ICIMOD	94.	Pradeep Mool
DHM	29.	Dr. Dilip K. Gautam	KEC	95.	K.N. Dulal
DHM	30.	Mr. Bijay K. Pokhrel	DOLD	96.	Arun Shankar Ranjeet
DHM	31.	Mr. Durga Prakash Manandhar	DOLD	97.	Bhawani Shankar Dongol
DHM	32.	Mr. Suman K. Regmi	NEA	98.	Neetra Timilsina
DHM	33.	Mr. Shiva P. Nepal	NP	99.	Prakash Regmi
NEA	34.	Mr. Bishnu Bahadur Singh	NTNC	100.	Ngamindra Dahal
	35.	Mr. Damodar Bhakta Shrestha	SEN	101.	Kanchan Shrestha
	36.	Mr. Hrishikesh Sharma	SOHAM	102.	Laxmi P Devkota

	37. Mr. Jagadishwor Man Sing	SOHAM	103.	Risab Risal
	38. Mr. Jayandra Man Tamrakar	SOHAM	104.	Adarsa P Pokhrel
	39. Mr. Khagendra Awasti	SOHAM	105.	B.N. Gurung
	40. Mr. Mahesh Man Shrestha	SOHAM	106.	Bidur Upadhayaya
	41. Mr. Mohammad Yusuf	SOHAM	107.	D.B. Nepali
	42. Mr. Parmadhir Sen	SOHAM	108.	Deepak Paudel
	43. Mr. Pradeep Kumar Thike	SOHAM	109.	Dharmandra Rajbhandari
	44. Mr. Radheshyam Pradhananga	SOHAM	110.	Dhiraj Pradhananga
	45. Mr. Rajendra Prasad Byanju	SOHAM	111.	Janak Nayava
	46. Mr. Krishna Prasad Shrestha	SOHAM	112.	K.B. Manandhar
	47. Mr. Sanjiv Man Rajbhandari	SOHAM	113.	K.N. Shrestha
	48. Mr. Shyam Sundar Shrestha	SOHAM	114.	Kiran Shankar
DOI	49. Mr. Bijaya Shankar Mishra	SOHAM	115.	Madan Lal Shrestha
	50. Mr. Krishna Bahadur Shrestha	SOHAM	117.	Sarojani Pradhan
	51. Mr. Mahendra Bilas Bajracharya	SOHAM	118.	Sohan Subdar Shrestha
	52. Mr. Navraj Shrestha	SOHAM	119.	Suresth Marahatta
	53. Mr. Prabin Maskey	KU	120.	Rijan B. Kayastha
	54. Mr. Purushottam Shah	TU, CDES	121.	Barsa Sharma
	55. Mr. Sanju Upadhyaya	TU, CDES	122.	Sumnima Shrestha
	56. Mr. Surendra Mehar Shrestha	TU, CDG	123.	Narendra Khanal
DWIDP	57. Dhruba Prasad Acharya	TU, CDHM	124.	Amrit Ghale
	58. Mr. Rishab Risal	TU, CDHM	125.	Binod Parajuli
	59. Mr. Rojan Man Shrestha	TU, CDHM	126.	Chiranjibi Vetwal
	60. Mr. Rajaram Shrestha	TU, CDHM	127.	Damodar Bagale
	61. Mr. Rajendra Sharma	TU, CDHM	128.	Deepak Aryal
WECS	62. Mr. Gautam Rajkarnikar	TU, CDHM	129.	Dinkar Kayestha
	63. Mr. Ramesh Prasad Paudel	TU, CDHM	130.	Divas Shrestha
	64. Mr. Madhav Dev Acharya	TU, CDHM	131.	Indira Kandel
	65. Mr. Charma Ratna Tuladhar	TU, CDHM	132.	Lochan Devkota
	66. Mr. Purushottam Joshi	TU, CDHM	133.	Min K Aryal
	67. P.C. Jha	TU, CDHM	134.	Nitesh Shrestha
	68. Durga Sangraula	TU, CDHM	135.	Raju Pradhananga
	69. Khem Paudel	TU, CDHM	136.	Rameswor Rimal
NEC	70. Dr. Hari K. Shrestha	TU, CDHM	137.	Santosh Regmi
KU	71. Dr. Maya Bhatta	TU, CDHM	138.	Suman Sijapati
WINTOCK	72. K. B. Shrestha	TU, CDHM	139.	Sunil Acharya
CEMAT	73. K.P. Shrestha	TU, CDHM	140.	Sunil Aryal
BPC	74. Bhuwan Dhakal	TU, CDHM	141.	Suresh Maharjan
CEMAT	75. K P Shrestha	TU, CDHM	142.	Tek Bahadur KC
DHM	76. Barun Paudel	TU, CDHM	143.	Tirtha Adhikari
DHM	77. Biju Pradhan	TU, TC	144.	Ambrish Pokhrel
DHM	78. Chok Bahadur Gurung	TU, TC	145.	Rupak Rajbhandari
DHM	79. Indra Kumari Manandhar	TU, TC	146.	Sagar Manandhar
DHM	80. Keshav Bam Malla	DOS	147.	Kumar Rajbhandari
DHM	81. Madan Bajracharya			