Application of satellite snow cover for the prediction of runoff of Arun River

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ABSTRACT:

This paper presents the analysis of areal extent snow cover and snowmelt runoff of Arun river of Nepal Himalaya using simple linear regression model from limited available satellite data. The result of the study showed that 84% of the total variation in the discharge is explained by the regression model with the standard error of 18.92 cumecs and the remaining 16% is unaccounted (not explained by the model). The confidence interval on regression line with probability of 95%, within which the predicted values of discharge lies, based on Student t. The t-test further showed that the significant amount of variation in discharge is explained by the derived regression equation at 95% confidence. Therefore the paper concludes that the simple regression model can be improved better by including other variables which influence discharge.

Key words: snow cover, satellite image, runoff, Arun River

1. INTRODUCTION

In Nepal Himalayas, measurement of essential parameters of snow, ice and glaciers pose a great challenge due to the inaccessibility in many parts of the snow and glacier regions. Vast amount of fresh water is stored in the form of snow and glacier ice and considered as most important fresh water resources. Proper management and efficient use of the melt water from snow and glacier plays an important role for the development of many water resources projects such as hydroelectric power, irrigation, drinking water supply etc. where water demand is immense during dry period. Melt water from snow and glacier is only the means of water supply that can fulfill the water demand during dry period before commence of summer monsoon. It is, therefore, imperative to have knowledge about the information on contribution of snow and glacier to river flows. The application of remote sensing technology for the modeling of snowmelt runoff is particularly useful in Himalayan catchments which are not easily accessible for detailed ground surveys and do not have sufficient climatological and hydrological data networks. Snow cover extent and its distribution, water equivalent, water content etc. are essential parameters in the assessment of glaciers and snow pack's contribution to runoff. Snowmelt from snow cover area has been assumed to be responsible for the first rise in water level after the month of February (Sharma, 1977) and therefore, snow cover is an important index for predicting the spring melt, and it is interpreted better than other snow parameters (Thapa, 1992). The snow fed river of the upper reach of basin clearly the diurnal cycle of snowmelt runoff in hourly discharge data. In this study, an attempt has been made to predict the snowmelt runoff from the satellite image of snow cover of the Arun catchment using simple linear regression model.

2. DATA AND METHODOLOGY

2.1 STUDY AREA

This study has considered only the part of the basin located within Nepal. This study area (5056 Km^2) is situated in the central part of the Eastern

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Development Region and lies in the Inner and Higher Himalayas to Midland zone with relief ranging from about 150m (a.m.s.l) at Tribeni (outlet point of Arun river) to 8475 m (a.m.s.l) at Mt. Makalu (Figure. 1). Ice cap ridges occupy the western, northwestern and eastern parts of this watershed. The length of Arun river within Nepal from China boarder to Tribeni area where it joins with Sunkoshi and Tamor river is 139 km (Malla et al., 1988). The major glaciers are upper and lower Barun glaciers. The major glacier lakes in the watershed are Barun Pokhari and Lower Barun. Some small-unnamed glaciers and glacier lakes are also located in this watershed.

Figure 1: Location of Arun Watershed within Nepal and Landsat Scene Coverage (dotted lines)

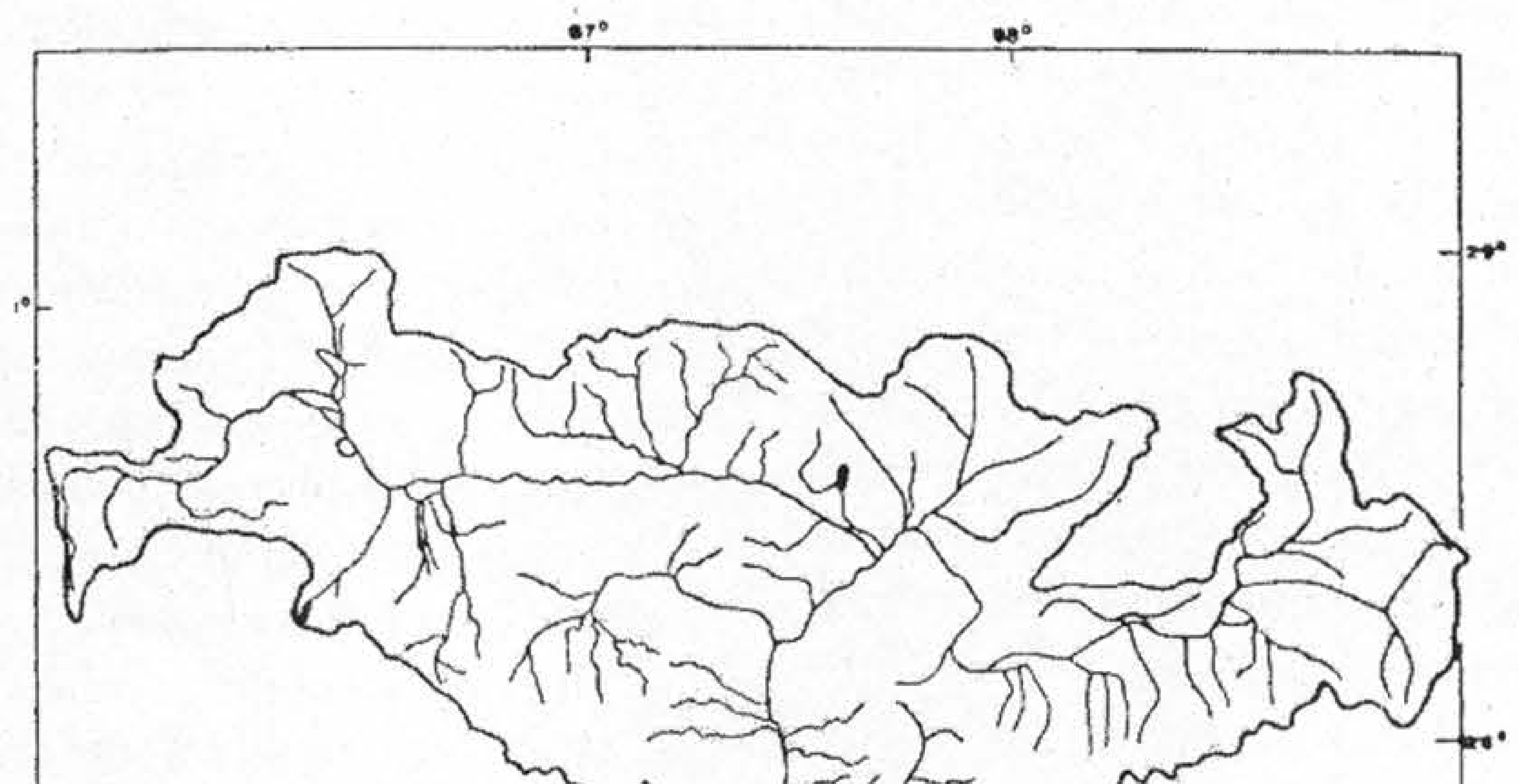

Figure. 2 Major Drainage System of Arun Watershed in Nepal and Tibet, Peoples Republic of China.

2.2 DATA

For the snow-melt runoff study of Arun watershed, the snow cover information, particularly the area, has been extracted from Landsat images and Space Lab photographs which are available for 6 different period of the year as given in table 1.

Table 1: Images used for snow cover area delineation

Sr. no	Landsat Image ID No.	Landsat Series No.	Date of Image
1	E 1107-04115	1	7 November 1972
2	E 2697-03473501	2	29 December 1976
3	20787-0343	2	19 March 1977
4	4-0633-04085	4	09 April 1984
5	5035104123	5	15 February 1985
6	Photograph No. 01-0014-01	Space Lab Photo	02 December 1983

(Source: National Remote Sensing Center, Dept. of soil Conservation and Watershed Management, 1988)

One of the major problems to map the snow cover from satellite images is to distinguish snow from clouds and the snow in the shaded area. Snow cover on the Himalayas follows the same geological patterns as the mountain ranges, which are different from the patterns of clouds views from space (Budhathoki, 1985). The landsat images of almost cloud free periods were used for the mapping of snow cover because of the difficulties to distinguish cloud from snow. Shadows in the imageries are formed due to the low sun angle and on the northern slopes of mountain and can mislead to interpret the

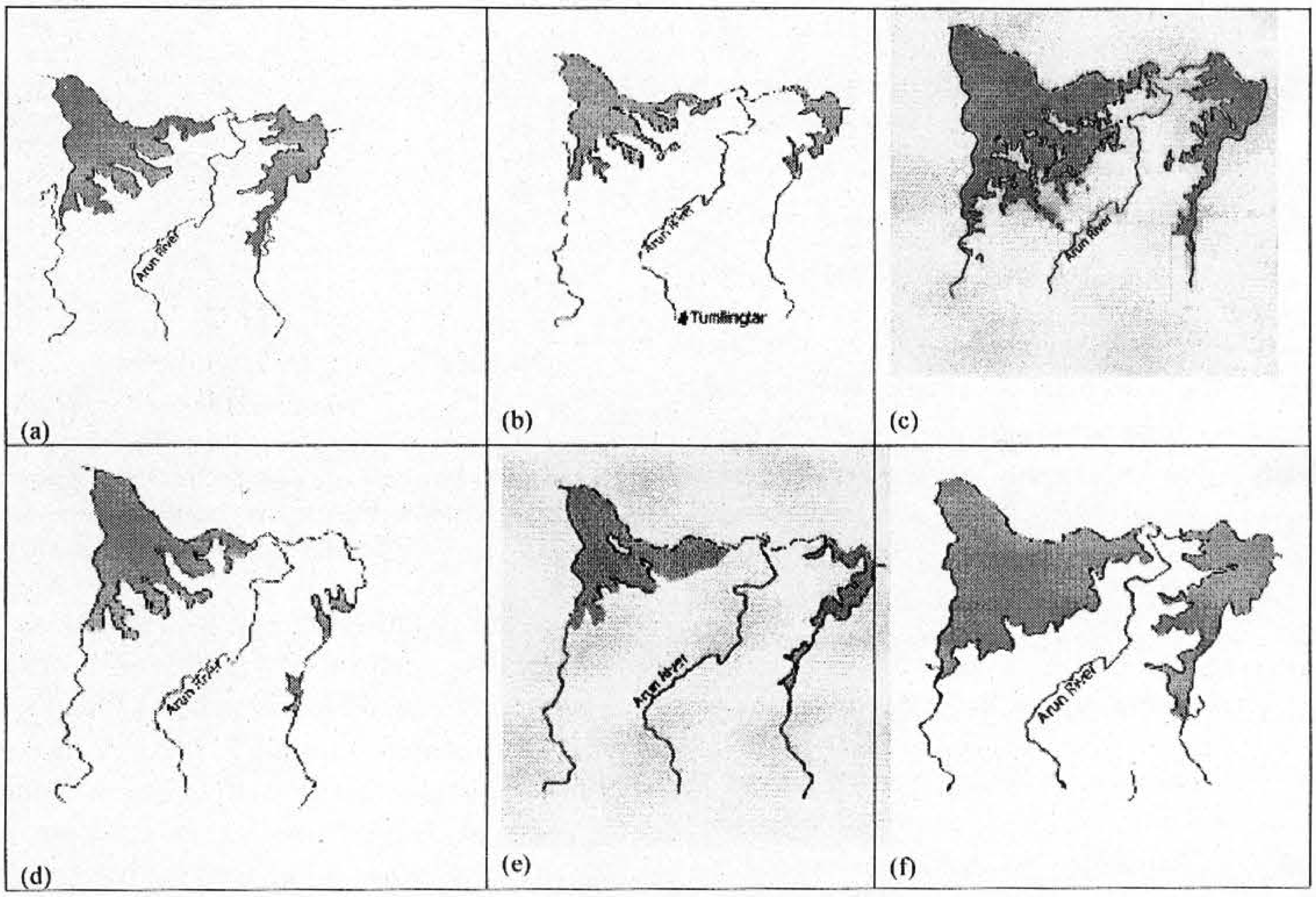

Figure 3: Snow cover area obtained from (a) Landsat image (MSS), 7.11 1972 (b) Landsat image (MSS), 29.12.1976 (c) Landsat image (MSS), 19.03.1977 (d) Space Lab Photograph, 02.12.1983 (e) Landsat image (TM), 09. 04.1984 (f) Landsat image (TM), 15.02.1985

snow in the images. Aerial photographs were also used to minimize such type of possible error. In this study Space Lab 1 mission STS-9 Metric Camera Infrared photographs at the scale of 1:399,999 taken from space shuttle at the elevation of 250 km were used.

2.3 SNOW COVER ESTIMATION

All together six images of different years have been taken for the study (Figure 3). Among the available images, the images from 1972 to 1985 were unusable because of massive cloud cover. Even though, few small patches of cloud randomly spread over in the few selected images created difficulty to demarcate the snow line exactly. The area of snow cover at different years and corresponding observed discharge are shown in Table 2.

Table 2: Snow cover area

Year	Snow cover (km^2)	Remarks
7 November 1972	946	Small cloud patches in the image
29 December 1976	548	Snowy area covered by cloud patches
19 March 1977	806	Small cloud patches in the image
02 December 1983	810	Small cloud patches in the image
09 April 1984	275	Few cloud, No rain and melting predominant
15 February 1985	1315	Negligible cloud lumps

2.4 HYDROLOGICAL DATA

River gauging station is located at Tumlingtar. This station is located in the midland mountains, hills and valley. The discharge data of this station are available and used for the study.

2.5 LINEAR REGRESSION MODEL

Statistical linear regression model has been applied to develop the relationship between aerial extent of snow cover and discharge. The model used is based on the assumption of a linear relationship between two variables. Generally, this model provides a means of predicting or estimating dependent variable (discharge), from knowledge of second independent variable (snow cover area).

3. RESULT AND DISCUSSION

There exits relationship between aerial extent of snow cover and discharge showing linear dependence of discharge of 0.1104 cumecs for a unit increases in snow cover area (Figure 4). The estimated regression equation has been obtained as

$$Q = 95.37 + 0.1104 * X_{sc}$$

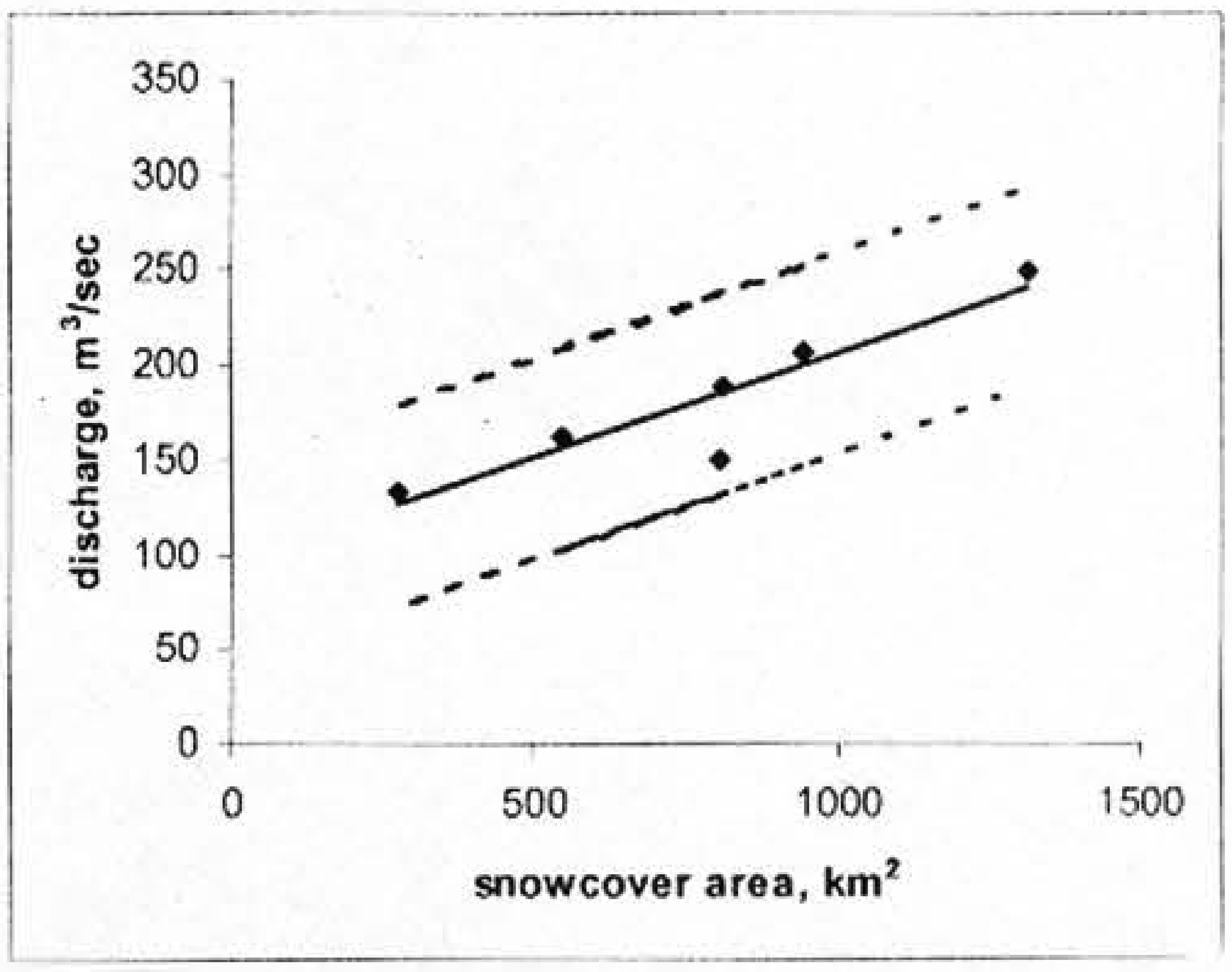

Figure 4: Linear Regression between snow cover area and discharge and confidence interval of predicted discharge.

Where **Q** is the discharge (m^3/s) and $\mathbf{X_{sc}}$ is the snow cover area (km^2).The standard error of **Q** estimated has been found to be 18.98 cumecs and the coefficient of determination, $r^2 = 0.84$ ($r = 0.92$) shows that 84 % of the total variation in discharge has been explained by regression equation. In other words, the regression with snow cover area accounts for 84% of the variance of the discharge. The remaining 16 % of variation is due to unexplained causes. Obviously, there are other variables, which influence the runoff, for example some of the important variables which can influence the discharge are rainfall, temperature, solar radiation etc. If these variables are included in the model as predictors, the value of r^2 will be increased significantly and the model can provide better estimates by the use of the multiple regression model.

The confidence interval on regression line with probability of 95%, within which the predicted values of discharge lies, based on Student t (=2.78) with 4 degrees of freedom has been obtained (Table 3). The t-test further showed that the significant amount of variation in discharge is explained by the derived regression equation, since tcal=4.6> $t_{tab, 0.05}$= 2.78 at 95% confidence (Figure 4).

Table 3: Observed and predicted discharge with confidence level at 95%

Year	Snow cover (km^2)	Observed Discharge* (Cumecs)	Predicted Discharge (Cumecs)	Confidence level at 95%
7 November 1972	946	207.4	199.81	199.81 ± 52.76
29 December 1976	548	161.7	155.87	155.87 ± 52.76
19 March 1977	806	149.9	184.35	184.35 ± 52.76
02 December 1983	810	188.7	184.79	184.79 ± 52.76
09 April 1984	275	133.7	125.73	125.73 ± 52.76
15 February 1985	1315	249.7	240.55	240.55 ± 52.76

(Source: Department of Hydrology and Meteorology)*

4. CONCLUSION

It can be concluded that simple regression model is useful for snow-fed river to predict discharge from snow cover area. Although there are several snowmelt runoff models available which require large amount of meteorological and hydrological input, this is one of the simple and readily available model which require knowledge of basic statistics. Since the study is carried out with limited data and available snow cover information, regression model can be improved by using multiple regression model which requires the input of other meteorological variables and number of years of satellite imagery data. The study shows that this model has wide practical application provided that number of years of data are sufficiently available.. This model has been used in many studies for example rainfall runoff, trend analysis of temperature etc. The model provides a scientific basis for optimum use of water resources especially for hydropower generation, irrigation and drinking water supply where melt water from snow and glacier play a significant role.

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