MULTISENSOR AND MULTITEMPORAL SATELLITE DATA FOR RUNOFF FORECAST IN HIGH ALPINE ENVIRONMENT

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ABSTRACT:

Accumulation and ablation of snow controls the hydrological environment of high mountain river basins. Multisensor and multitemporal satellite data enables to monitor seasonal changes in snow cover and evaluate its contribution to runoff. In the present study, nine LANDSAT 4 and 5 Multi Spectral Scanner and Thematic Mapper images in a hydrological year have been analysed by digital image processing. Supervised maximum likelihood classification was used for estimating areal distribution and seasonal changes in snow cover over upper Cordevole river basin located in the high Alpine environment of eastern Italian Alps. Digital elevation model, slope, aspect and exposition maps were used in the analysis. The seasonal snow cover have been integrated with meteorological and hydrological data to develop runoff forecast model for the basin. Performance evaluation of the model indicates Coefficient of Determination and Volume Deviation as 0.86 and -0.01% respectively comparable with results of World Meteorological Organization. Performance evaluation of the model on monthly basis is also studied and found to be good.

KEY WORDS: Landsat, Multispectral, Remote Sensing Application, Hydrology, Snow, Runoff Forecasting.

1. INTRODUCTION

Satellite remote sensing has become increasingly important to hydrologists as the data provide information on the temporal and spatial distribution of hydrological parameters. The alpine snow cover in the middle latitudes have a very large storage capability of water. The seasonal snow cover in Italian Alps decreases gradually during snowmelt season. The remote sensing data being collected by earth observation satellites allow to monitor these seasonal changes as the radiometric data provides spatial and temporal information on snow covered areas that are difficult to monitor routinely because of severe environment and large areas involved. Several examples were found where the traditionally prepared snow map disagree with a snow extent line clearly visible on the satellite image (Lillesand et al, 1982).

Most of the reservoirs in the Italian Alps are characterized by a nivo-pluvial regime and receive about 40 to 70% of their annual contribution during May, June and July months. Studies on seasonal forecasting behaviour of the river discharges during snowmelt season in Italian Alps are very important as the snowmelt runoff is being used for hydropower generation, domestic and industrial water supply etc. These studies are also important towards reservoir management as spring snowmelt can heavily affect the optimality of the long term operating rule.

Based on snow cover derived from remotely sensed data, Rango and Martinec (1979) developed a catchment-conceptual-deterministic-temperature index snowmelt runoff model. In the present work application of the same methodology as a lumped model is studied over a catchment in the high mountainous Italian Alps by integrating the satallite derived information with meteorological and hydrological data.

2. AREA OF INVESTIGATION

Upper part of Cordevole river basin in the eastern Italian Alps was selected for the present study (Figure 1). The Cordevole river joined by the tributaries viz., Pettorina and Fiorentina originates in the altitudes of about 3100 meters above sea level and joins at the down stream into the Lake Alleghe. The area of the basin measures to 248 square kilometers with mean altitude of 1900 meters above sea level. The watershed is characterized by very low permeable geological formations of the area known as calcareous dolimitic rocks.

3. METEOROLOGICAL AND HYDROLOGICAL DATA

Precipitation and hourly air temperature data are being collected at Arabba (1620 m asl), Andraz (1400 m asl) and Caprile (1000 m asl) by Centro Sperimentale Valanghe e Difesa Idrogeologica-Regione Veneto (CSVDI) which is a research center for avalanches and hydrological control located in Arabba (Figure 1). In addition, Ente Nazionale per l'Energia Elettrica (ENEL), which maintains a hydropower station at Lake Alleghe is computing discharges of Cordevole river from water level measurements in Lake Alleghe using an appropriate algorithm. These discharges are being corrected for the water pumping carried out by the hydropower station.

The fifty year normal annual precipitation (1925-74) over Cordevole river basin is 1070 mm. Hydrologic regime of the basin is characterized by a peak of water flow during the late spring/early sumer (snow melt season) and by a minimum during winter (snow accumulation season).

4. MORPHOLOGICAL PARAMETERS

Altitude contours were digitized from topographic maps at 1:50000 scale of the Istituto Geografico Militare d'Italia (IGMI) using a graphic tablet and AUTOCAD software for every 200 meters and at some specific areas for every 100 meters. A digital elevation model has been generated using weighted distance of known altitudes in neighbours of a generic point as the interpolation procedure. The model was generated with a resolution grid to match Landsat MSS pixel size. Morphometric parameters like slope, aspect and exposition were computer generated using locally developed software. For a better evaluation of snow cover extension, the numerical relief was sub divided into five classes of slope: 0-15, 15-30, 30-45, 45-60 and >60.

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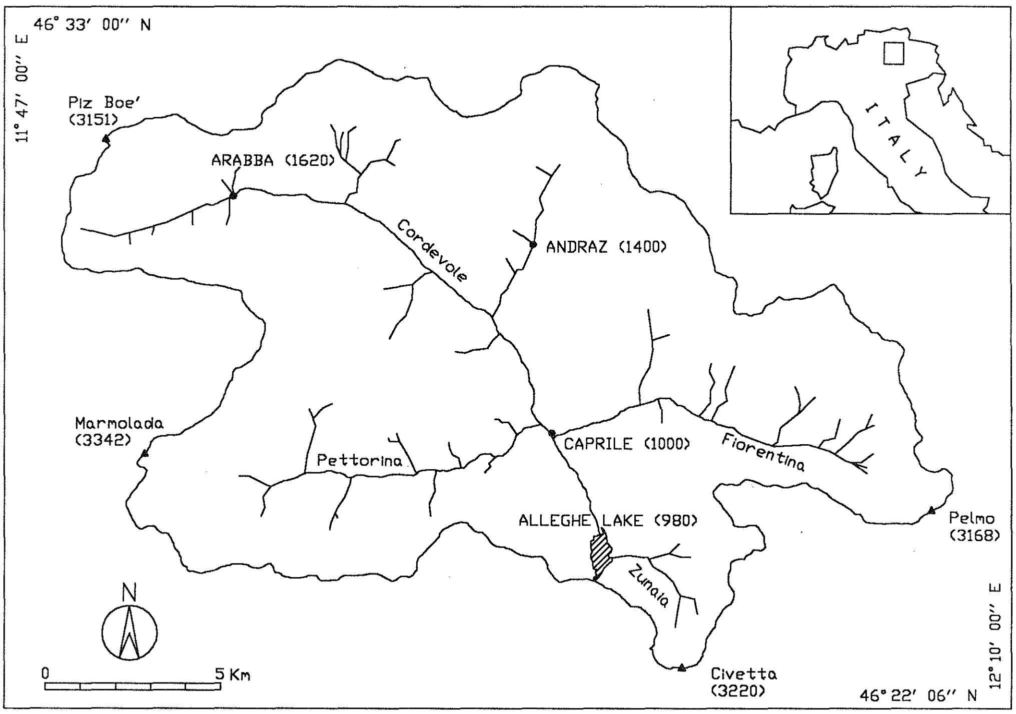

Figure 1. Upper Cordevole river basin.

5. EXTRACTION OF AREAL SNOW COVER

Snow cover areal extent being a fundamental parameter for all snowmelt runoff models, well fits with typical characteristics of satellite remote sensing (Baumgartner et al, 1987). It seems the first earth resources application of satellite observation was to map snow cover from the initial pictures taken by first weather satellite TIROS-1 (Bowley and Barnes, 1979). Many investigations have been made to map snow cover areas as well as derive snow cover depletion rates from multi-temporal reflected and emitted radiation measurements (Leaf, 1969; Meier, 1973; Itten, 1975; Rango and Itten, 1976; Haefner, 1979; Lichtenegger et al, 1981; Rott and Markl, 1989; Gangkofner, 1989).

5.1 Limitations of Satellite Data

The high spatial resolution satellites such as Landsat and SPOT and the medium resolution satellite NOAA are widely used for mapping snow cover. The selection of appropriate sensor from the above satellites for snow cover mapping depends on a trade off between spatial and temporal resolution (Rott, 1987).

Landsat MSS is observed to be suitable for snow mapping in basins larger than about 10 km^2 (Rango et al, 1983) but Thematic Mapper band 5 allows snow/cloud discrimination (Dozier and Marks, 1987). The high spatial resolution satellites have poor temporal resolution for snowmelt runoff forecasting studies. The nominal repetition frequency of Landsat is 16 days and of SPOT about 26 days. Due to cloud cover during snow melt period, particularly in high mountainous region of Italian Alps, only few images of the above satellites in a hydrological year could be effectively used for snow cover studies. However, for snowmelt forecast purposes, especially during snowmelt season an assured observational frequency of 1 - 2 weeks is required (Rango et al, 1983).

The medium resolution sensors such as NOAA-AVHRR are able to provide high temporal resolution data which is very useful for snowmelt forecast studies. With NOAA type satellites a cloud free image can generally be secured at least once a week (Foster, 1983). High level clouds which are often difficult to detect in the visible and near infra red are easily identifiable in channel-4 and channel-5 of AVHRR data (Harrison and Lucas, 1989). The cost of each NOAA-AVHRR scene on a computer compatible tape (CCT) covering large drainage basins is approximately U.S.$100. Low cost AVHRR receiving and processing system to cover a NOAA ground track of approximately 1400 km are available (Baylis et al, 1989). User organizations could maintain such type of system to receive the data, process and classify snow covered area in real time. This information can be inserted along with meteorological and hydrological data into a snowmelt runoff model to forecast river discharge in real time. However, there is a limitation in the use of NOAA-AVHRR data to assess snow cover from small catchments (<600 km^2). It was also observed that from AVHRR data only two categories of snow surface "snow covered" and "aper" could be assessed (Baumgartner et al, 1987). Hence, any snowmelt runoff forecasting model developed for operational purpose using remote sensing information must take the above fact into consideration.

5.2 Satellite Data Analyses

For the present study, nine sets of Landsat Multi Spectral Scanner (MSS) and Thematic Mapper (TM) CCT's covering snow accumulation and depletion periods in a hydrological year were acquired. However, due to severe clouds over snow covered areas, only five CCT's covering April to July

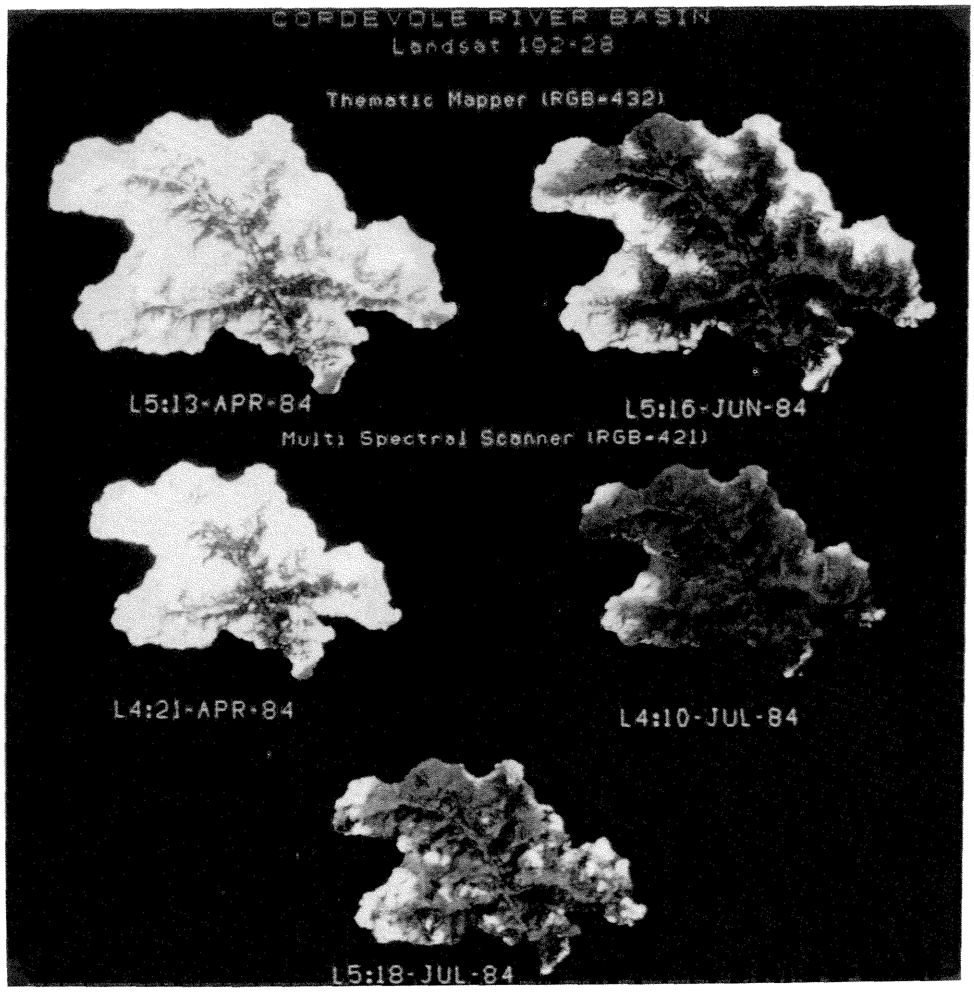

Figure 2. Black and white representation of false colour composite of various Landsat-4 & 5 images.

months of the year 1984 were finally examined in detail. Table 1 gives the particulars of the satellite data considered:

Table 1: Details of Satellite Images

Satellite	Sensor	Path & Row	Date
Landsat-5	TM	192-28	13-APR-84
Landsat-4	MSS	192-28	21-APR-84
Landsat-5	TM	192-28	16-JUN-84
Landsat-4	MSS	192-28	10-JUL-84
Landsat-5	MSS	192-28	18-JUL-84

All images were geometrically corrected with the support of Ground Control Points. The catchment area from each satellite image was extracted using an overlay mask. Figure 2 presents the black and white representation of false color composite of the extracted catchment areas from multi temporal satellite images. From the figure, the seasonal snow cover depletion during various months can be clearly visualized. These images were analysed into two categories "snow" and "aper" by digital image processing on II^{2}S 600 Image Processing System using maximum likelihood classification. Some problems concerning the shadow regions were solved by taking into consideration the ratio images of various bands as well as slope and aspect maps. Possible corrections were made for the clouds over snow covered area. Figure 3 shows the classified images with respective snow and snow free areas. Table 2 presents the snow covered surface expressed as percentage of total basin area.

Table 2: Snow cover surface from Landsat images

Date	Snow surface expressed as % of basin area
13-APR-84	84.2
21-APR-84	75.6
16-JUN-84	24.0
10-JUL-84	9.7
18-JUL-84	7.4

The typical shape of snow cover depletion curves can be approximated by the equation given below (Hall and Martinec, 1985):

$$S = \frac{100}{1 + \exp(b * n)} \qquad (1)$$

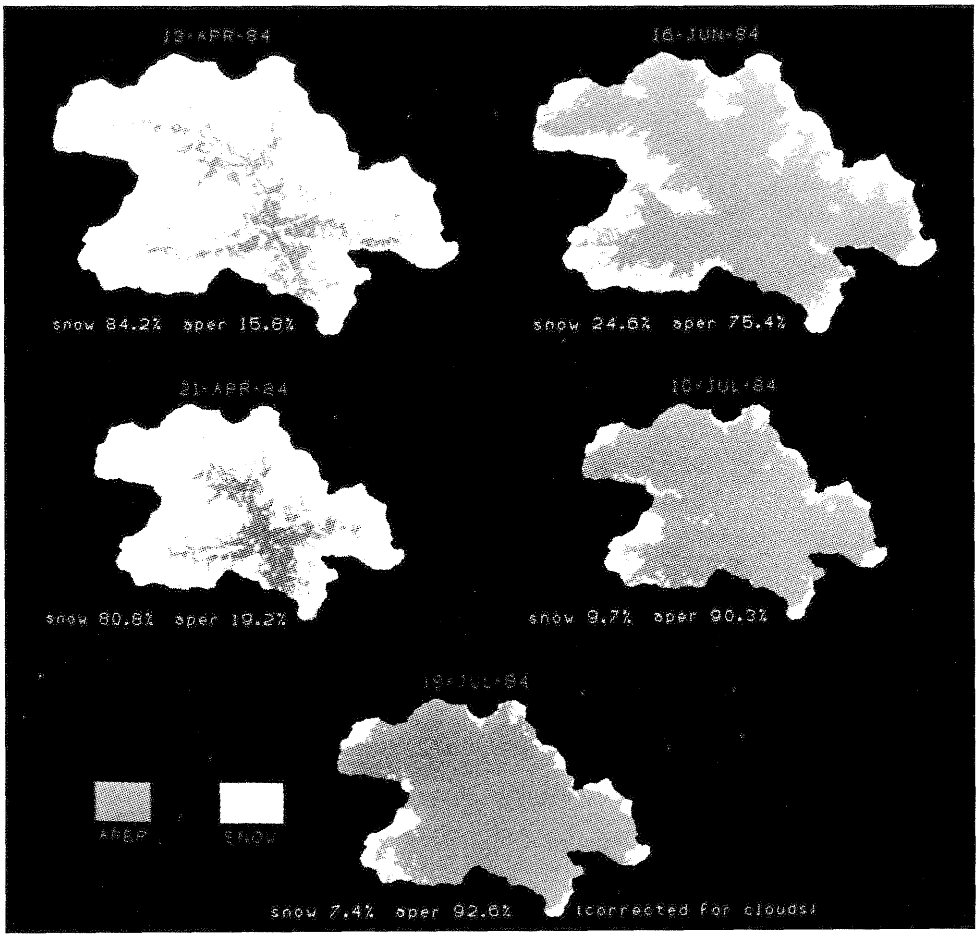

Figure 3. Extracted snow cover from satellite images.

where S is the snow covered area in %, 'b' is a coefficient and 'n' is the number of days before (-) or after (+) the date at which S = 50%. From the extracted snow cover data (Table 2), daily snow cover depletion has been computed using the equation (1) with b = 0.04. Figure 4 shows the computed daily snow surface depletion curve which fits well into the extracted snow surface on different dates.

6. SNOWMELT RUNOFF MODEL

Snowmelt runoff model should be able to simulate the contribution due to the snow depletion in the basin to the total river discharge day by day during the melting season. In the present study the snowmelt runoff model given by Martinec et al (1983) has been used by treating the entire basin as a single elevation zone. The equation considered is given below:

$$Q_{n+1} = \left[C_{sn} \, . \alpha_n \left(T_n + \Delta T_n\right) S_n + C_{rn} \, . \, P_n\right] \frac{A * 0.01}{86400} \left(1 - k_{n+1}\right) + Q_n \, . \, k_{n+1} \qquad (2)$$

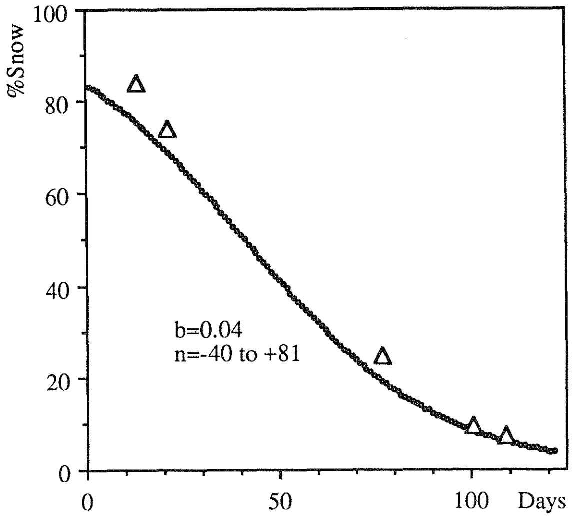

Figure 4. Snow surface depletion curve (1 april-31 july 1984).

where Q = average daily discharge ($m^3\ s^{-1}$)
C = runoff coefficient with C_s refering to snowmelt (0.9 to 0.6) and C_r to rain (0.9 to 0.4)
α = degree day factor (cm $^oC^{-1}$ day^{-1}) (0.3 to 0.5)
T = number of degree days above the base of 0^o C (^oC day) (hourly weighted temperatures used)
ΔT= the adjustment by temperature lapse rate for different altitudes of meteo stations (^oC day) (-3.92)
S = ratio of the snow covered area to the total area
P = Precipitation contributing to the runoff
k = recession coefficient ($0.9386\ Q^{-0.0794}$ derived from historical discharges)
A = Area of the basin (m^2)

In the above equation T, S and P are the daily measured variables while C, α, k and ΔT are parameters characterizing the given basin/or climate determined a priori using actual data and by analogy with other basins.

7. RESULTS

Using equation (2) discharges were computed for upper Cordevole river basin for the entire snowmelt period i.e. 1 April to 31 July of the year 1984. Figure 5 shows the measured and simulated discharges for the above period. Figure 6 shows the regression between measured and simulated discharges. The correlation coefficient (r) has been computed as 0.93 indicating a strong correlation between measured and simulated discharges.

For evaluating the performance of the model over Cordevole river basin, the Nash-Sutcliffe Coefficient (Nash and Sutcliffe, 1970) is computed using the formula:

$$R^2 = 1 - \left[\frac{\Sigma(Q_m - Q_w)^2}{\Sigma(Q_m - Q')^2}\right] \qquad (3)$$

where Q_m = daily measured discharge ($m^3\ s^{-1}$)
Q_w = daily simulated discharges ($m^3\ s^{-1}$)
Q' = seasonal average of measured discharge ($m^3\ s^{-1}$)

The R^2 value of 0.86 is found to be comparable with values obtained for various test basins by World Meteorological Organization as given in table 3 (Hall and Martinec, 1985).

Table 3: Comparison of R^2 values

Catchment	Area(km2)	Years	R^2
Durance(France)	2170.0	1975-79	0.850
W-3 (USA)	8.7	1969-78	0.799
Dischma(Swiss)	43.3	1970-79	0.836
Dunajec(Poland)	680.0	1976	0.759
Cordevole(Italy)	248.0	1984	0.860

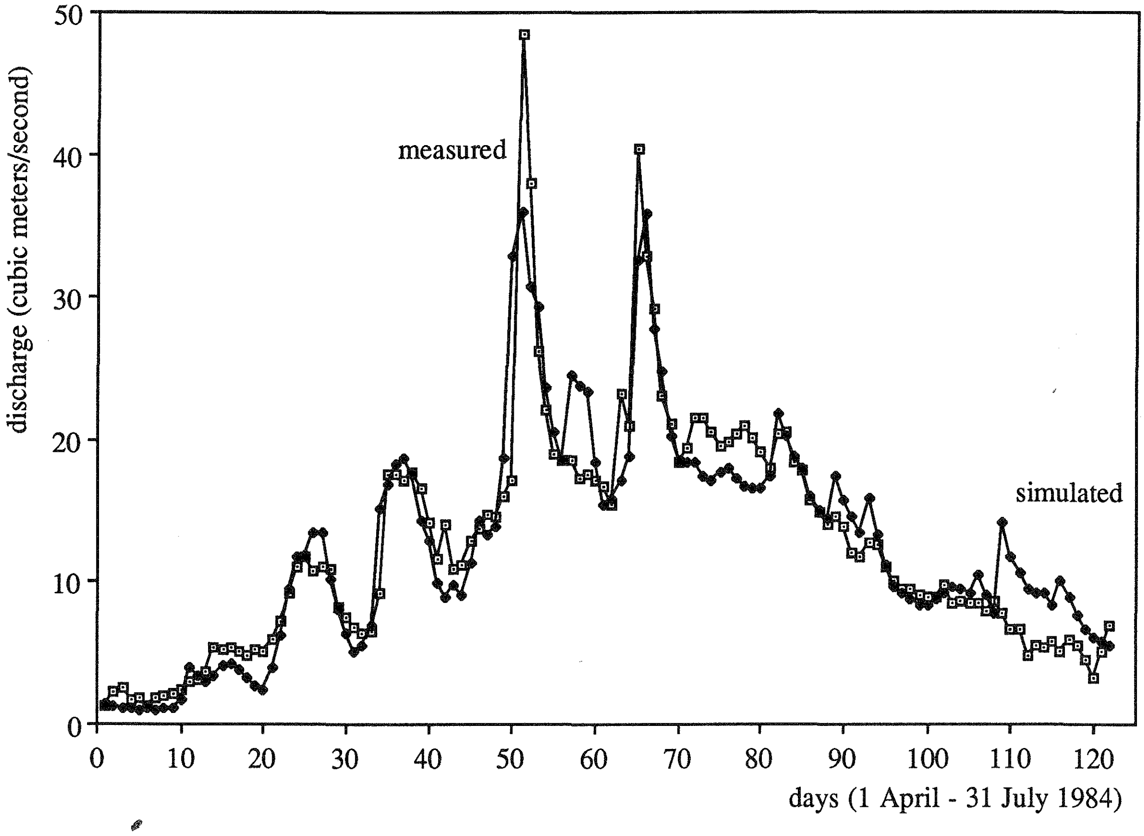

Figure 5. Distribution of measured and simulated discharges.

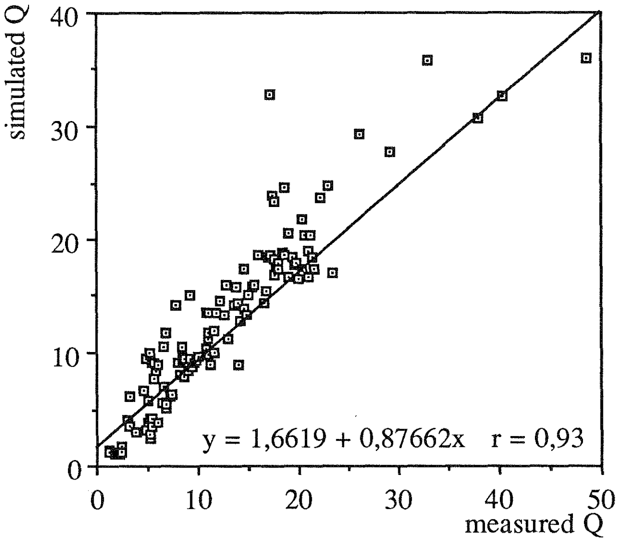

Figure 6. Regression between measured and simulated discharges.

The model accuracy is also studied by deriving the percentage volume deviation as given below:

$$D_V = \frac{V - V'}{V} * 100 \qquad (4)$$

where V and V' are the measured and computed runoff volumes. For the period 1 April to 31 July the volume deviation between measured and simulated discharges at Cordevole river basin is -0.01%. Seidel et al (1989) have computed the same parameter as -1.91% and -3.09% for Sedrun and Tavanasa catchments in Swiss Alps. The seasonal volume deviation of Cordevole river basin is in good agreement with the above values.

The correlation coefficient (r) and percentage volume deviation (D_V) were also computed for individual months and given in Table 4. From the table it can be observed that there is good correlation between measured and simulated discharges for the months April, May and June. The table also shows similar pattern for volume deviation. The relatively poor performance of the model results in July may be attributed to the errors associated with the of lake level measurements for estimating discharges.

Table 3: Monthly model performance evaluation

Month	Correlation Coefficient	Volume Deviation (%)
April	0.96	+10.9
May	0.83	- 2.1
June	0.89	+ 5.4
July	0.63	-21.4

8. ACKNOWLEDGMENTS

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