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Evaluating a Model of Snow Cover Area versus Runoff against a Concurrent Flow Correlation Model in the Western Himalayas

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This study evaluates the estimates of seasonal snowmelt runoff in the Sutlej, Indus, Kabul and Chenab rivers derived from the model of snow cover area vs. runoff against those obtained from cross correlation of concurrent flows in the rivers. The concurrent flow correlation model explains more than 90 percent of the variabililty in flow of these rivers. Compared to this model, the model of snow-cover area vs. runoff explains less of the variability in flow. However, unlike the snow-cover model, the concurrent flow correlation model cannot be used for operational forecasting procedures. Where the strength of correlation is high, the concurrent flow correlation model has potential for use in retrospective analysis of flow for estimating missing data, extending time series and for evaluating estimates derived from other models. In the Himalayan basins under study and at least for the period under observation, the concurrent flow correlation model provides a set of results with which to compare the estimates from the snow cover model.

Introduction

Estimation of snowmelt runoff in mountainous river basins using satellite remote sensing techniques is being increasingly recognized as an immensely useful procedure in water resources research and management (Bowley et al. 1981; Dey et al. 1979; Rango 1975; and Rango and Peterson 1980).

Few such studies to date have focussed on the Himalayan rivers which carry considerable snowmelt runoff (Rango et al. 1975, 1977; Ramamoorthi and Subba Rao 1981; Gupta et al. 1982; Dey and Subba Rao 1984; Dey et al. 1983). Prediction of snowmelt runoff in the Himalayan rivers has great potential for application in irrigation, hydro power generation, and domestic and industrial water supply. The studies conducted so far have demonstrated that the seasonal runoff estimated from satellite-derived snow cover area data compares well with the measured runoff and is therefore of great practical significance in operational water resource management practices. Each of these studies, however, indicated several areas of deficiency of the database: low frequency of coverage of the high-resolution satellite overpass, high percentage of cloud cover, limited physical accessibility and sparce network of hydrometeorological observations. An evaluation for the seasonal runoff forecasting model based on satellite snow cover data for the Himalayan basins is attempted here using, for comparison, a model based on cross-correlation of concurrent flows in adjoining Himalayan basins. A unique feature of the hydrology of the Himalayan rivers is the high degree of correlation of concurrent flows in adjacent rivers (Goswami 1983). This may be linked with the similarities in the physical environment, climate and timing of snowmelt that characterize these Himalayan basins. So, it is possible to estimate seasonal snowmelt in one river by correlation with the corresponding flows in an adjacent river. The results obtained from cross-correlation of flows provide a basis against which the estimates derived from the satellite snow covered area model can be examined and their accuracies assessed. Moreover, the correlation model offers a simple method of filling in the missing flow data as well as extending the time series.

Study Area

The Study focuses on four adjoining river basins in the Western Himalayas – the Indus and its three tributaries, the Kabul, the Sutlej and the Chenab (Fig. 1). These rivers carry significant amounts of snowmelt runoff which, on the average, account for more than 55 percent of the mean annual flow. The mean annual snowmelt runoff (April-June) in the Indus, Kabul, Sutlej and Chenab rivers are 4,027, 851, 735 and 1,508 m^3/sec respectively. Since precipitation in the form of rainfall is generally low during these months, the snowmelt alone provides the bulk of the water needed for agriculture, power generation, and domestic and industrial use.

The Indus basin rivers rise in the Hindukush, Karakoram and Himalayan mountains at elevations between 5,400 to 7,500 m. The catchment area above the gaging station at Besham is 162,100 km^2. The Kabul river originates in the Hindukush mountains and covers a drainage area of 88,600 km^2 in eastern Afganistan and northern Pakistan. The Sutlej river rises near Dharama Pass in the vicinity of Manasarowar Lake at a height of 4,350 m and defines a drainage area of 38,000 km^2 above the Bhakra Reservoir, India. The Chenab river originating in the Lahul Himalayas covers a drainage area of 26,155 km^2.

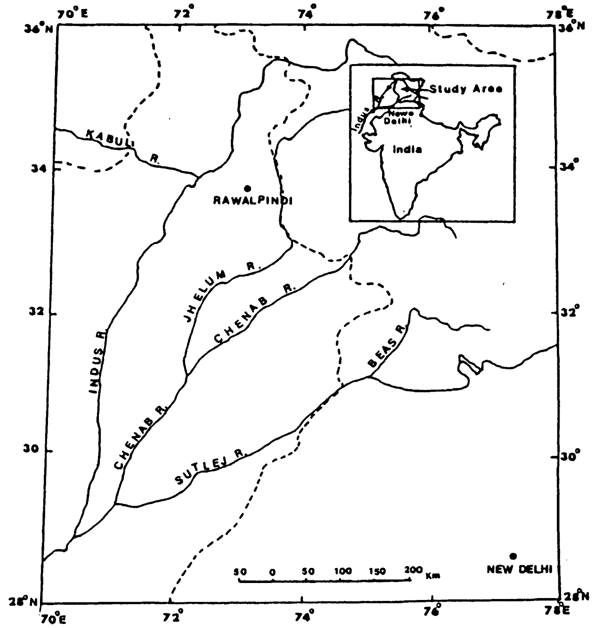

Fig. 1. Location map of the Sutlej, Indus, Kabul and Chenab Basins.

Methodology

NOAA/TRIOS images that provide daily coverage over the Indus, Kabul, Sutlej and Chenab basins were used in the analysis. Simple photo-interpretation techniques using a zoom transfer scope were employed to extract April snow cover area data for the period 1975-79. Basin snow-covered areas delineated on base map overlays, were measured with a digital planimeter. The average per cent snow cover for April was obtained by comparing the snowcovered area with the area of the entire basin.

Mean monthly concurrent flows in the Indus, Kabul, Sutlej and Chenab rivers of the Western Himalayas during the snowmelt season, April through June, are correlated with one another for the period 1975-1979. Pairs of rivers in which the flow shows a high degree of correlation, as evident in the correlation matrix, are selected and linear regression equations defining the flow in one river as a function of the concurrent flow in the other are derived. The estimates of seasonal snowmelt runoff for each of the study basins based on satellite derived snow cover area data are obtained from the earlier studies in the same basins and for the same period by Dey and Subba Rao (1984) and Dey et al. (1983). The results of both the concurrent flow correlation as well as the satellite snow cover area models are tabulated and the two estimates are compared in terms of their ability to explain the standard errors of estimate.

Results

The linear regression equations relating mean monthly concurrent flows during the snowmelt season, April through June, 1975-79 and the satellite snow cover area equations for the same basins and years of study from Dey and Subba Rao (1984) and Dey et al. (1983) are presented in Table 1. Scatter plots representing the relationship of concurrent flow in best-matched rivers are illustrated in Figs. 2, 3 and 4. In each of these cases, about 90 percent of the variability in flow of one river is explained by the other.

The concurrent flow in the Kabul river explains about 97 percent of the variability in flow of the Sutlej river during the snowmelt season, 1975-79 (Fig. 2). For the same period, the snowcover area-runoff model (Dey and Subba Rao 1984) explains 91 percent of the variability in the Sutlej flow. The standard error of estimate for the concurrent flow model is 5.6 percent of the mean seasonal flow versus 9.7 percent for the snow cover area runoff model.

The variability in the Indus river seasonal flow during 1975-79 is best explained by the concurrent flow in the Chenab river. The linear regression model explains about 90 percent of the variability in flow (Fig. 3). The snow cover area model for the same period (Dey et al. 1983) explains only about 57% of the flow. However, the standard errors of estimate are lower in the case of the snow cover area model as compared to the concurrent flow correlation model. For the period 1975-79, the concurrent flow correlation model explains flow variation better than does the snow cover area-runoff model (Tabel 1).

For the Kabul river, the correlation of concurrent flow with the Sutlej river during 1975-79 explains about 97 percent of the variability in the flow (Fig. 4). The snow cover area model for the same period (Dey et al. 1983) explains only about 64 percent of the variability. The standard error for the concurrent flow model is also lower than the one for the snow cover area-runoff model. However, for the period 1971-79, the snow cover area model explains 91 percent as against 71 percent by concurrent flow correlation with the Indus river.

For the Chenab river, a snow cover area runoff model is not available and so comparison with the concurrent flow correlation model could not be made. However, as presented in Table 1, the concurrent flow correlation with the Sutlej, Indus and Kabul rivers explains 95, 90 and 94 percent respectively of the variability in its flow.

Explanation of symbols:
Y = seasonal runoff, April-July, $10^9 m^3$
X = Average percent snowcover of the basin
Q = Mean monthly runoff, April-June, m^3/sec
$S.E.$ = standard error; r^2 = coefficient of Determination
Subscripts, S/J = Sutlej River K/L = Kabul River
I/S = Indus River C/B = Chenab River

Table 1 – Comparison of snowcover Area-runoff and concurrent runoff correlation Models in the Sutlej, Indus, Kabul and Chenab Rivers of Western Himalayas.

	Snowcover area-runoff relationship	As a function of Sutlej flow	As a function of Indus flow	As a function of Kabul flow	As a function of Chenab flow
Sutlej R.	(1975-79) $Y=0.06493x-0.363325$ $r^2=0.914$ $S.E.=9.66\%$ of mean seasonal flow		(1975-79) $Q_{S/J}=0.145855\ Q_{I/S}+116.8472$ $r^2=0.84$ $S.E.=20.8\%$ of mean seasonal flow	(1975-79) $Q_{S/J}=0.74709\ Q_{K/L}-530.507$ $r^2=0.9687$ $S.E.=5.58\%$ of mean seasonal flow	(1975-79) $Q_{S/J}=0.60568\ Q_{C/B}-170.0495$ $r^2=0.945$ $S.E.=9.4\%$ of mean seasonal flow
Indus R.	(1971-79) $Y=0.472x+4.73895$ $r^2=0.52$ $S.E.=11.9\%$ of mean seasonal flow			(1971-79) $Q_{I/S}=3.1336\ Q_{K/L}-1744.136$ $r^2=0.71$ $S.E.=27.1\%$ of mean seasonal flow	
	(1975-79) $Y=0.6493x-13.308$ $r^2=0.57$ $S.E.=7.59\%$ of mean seasonal flow	(1975-79) $Q_{I/S}=5.78387\ Q_{S/J}-251.90439$ $r^2=0.844$ $S.E.=22.6\%$ of mean seasonal flow		(1975-79) $Q_{I/S}=4.42413\ Q_{K/L}-3464.108$ $r^2=0.86$ $S.E.=21.4\%$ of mean seasonal flow	(1975-79) $Q_{I/S}=3.560182\ Q_{C/B}-1445.7821$ $r^2=0.904$ $S.E.=15.7\%$ of mean seasonal flow.
Kabul R.	(1971-79) $Y=0.54337x-5.24243$ $r^2=0.91$ $S.E.=6.81\%$ of mean seasonal flow		(1971-79) $Q_{K/L}=0.22582\ Q_{I/S}+819.9314$ $r^2=0.71$ $S.E.=19.6\%$ of mean seasonal flow		
	(1975-79) $Y=0.45132x-1.487995$ $r^2=0.64$ $S.E.=6.04\%$ of mean seasonal flow	(1975-79) $Q_{K/L}=1.296648\ Q_{S/J}+731.5441$ $r^2=0.9687$ $S.E.=2.59\%$ of mean seasonal flow	(1975-79) $Q_{K/L}=0.19363\ Q_{I/S}+870.829$ $r^2=0.857$ $S.E.=9.4\%$ of mean seasonal flow		(1975-79) $Q_{K/L}=0.79044\ Q_{C/B}+495.8538$ $r^2=0.937$ $S.E.=4.99\%$ of mean seasonal flow

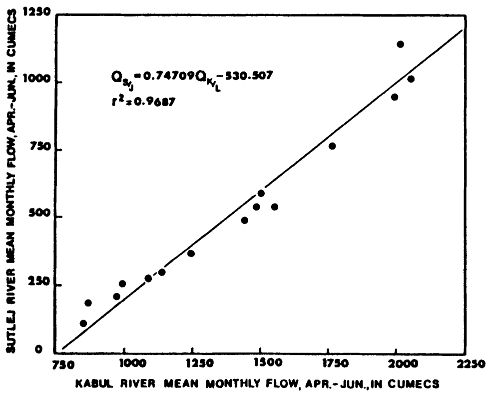

Fig. 2. Sutlej River mean monthly flow, April-June, 1975-79, as a functional of concurrent flow in the Kabul River.

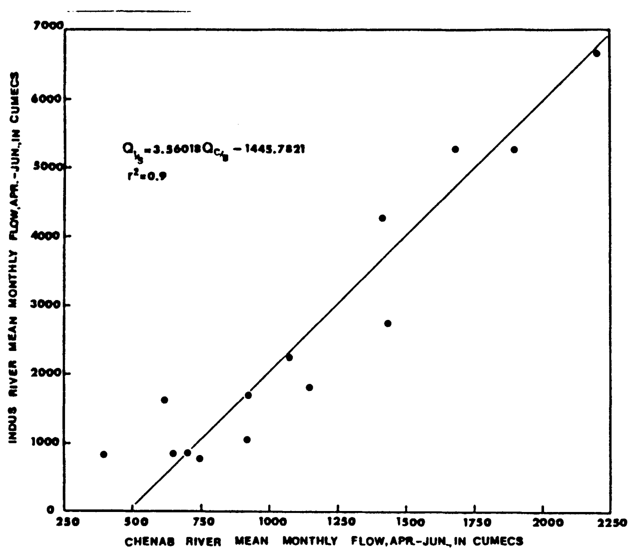

Fig. 3. Indus River mean monthly flow, April-June, 1975-79, as a function of concurrent flow in the Chenab River.

Summary and Conclusions

The results obtained from models of snow-cover area versus runoff are evaluated against the estimates derived from correlation of concurrent flows for the same study period. In all the basins under study, correlation of concurrent flows explains the variability in flow better than by the snowcover area-runoff model. However, in view of the inadequate data base, the strength and weaknesses of the

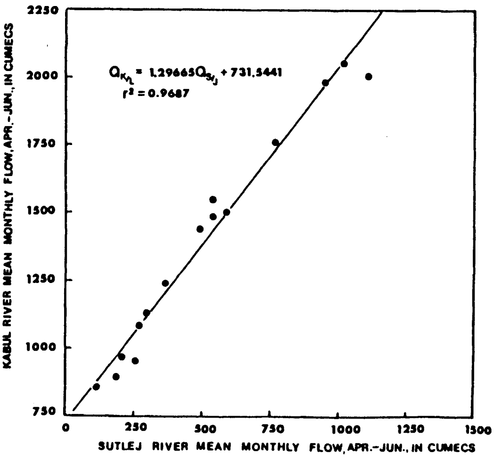

Fig. 4. Kabul River mean monthly flow, April-June, 1975-79, as a function of concurrent flow in the Sutlej River.

models as revealed by the comparison are to be accepted with caution. As the data base improves in size and diversity, more rigorous and elaborate statistical techniques could be used to compare the efficiency of these models. It is, however, to be remembered that unlike the snow cover area model, the concurrent flow correlation model cannot be used for operational forecasting procedures. Its potential lies mainly in simulating flows, filling missing data points and extending flow records for infrequently or inadequately gaged watersheds and in being used as a basis for evaluating and upgrading the snow cover area-runoff models. Dey et al. (1983) demonstrated the usefulness of concurrent flow correlation as an additional input parameter in the snow cover area model for the Indus river. The snow cover area-runoff models that are being increasingly used in water resources studies and management need to be evaluated in regard to their efficiency and adequacy and for that matter the concurrent flow correlation model suggested here provides an alternative.

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