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Sediment yield alteration of mountain rivers and climate change in central Asia

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Abstract Analysis for this study reveals that sediment yield depends on 11 orographic, meteorological and hydrologic parameters that were considered for 40 mountain rivers in the Amudarya and Syrdarya basins. The parameters were the data base for principal components factor analysis. Input of an initial five parameters explains 87% of variation. The first component is variation of elevation in the catchments, the second is basin resistance to erosion induced by rainfall, and the third is the influence of total channel network length. The relation between sediment yield and principal components was found to depend on climate change, as specific discharge, area of glaciation and percent solid precipitation are functions of air temperature and variability of precipitation. A modern scenario of sediment yield alteration for some mountain basins due to climate change through the year 2010 is reported.

INTRODUCTION

Accurate assessments of water resources and sediment yields from basins of mountain rivers in central Asia are essential to management. Runoff and sediment yield from these catchments depend on topography, soil and rock resistance to erosion, and parameters of meteorology and hydrology. Through factor analysis (Harman, 1967), we evaluated the principal factors and calculated expected change in sediment yield due to predicted climate change.

METHODS

All river basins can be described by a large number of parameters, and many of the parameters are highly correlated with one another. The correlations are explained by the observation that the initial parameters are only "outward" ones, but it also can be observed that there are a number of "latent", or "essential" parameters that can not be measured. The latent parameters determine or control the outward parameters. In this paper we refer to latent parameters as "factors".

Consider n river basins, each of which is described by m initial variables. The first step is to recognize latent factors. Every variable must be standardized so that its mean value and variance are equal to 0 and 1, respectively. A matrix, Z, with dimensions (m,n) of these data is constructed. For such variables, the correlation matrix is equal to one of covariation:

$$R = [1/(n - 1)]Z \times Z^T \tag{1}$$

The basis of component analysis is the hypothesis that any element of Z can be expressed as a linear function of m uncorrelated components:

$$Z = A \times P \tag{2}$$

in which the matrix A defines the sediment loads that are regression coefficients of the components with the initial variables, and P is the matrix of principal components.

It is known that $R = A \times A^T$ and $P = \Lambda^{-1} \times A^T \times Z$, where Λ is the square diagonal matrix of the eigenvalues $\lambda_1, \lambda_2, \ldots \lambda_m$ of the correlation matrix, in decreasing value. The input of the first k components into the total variance of all initial variables is:

$$G_k = (1/m)\sum_{1=1}^{k} \lambda_1 \qquad k \leq m \tag{3}$$

Equation (3) also identifies that part of total variance of the correlation matrix that is explained by the first k components.

The next step is to explain a physical significance of the factors. A useful procedure is factor rotation for separation of component loads. We used the "varimax" method (Harman, 1967). A final problem is to find a dependence of specific sediment yield on the factors. Then, if we calculate an alteration of the factors by climate change, we can identify a sediment yield alteration.

DATA

The analysis accounted for 11 initial variables in 40 mountain drainage basins in central Asia, the first seven of which do not require explanation; the variables were:

(a) specific discharge, M (l s^{-1} km^{-2});
(b) basin area, F (km^2);
(c) glaciation area, F_g (km^2);
(d) mean altitude of the basin, H (km);
(e) drainage density, D (km^{-1});
(f) mean annual air temperature at altitude H, T (°C);
(g) portion of solid precipitation in the total annual precipitation at the same altitude, X_s/X;
(h) coefficient of anti-erosion effect of vegetation, N (Jansen & Painter, 1974). This is the specific index assigned to each type of vegetation. For example, steppe and arable lands have an index of 2, and forest and alpine meadows have an index of 0. The coefficient, N, was calculated as a mean value for each basin.
(i) coefficient of stability of a catchment to erosion, g (Jansen & Painter, 1974). It was assumed that the stability depends on geologic age; accordingly, Quaternary age layers have an index of 2 and Cenozoic age layers have an index of 6. Determinations were made by use of geologic maps of central Asia.

(j) mean degree of seismic activity of the region, A, as determined by seismic maps.
(k) an annual distribution of streamflow, $Q_{July\text{-}Aug}/Q_{March\text{-}June}$, in which Q is monthly runoff in the designated months (Schulz, 1965).

All data were collected for rivers having measurement records exceeding 25 years.

RESULTS OF ANALYSIS

Five initial eigenvalues of the correlation matrix, λ_k, and inputs of the first components into total variance, G_k, are shown in Table 1. We took into consideration only five first components. For our data correlation, coefficients of components and initial variables at the 1% significance level must be more than 0.39. Analysis of significance loads to variables shows that the first principal component determines the basin altitude, and the second one determines the stability of basin surface to erosion by rain. The third component describes the total length of the river system and the fourth one describes the seismic activity in the basin area. The importance of this factor was noted by Shehegiova (1984).

ALTERATION OF SEDIMENT YIELD WITH CLIMATE CHANGE

We found the linear dependence of sediment yield on the first five components. The multiple correlation coefficient was equal to 0.688.

Table 1 The loads of initial variables on principal components (M-δ), the eigenvalues of correlation matrix (λ_k), and the input of principal components into total variance (G_k).

Initial variables	Principal components				
	I	II	III	IV	V
M	0.19	0.83	0.25	−0.19	0.11
F	−0.47	−0.60	0.48	−0.13	−0.21
F_g	−0.82	−0.17	0.15	−0.34	−0.10
H	−0.94	−0.15	0.0	0.11	0.17
N	0.0	0.90	0.05	0.03	0.11
g	−0.14	0.01	0.09	−0.10	0.93
T	0.83	0.15	0.11	−0.19	0.28
A	0.09	0.13	−0.07	0.94	0.10
D	0.14	0.21	0.90	0.09	0.15
X_s/X	−0.85	−0.01	0.05	0.08	0.38
δ	−0.83	0.01	−0.03	0.06	0.15
λ_k	4.35	1.83	1.26	1.10	1.02
G_k	39.5	56.2	67.6	77.6	86.9

Table 2 Specific sediment yield alteration with climate change.

River	F	Present day			Scenario 1			Scenario 2		
		F_g	X_s/X	M_s	F_g	X_s/X	M_s	F_g	X_s/X	M_s
Gunt	13 700	609	94	37	380	89	60	820	95	33
Muksu	6550	2085	100	2000	1680	100	2220	2310	100	1950
Kaphirnigan	3040	103	58	360	75	53	300	140	60	240
Shahimardan	1300	48	68	208	41	64	270	53	70	190
Pskem	2830	102	79	250	70	75	220	125	80	210

Some of the 11 variables alter with climate change. We should consider an alteration of four variables only if climate change is small. The specific discharge, M, changed proportionally with annual precipitation changes; alteration of glaciation area, F_g, was calculated by the method proposed by Glazyrin (1991). Alteration of air temperature, T, was the value known in any climate scenario, and the ratio of solid precipitation, X_s/X, was calculated by the method described by Glazyrin & Yakovlev (1990).

The prediction of long-term climate change is very important but has been an unsolved problem until now. There is a range of scenarios but some of them are contradictory. We worked out calculations for two scenarios. The first scenario (Budyko & Israel, 1987) gives the increase in precipitation by 1.22 times and in mean summer air temperature by 1.5°C to the year 2025. The second scenario was proposed by I. S. Kim in the Central Asian Hydrometeorological Institute (personal communication) and gives a precipitation change of 0.92 times and a temperature decrease of 0.5°C.

We calculated the alteration of specific sediment yield, M_s, for five rivers in different regions of central Asia. The main results are listed in Table 2. One can see that the alteration of M_s is rather sensitive to climate change. It is very interesting that trends of alteration can be different for various rivers under the same climate change.

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