Mudflood activity in the foothills of central Asia

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Abstract Hydrometeorological and synoptic conditions associated with mudflood occurrence in the foothills of central Asia are considered in this study. Mudflow hazard prediction techniques have been developed for two basic precipitation-forming synoptic conditions: cold fronts and upper lows. Due to lack of regular hydrometeorological data for the mudflows, the technique makes use of zones, the dependence of mudflood occurrence on atmospheric conditions over the mudflow-prone region and on changes in the thermohygrometric characteristics of air masses observed at different levels by radiosonde data. The techniques for mudflow hazard prediction which have been developed have been introduced into the operational practice of the mudflow warning service of the Hydrometeorology Administration of the Central Asian Republics.

INTRODUCTION

Central Asia is an area with a high degree of mudflow hazard. The most important mudflow-prone areas are the foothills of the Fergana Valley, the Zerafshan Valley, the Issyk-Kul basin, the central and southern parts of Tadjikistan and also the foothills of Kopetdag. In these areas, transitory destructive mudflow floods occur during the spring-summer period in small rivers and ephemeral channels.

The Hydrometeorological Administrations in each Central Asian Republic have systematically acquired information on mudflow-prone basins, and past mudflow floods. According to available data more than half of these mudflow floods have caused significant damage, and one third can be characterized as dangerous or spontaneous hydrological events causing damage to irrigation structures, transport systems, agricultural land and residential areas with an estimated value of the order of hundreds of thousands or even millions of roubles.

Despite their name, such mudflow floods or mudfloods do not always fully correspond to this term because of their solid sediment composition. The foothills and middle-mountain areas between 900-2000 m are the main mudflow-prone areas. Middle and Upper Palaeozoic sedimentary strata are widespread in this zone. These rocks comprise conglomerates, sandstones and clay-marls which easily disintegrate by weathering. Due to recent uplift of the mountain ridges which surround the intermontane depressions, the alluvial terraces are deeply dissected by rivers flowing from the mountain origin and are characterized by a dense network of ravines ("sais"). The compound hilly relief ("adyrs") of these areas favours mudflow activity. The possibility of cloudbursts initiating mudflows in the alpine zone is reduced due to the effects of the vegetation cover and the forests. Mudflows may, however, occur in warm weather due to the bursting of mountain lakes and glacier reservoirs.

GENERAL CHARACTERISTICS OF MUDFLOOD OCCURRENCE

Mountain mudfloods are conditioned by numerous physiographic, geological and other factors. Factors such as slope steepness, bed slope and the storage of loose material in a basin are essentially time invariant. Hydrometeorological factors such as storm rainfall, sharp increases of air temperature, soil saturation and snow cover accumulation exert a primary control on the incidence of mountain mudfloods. Rainfall plays the most important role in the formation of mountain mudfloods under central Asian conditions. Rapid snowmelt is only rarely responsible for mountain mudflood production. The combination of rapid snowmelt and intense storm runoff usually results in the occurrence of destructive mudfloods over vast territories.

Analysis of precipitation days associated with mudflows in the mudflow-prone areas of central Asia has shown that the threshold for mudflow initiation is a daily precipitation ranging from 20 to 32 mm. For a daily precipitation of 20 mm, the probability of mudflow occurrence in the Uzbekistan Fergana Valley is 45%, whilst in Tashkent region (with the same precipitation amount) it is only 20%. Antecedent precipitation plays an important role in mudflow initiation. The mean precipitation depth during the three days before a mudflow is 9-15 mm. However, although antecedent moisture conditions are an important influence on mudflow formation in those areas of central Asian such as central and southern Tadjikistan, the Tashkent region, and the Fergana Valley, it has little effect on Turkmenia.

Air temperatures in the period March-May are a very important factor for mudflow development. Certain synoptic conditions can result in sharp increases in air temperature in mountain areas of 5-6° on average, and of 10° in 20% of cases. Sometimes these increases in temperature can considerably weaken mudflow activity due to wet snow precipitation. However, studies have shown that the air temperatures on days with mudflows are 3°-7°C higher at altitudes up to 1500 m and more than 0°-2°C higher at 2200 m.

Low density mudflows are the most common. Such mudflows can occur simultaneously in 20 or more mountain rivers, for example, in Uzbekistan and Turkmenia. The greatest danger of mudflows in the central Asian foothills occurs from March up to September. Frequently they occur in the southern part of Uzbekistan and Tadjikistan in March and in the southwestern parts of Turkmenia in September. The period of maximum mudflow activity is from April to May.

The meteorological conditions associated with mudflow occurrence are characterized by different synoptic processes in central Asia (Bugaev *et al.*, 1957). During March and April mudflows in the foothill areas are formed mainly during western, and more rarely, northern-western intrusions associated with south-Caspian, Murgab and Upper Amu-Darja lows. Moist tropical air is swept out into the warm sector of these lows, promoting intensive snowmelt in the mountains and heavy rainfall at the approach of the cold front intrusion. During May and June, mudflow floods are caused by cold air intrusion from the northwest and west, and more rarely by a preceding outflow of low pressure.

During July and August and even in September cold fronts from the west and northwest, accompanied by heavy rainfall, can cause mudflow formation only in southwest Turkmenia. Here cold air interacting with warm moist air masses over the south of the Caspian Sea causes the development of heavy cloud and shower-type precipitation. During this period (excluding September), mudfloods are formed in the eastern mountainous regions of central Asia during the intrusion of cold air masses or the inflow of moister air masses from the north favouring the development of convective phenomena. The formation of upper or elevated lows on the isobaric surface of 500 hPa (near the Earth surface – small gradient field of high or low pressure) also plays an important role in the formation of mudfloods.

MUDFLOW PREDICTION

The Central Asian Regional Hydrometeorological Research Institute undertakes scientific studies on the development of techniques for mudflow prediction applicable to different mudflow-prone mountainous regions of central Asia with poor data on past precipitation and the absence of reliable procedures for predicting this precipitation (Liahovskaya, 1988; Salikhova & Liahovskaya, 1982, 1986, 1988). The method is based on the dependence of mudflow production on the atmospheric processes over the mudflow basin and on measurements of the thermohygrometric characteristics of air masses on different isobaric surfaces (850, 700, 500 hPa) determined by radiosonde data. The techniques for mudflow hazard prediction have been developed for two basic synoptic conditions over central Asia, namely, cold front and upper lows. The reliability of these techniques are 40% and 75%, respectively.

The thermohygrometric characteristics of warm air masses above the basin and of cold ones behind the front are used as predictors in forecasting mudflow hazard. The temperature and humidity characteristics of warm air masses above the basin and of cold ones behind the front are used as predictors in forecasting mudflow hazard. The temperature and humidity characteristics of air masses in the eastern half of the front were taken as predictors in the case of upper cyclones.

The early warning of mudflow hazard in the case of cold fronts is 1-2 days, depending on their velocity, while in the case of upper lows it ranges from 12 up to 24 h.

Discriminant analysis, widely used as an alternative means for forecasting meteorological conditions and avalanches has been employed as a mathematical tool for classification of documented case studies (Drozdovskaya & Imas, 1977; Salikhova & Liahovskaya, 1982; Peskov *et al.*, 1974).

For applying discriminant analysis to mudflow hazards two classification combinations of multi-dimensional predictor vectors (class with mudflows, class without mudflows) were prepared. The computation of the linear coefficients of the discriminant function was carried out simultaneously with sampling of the most informative predictors using a "filtering" technique. The filtering procedure consists of step-by-step analysis of every predictor along with the previously chosen ones, on the basis of Fisher's criterion of class divisibility.

In the course of the step-by-step filtering procedure the following set of physically-based predictors was established for warm (wm) and cold (cm) air masses for mudflow hazard prediction during the passage of cold fronts.

1. Temperature on the 850 hPa isobaric surface: T_{850}.
2. Dew-point deficit: $T - T_d$.
3. Total dew-point deficit at the 850-500 hPa level:
   $$\sum_{850}^{500} T - T_d.$$
4. Mass portion of water vapour: q.
5. Mass portion of water vapour at the 850-500 hPa level:
   $$\sum_{850}^{500} q.$$
6. Condensation temperature of a particle ascending in a warm or cold air mass from the 850 hPa level under dry adiabatic conditions up to condensation level: T_k.
7. Precipitation total at the reference meteorological station three days before mudflow initiation (an indirect characteristic of soil moisture conditions in the basin):
   $$\sum_{1}^{3} X_{sm}.$$

The predictors are almost independent of each other in the prognostic functions. The coefficient of correlation is expressed as: $r = 0.1\text{-}0.32$. Below we present the discriminant function expression for basic short-range hydrological forecasting of mudflow hazard in the case of cold fronts passing through the Fergana Valley (Uzbekistan):

$$v(x) = 0.696 + 0.748 T_{k850} + 0.023 T_{850cm} + 0.380 T_{d850} - 0.181 (T - T_d)_{850wm}$$

The following expression is for central Tadjikistan:

$$v(x) = 0.45 \sum_{850}^{500} q_{cm} + 0.30 \sum_{850}^{500} q_{wm} + 0.07 \sum_{1}^{3} X_{sm} - 9.60$$

If $v(x) > 0$, then mudflow occurrence is possible in these regions.

In the synoptic situation with the formation of upper lows the best predictors are as follows:

1. Total dew-point deficit in the 1.5-5 km layer in the front part of cyclone: $\sum_{850}^{500} T - T_d$.
2. Condensation temperature of an air particle ascending under dry adiabatic conditions from the 850 hPa level: T_{k850}.
3. Air temperature at 700 hPa (3 km) and 500 hPa (5 km): T_{700}, T_{500}.
4. Dew point: T_d.
5. Difference in geopotential on the isobar surface 500 hPa in the cyclone eye and on its margins – as a characteristic of its intensity: ΔH_{500}.
6. Preceding moistening of the basin: ΣX_{sm}.

Mudflow hazard in the foothills of the Fergana Valley can be computed by the following discriminant function:

$$v(x) = 1.68 - 0.13\sum_{850}^{500} (T - T_d) + 0.39 T_{k850}$$

Mudflow occurrence is possible in this region with positive values of this function.

CONCLUSION

Methods of mudflow hazard prediction have been developed for most mudflow-prone areas of central Asia. The computational procedure which uses prognostic discriminant functions has been automated to reduce the time taken to issue forecasts and to increase their reliability. The technique developed serves as a basis for the issuing of mudflow danger warnings by the hydrologist-forecasters in the Hydrometeorological Centre of Central Asia.

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