A preliminary study of the relationship between heavy rainfall and serious debris flows

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Abstract A study of a series of serious debris flows in western Sichuan Province and southern Shaanxi Province during the summer of 1981 has been undertaken. It was found that there are two types of disastrous debris flows corresponding to two types of heavy rainfall. The relationship between the two types of heavy rainfall and debris flows and the synoptic meteorological conditions associated with the heavy rainfall causing the debris flows are discussed.

INTRODUCTION

Heavy rainfall frequently causes floods in lowland areas and debris flows and landslides in mountain areas. In areas with susceptible geological conditions, the timing and frequency of debris flows are closely related to the incidence of heavy rainfall. In this paper, the relationship between heavy rainfall and debris flows, and the synoptic meteorological conditions associated with heavy rainfall are investigated.

THE TWO TYPES OF HEAVY RAINFALL ASSOCIATED WITH DEBRIS FLOWS

By analysing a series of serious debris flows which occurred in southern Shaanxi Province and western Sichuan Province during the summer of 1981, it was found that there were two types of debris flow corresponding to two types of heavy rainfall. Their characteristics are explained as follows using the events on 9 July and 21 August 1981 as examples.

The first type is the regional debris flow triggered by sustained regional heavy rainfall. On 21 August 1981, serious regional debris flows occurred at several tens of sites around Lueyang, Fengxian and Baoji in Shaanxi Province and Liangdang, Chengxian and Tianshui in Gansu Province and other places. The total area involved was about 40 000 km^2 (Fig. 1(a)). The debris flows were triggered by a heavy rainfall event in which the daily total exceeded 100 mm. It can be seen from Fig. 1(a) that the area where the debris flows occurred closely coincided with the storm centre. Starting on 14 August 1981, about a week before the heavy rainfall, a quasi-stationary belt of rain oriented NNE to SSW had been sustained over this area, extending for 1000 km from Xian to Xichang and 200-300 km in width. The debris flows occurred in the northern part of the rainfall zone where the daily rainfall was less than 50 mm (Fig. 1(b)). This continuous antecedent precipitation which lasted for several days saturated the soil. The regional debris flows were therefore triggered almost immediately the heavy rainfall occurred.

The second type is the local debris flow triggered by local heavy rainfall. It differs from the first type in that the rainfall is limited and it is relatively dry for several days before the debris flow occurs. For example, it was dry in the south of the Emei Mountains of Sichuan Province between 2 and 7 July 1981 and the total rainfall for the six days was less than 10 mm. During the afternoon of 8 July 1981, a local intense convective rainstorm suddenly broke out with discrete centres of heavy rainfall of less than 100 mm day^{-1} (Fig. 1(c)). Early the following morning serious debris flows occurred at Xiquzhen in Mabian County and Liziyidagou in Ganluo County in southern Sichuan Province. The nearest heavy rainfall centre to the debris flows was 50.7 mm at Leshan, 70-90 km to the north. Although the total rainfall amount associated with this type of local intense heavy rainfall is not very great, it is usually accompanied by strong thunderstorm activity and northerly winds. Both the Mabian and Ganluo areas are located within a bell-shaped valley and on the upwind side of the mountain slope. The terrain played a role in amplifying the heavy rainfall and promoting convergence of the runoff, leading to the serious debris flows.

The two types of heavy rainfall exhibit different characteristics in terms of maps of the departure of monthly rainfall in relation to the long-term mean. For example the first type of heavy rainfall which occurred on 21 August 1981, which was a quasi-stationary belt of rain, resulted in a monthly rainfall considerably in excess of the mean. A maximum value of 316% was located at Baoji (Fig. 2(a)) in Shaanxi Province where the debris flows occurred. The second type of heavy rainfall is usually insufficient to result in above-normal monthly rainfall. Sometimes, the second type of heavy rainfall is even associated with below-normal monthly rainfall (Fig. 2(b)).

THE SYNOPTIC METEOROLOGICAL CONDITIONS

The first type of heavy rainfall is usually formed in a southwesterly airflow ahead of a shortwave trough in the middle troposphere, e.g. 500 mb (see Fig. 3(a) for an example), which corresponds to rain-producing weather systems such as the cyclonic vortex and a shear line at 850-700 mb in the lower troposphere. On the surface synoptic chart, the quasi-stationary belt of rain and low pressure are maintained. Based on studies of heavy rainfall undertaken in recent years, many types of subjective and objective forecasting

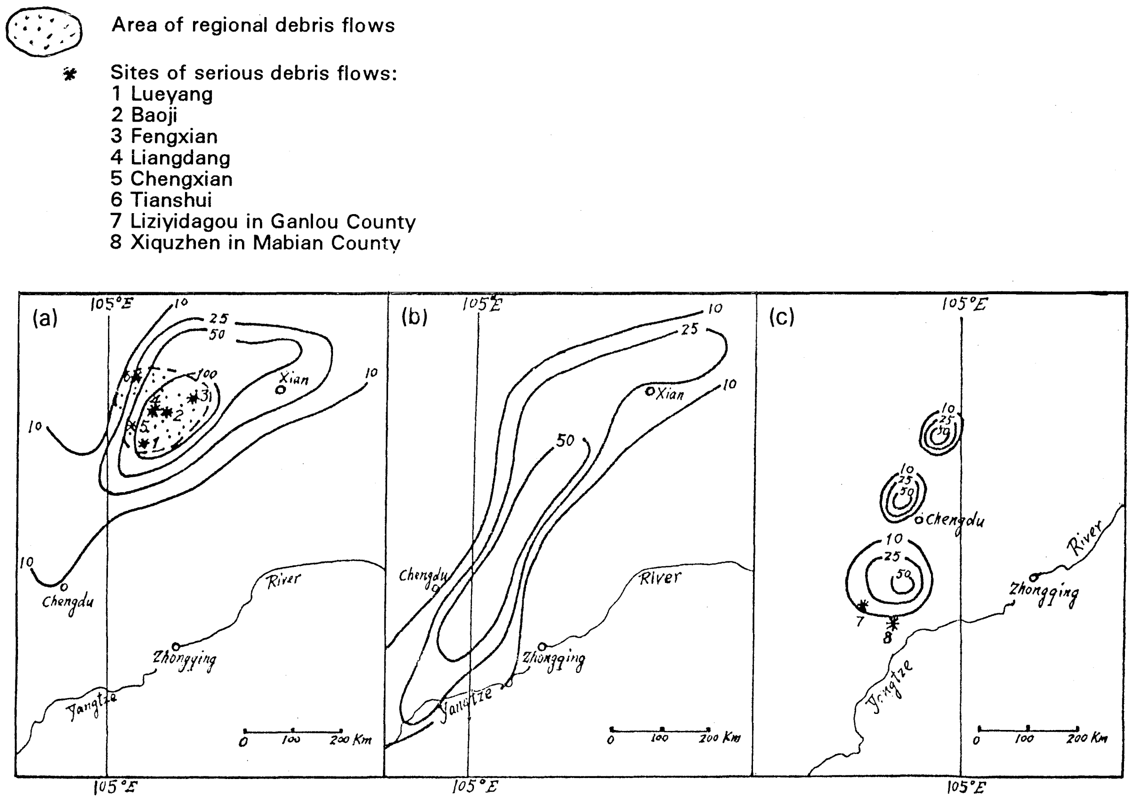

Fig. 1 Daily rainfall (mm) maps for: (a) 21 August 1981, (b) 17 August 1981, (c) 8 July 1981.

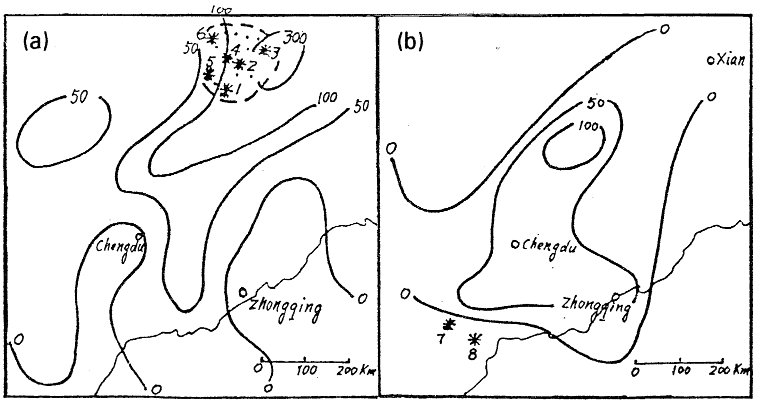

Fig. 2 Maps of monthly rainfall anomaly (%) in relation to the mean monthly rainfall: (a) August 1981, (b) July 1981. Legend same as for Fig. 1.

methods have been developed for the first type and the accuracy of prediction has been greatly improved. Therefore, it is possible to predict regional debris flows based on the heavy rainfall predictions provided by a meteorological observatory.

The second type of heavy rainfall is primarily a local intense convective precipitation which breaks out suddenly and is much more closely related to the mesoscale weather system. In general, there is no evidence of a large-scale meteorological field. For example, the heavy rainfall which occurred on 8 July 1981 was associated with high pressure at 500 mb (Fig. 3(b)). Compared with the first type of heavy rainfall, its temporal and spatial scale are much less, only lasting for several hours and extending over only tens of kilometres. Thus it is easy for it to be missed by an observation network with the temporal and spatial density commonly found today. It is quite difficult to predict this type of heavy rainfall. By using various advanced techniques such as satellite remote sensing and Doppler radar etc., meaningful prediction of this type of heavy

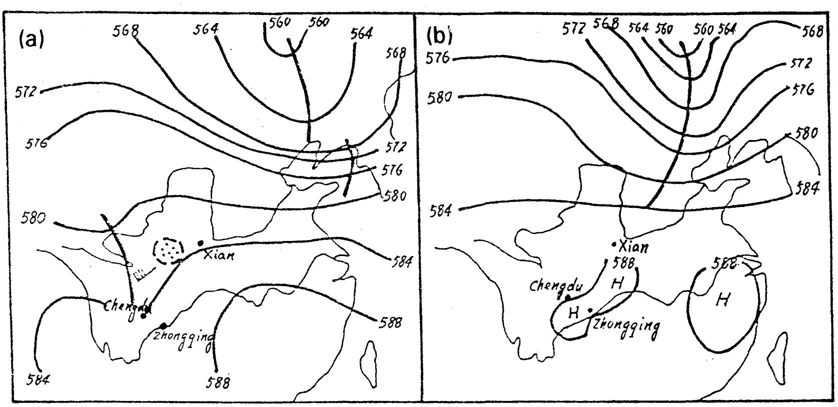

Fig. 3 The 500 mb charts (contours are in 40 gm intervals) for: (a) 0000 GMT, 21 August 1981, (b) 0000 GMT, 8 July 1981. The legend is the same as for Fig. 1.

rainfall can be made 6-12 h in advance. Because the second type of heavy rainfall is usually associated with thunderstorms, strong local winds and high rainfall intensities for short periods, the second type of debris flow can cause more serious disasters in a small area than the first type.

VARIATION OF THE SURFACE PRESSURE DEPARTURE

Some significant results have been obtained from an analysis of the variation of surface pressure at the meteorological station in the centre of the heavy rainfall. Figure 4 shows the daily rainfall and surface pressure departure at each synoptic observation time (0000, 0600, 1200, 1800 GMT) before and at the time that the debris flows occurred. Before the first type of debris flow (e.g. 14-19 August 1981, Fig. 4(a)), the precipitation and below-normal

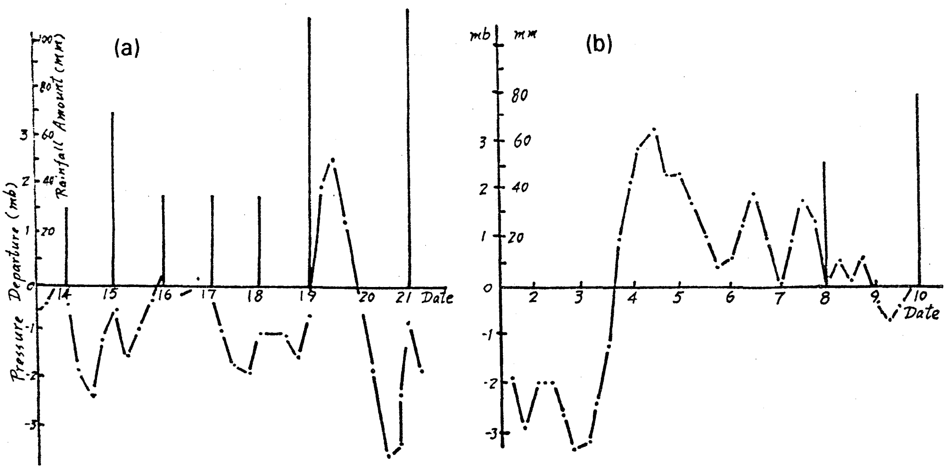

Fig. 4 Chart of daily rainfall (mm) and the pressure departure (mb). (a) 14-21 August 1981 at Lueyang, (b) 2-10 July 1981 at Leshan, which was the heavy rainfall centre nearest to the debris flows, 70-90 km to the north.

departure of surface pressure was sustained for several days. The area where the debris flow occurred was located in a quasi-stationary belt of rain and a large low pressure. Before the second type of debris flow (e.g. 4-8 July 1981, Fig. 4(b)), rainfall had been limited and an above-normal departure of surface pressure had been sustained. The debris flows were located near the centre of the high pressure area. These findings are consistent with the synoptic meteorological conditions discussed above.