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Discussion

Foregoing review highlights the current status in terms of data availability of detailed information on geology, geomorphology, landslide inventories and climate. The available information regarding geology and tectonic history of the area helps to develop a broad picture of geological setting of the four districts East, West, North and South where the landslides pose risk. However detailed engineering gelogical information required for quantitative landslide analysis for quantitative landslides is sorely lacking. Recent project undertaken with DST's sponsorship for example Geotechnical studies of Chandmari Landslide by Jadavpur University Kolkata, and the work being done by C.S.M.R.S. New Delhi in collaboration with NGI Norway is representative of the kind of investigations which are required to be undertaken for other landslides in the state. At Chandmari landslide a rain gauge and piezometers have been installed by CSMRS and large scale mapping at a scale of 1:500 with a contour interval of 1 m., and field and laboratory geotechnical studies have been carried out by Jadavpur University, Kolkata.

Geomorphology of the state is essentially controlled by its tectonic history and the active erosion by Teesta and its tributaries, as it flows almost along the axis of the major antiform. This has resulted in the formation of ridges, which are largely aligned N-S, NE-SW and NW – SE. Majority of ridges are aligned NE - SW and NW – SE. A detailed statistical analysis of the geomorphological features of the state needs to be carried out. Except for some limited detailed work by DGM Sikkim and GSI there is no work as such on the gemorphology of the state, which can be useful to establish relationship with landslides. Detailed geomophorlogical studies of the state need urgent attention. Two main areas of focus in such investigations would be mapping of Quaternary deposits and their thickness, and topographic and geotechnical mapping at large scale (1: 500 to 1: 2000) in areas of known instability. For these studies currently available geophysical instruments: engineering seismograph along with GPS should be used.

More meaningful landslide zonation studies can be undertaken after detailed geological, topographical and geomorphological information is available. In this context the earlier work on zonation by CBRI Roorkee needs improvement. Once data on large scale mapping is available in critical areas, a representative DTM can be prepared which would help in utilising GIS for the preparation of landslide zonation maps, which can be used by local agencies. Based on detailed review of published and unpublished literature, an attempt has been made to prepare an inventory of landslides in the state this is tabulated in (Table 4.I). It will be seen in respective of many parameters tabulated in the format sheet are lacking. Specific comments in respect of each factor used in the inventory (Table 4.I) have already been made to highlight critical gaps in the available data. The lat. / long. values are only approximate. Using a GPS, this situation can be rectified readily for at least the landslides listed in the (Table 4.I). With this information on location, these landslides can be transferred to a large-scale map district wise. Also exact time and date of occurrence of these landslides is missing in most cases; lack of this information in particular does not allow determining the rainfall intensity, which may have triggered the slide. Number of rain gauges currently used to record rainfall do not permit evaluation of rainfall intensity which is representative for the site of any landslide. This would require setting up of rain gauges on most slopes in areas of known instability. Perhaps because of this reason most reports on the causes of landslide only refer to very high rainfall with no quantification.

Clearly a more systematic effort is required to prepare an inventory of landslide for each district of the state. While preparing such an inventory, it is imperative that internationally accepted nomenclature for classification of landslides types is used. In literature standard formats are available for collecting detailed data required for preparing landslide inventories. With proper care a suitable format should be selected for use in field studies in the state.

In general there is an intimate relationship between geology, geomorphology and rainfall in a given region. Development activities like building of roads and housing in mountainous terrain can induce instability depending on the way such development work is carried out. In the context of Sikkim all these factors seems to be operative. The intensity of tectonic deformation caused during the development of Sikkim culmination (Fig 3.2) of the rocks, and rainfall conditions have direct bearing on the landslide hazard experienced in the state. Careful study of available data for landslides listed in Table 4.1 reveals that about 75% of the landslides are located in Dalings. There is urgent need for detailed geotechnical and geological studies of Dalings in particular. At present very little quantitative information is available. Since 66% of landslides (listed in Table 4.1) are located in Eastern Sikkim, the recommended studies should be focused in this area as a first step.

Climate rainfall trends

In general annual precipitation increases as one moves from Western Himalaya to Eastern Himalaya (Fig 2.3). The highest annual rainfall for an individual station in Sikkim may exceed 5000 mm with the average number of rainy days (precipitation > 2mm) ranging from100 at Thangu to 184 days at Gnathang. The monsoon storms forming in the Bay of Bengal, approach the Sikkim Himalaya as indicated in (Fig 2.6) (Starkel 1972). The water-laden clouds eventually enter Sikkim by turning NW over the Southern tip of Bhutan. The high rainfall zones in Sikkim: East, South, West and southern parts of North district are along the path followed by the water laden monsoon clouds as they move towards Eastern Nepal. One of the high rainfalls axes in Teesta valley is along Padamchen – Rongali-Mangan (seeTejwani 1981). Gangtok the state capital lies along this axis but the rainfall records from 1960 – 1998 seem to suggest that some how Gangtok misses out very high intensity storm quite often. For example (Chandra 1975) reports 1580 mm rainfall in 36 hours at Padamchen (SE of Gangtok) during the 2 – 5 October 1968 storm which caused great devastation from resulting floods and landslides in Sikkim and Darjeeling but Gangtok received only 180 mm in 24 hours during that period. While very heavy intensity rainfall in Sikkim, Himalaya (24 hours precipitation mm>250mm) is reported more than 40 times during the 1891 – 1975 period, (Chopra 1968) – the 24 hour maximum rainfall data from 1960–1998 for Gangtok, however indicates that only on three occasions the value exceeded 200 mm, the mean value of 24 hour maximum rainfall during this period being 139 mm. Highest rainfall in 24 hours recorded at Damthang in West Sikkim was 341.4 mm on 4th August 1964 (Tejwani 1981). Bhasin et.al. (2002) report 501 mm during February 1974 in 24 hours at Gangtok but this values sounds suspect. During the month of February in Gangtok it would suggest approximately 2-m thick snowfall in the city which does not seem possible.

Analysis of 24 hr. maximum precipitation for the period 1960 – 1998 was carried out using extreme value distribution for extreme hydrologic events as suggested by Chow et.al.(1998). For this purpose frequency analysis using factors was carried out. Values X_T of 24 hours maximum rainfall with a given return period T (years) may be given as:

$$X_T = X_m + K_T \sigma \qquad (1)$$

Where X_m s the mean value of 24hr maximum precipitation (139.15mm)

σ is the standard deviation (43.42 mm)

and K_T is the frequency factor calculated from the relationship.

$$K_T = \sqrt{6}/\pi \{0.5772+\ln [\ln(T/T-1)]\} \quad (2)$$

The mean value of 24 hour maximum rainfall has a return period of 2.5 years where as the 09 June 1997 storm at Gangtok (224mm in 24 hrs) has a return period of more than 20years. For comparative purposes, the corresponding data for Darjeeling over the period 1949 – 1986 (Starkel 1972, Froechlich et.al.1990)was also analysed. The 24-hour maximum precipitation, mean and standard deviation values for Darjeeling are 183.51 mm. and 85.06 mm. respectively. Interestingly the return period for the June 1997 type storm will be 4 years as compared to 20 years for Gangtok. ***This highlights significant fluctuations in rainfall pattern over relatively short distance for comparative altitude in Sikkim Himalaya.*** This observation calls for installation of large number of rain gauges on the southern slopes in areas of known instability.

Rainfall intensity – duration threshold criteria have been used for relating rainfall conditions in a region with the triggering of slope instability (Caine1980). Such an approach for predicting landslide incidence would require detailed data on rain triggered landslides. Starkel (1972) and Froehlich et.al.(1990), based on data for 1950 and 1968 storms which triggered destructive landslides in Darjeeling, have proposed that 130-140 mm rainfall in 24 hour is likely to trigger shallow slides and debris flows. Unfortunately no credible information in terms of actual rainfall intensity is available for landslides in Sikkim during those storms. As a matter of fact 224-mm rainfall in 24 hours associated with the 09 June 1997 landslides in Gangtok is the only quantitative record available. In the absence of such an information, no definitive criteria can be formulated for Gangtok.

However, the 1968 – 1998 rainfall records have been critically analysed to understand the long – term rainfall characteristics of the area. Analysis of this data suggests an average daily rainfall of 20 mm during May to October. Furthermore, average number of rainy days (rainfall >2mm) during the monsoon vary from 22 in May, 25 in June, 28 in July, 27 in August, 23 in September and 9 in October. The review of 24 hours maximum rainfall data over the same period further shows that the high intensity storm in Gangtok during the month of June and October are associated with the major landslide during those months. High intensity rainfall in the month of May normally does not seem to initiate landslides and this may be partly due to the fact that the overburden may not be fully saturated at that time of the year. An average of 1000 mm rainfall up to the end of May however appears to be sufficient to fully saturate soils which may prepare the slope for landslides during subsequent monsoon months. The story of October is also interesting when the monsoons are receding. Even though average annual rainy days in October are 9 only, very high intensity storms occur during those days and since the slopes are underlain by fully saturated soils by that time of the year, landslides should be expected during these storms. With these long-term rainfall characteristics and the conditions in the neighbouring Darjeeling area, it may be tentatively suggested that daily rainfall in the range of 130 – 140 mm (with return period of 1.5 to 2.5 years) may be taken as the threshold values for triggering of landslides in East Sikkim.

On the basis of the rainfall characteristics reviewed here it may be further suggested that daily rainfall in the range of 130 – 140 mm (with return period between 1.5 to 2.5 years) may be taken as the threshold value for occurrence of shallow landslides and debris flows in Gangtok. More than 200mm daily rainfall storms have low probability (return period > 20 years) but are likely to cause devastating landslides, like the events 09 June 1997 in Gangtok. Such events are most likely to occur during months of June and October.

Furthermore, the 1580mm rainfall in 36 hours at Padmchen (East Sikkim) during 2 – 5 October 1968, as reported by Chandra (1975), would suggest an intensity of 43.9mm/h. which is much higher than the 9.3 mm/hr. experienced during 09 June 1997 storm. This high intensity storm may explain the existence of a very extensive landslide in Tsochen – Pheri Barapathang area that is just 8 kilometers West of Pademchen. This landslide appears to have been reactivated during the June 1997 storm (see Sharma et.al. 1999). The intensity – duration values triggering massive landslides during October 1968 in Pademchen and surrounding areas and June 1997 in Gangtok storms lend support to the suggested 130 – 140 mm threshold value for 24 hour rainfall to trigger shallow slides and debris flows.

It is important to stress here that there is an urgent need for gathering credible rainfall data from closely networked rain gauges (preferably automatic ones) which can be correlated with the occurrence of landslides whose exact location and time are available. Such a database would help to improve/modify the suggested threshold values for triggering landslides.

Some of these gaps highlighted here need to be filled before an effective landslide mitigation program can be evolved. In this regard it is important to note that the status of geotechnical investigations in relation to landslide studies leaves much to be desired. Other than Chandmari landslide studies by CSMRS New Delhi and Jadavepur University under DST sponsored project, no credible geotechnical investigation work has been carried out. Furthermore the zonation studies based on the use of small scale and low resolution remote sensing imageries without commensurate field validation, have resulted in very broad and vague conclusions with limited practical use. A more detailed large scale and thoughtful exercise is needed to carry out credible landslide zonation studies in Sikkim to achieve meaningful and accountable results.