Journal of Geological Society of Sri Lanka Vol. 13 (2009), 59-63

MASS MOVEMENTS AROUND KOTMALE RESERVOIR

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ABSTRACT

Central Highlands forming more than 20% of the total land area of Sri Lanka is most prone to mass movements. Frequent occurrence and reactivation of mass movements are common in these areas causing severe damage to life and property.

Kotmale reservoir is located in the Upper Mahaweli River System of Sri Lanka. It is found at an elevation of 700m above MSL. Thick overburden is prominent due to the existence of highly fractured high-grade metamorphic rocks in the area surrounding the reservoir. Hence there is a tendency for the occurrence of major and minor landslides. Empirical observations indicate that the rate of mass movements and the spacing of tension cracks increase proportionately during the drawdown stage of the reservoir. This phenomenon occurs since the impoundment of the reservoir in 1982. Groundwater level in the surrounding soil slopes also varies in proportion to reservoir water level fluctuations.

Several instances of ground subsidence, cracking of houses and other structures, and frequent minor earth tremors have been reported in the area. According to present ground conditions around the Kotmale reservoir, several houses immediately above the buffer zone previously demarcated without considering geological factors are already damaged and therefore the area is unsuitable for human settlement. Mitigating measures such as suitable drainage systems, retaining structures and planting deep rooted trees are recommended.

Keywords: ground subsidence, tensional cracks, reservoir induced landslides

INTRODUCTION

Landslides are one of the most hazardous environmental problems in the hilly areas of Sri Lanka. Damages and losses to investments on various development projects, infrastructure and more importantly to lives are the major impacts due to frequent landslide occurrences. Loss of life and property due to landslides has increased rapidly the last few decades (Abeykoon *et al.*, 1994). Monitoring of these movements, changes in geometry and development of possible criteria to predict the optimum parameters for stability are of vital importance in to minimizing the losses caused.

Central region of Sri Lanka is hilly and mountainous and is underlain by highly fractured and folded basement rocks associated with residual and colluvial soil layers. The elevation of the hilly region ranges from 185 m to 2717m above MSL. This region accounts for more than 20% of the total land area and is occupied by 30% of the total population. Frequent occurrences of mass movements and reactivation are causing severe damage to life and property (Bandara and Bandara, 2005).

Kotmale reservoir is located in the Upper Mahaweli catchment of Sri Lanka. When compared to other Mahaweli Project reservoirs, it is situated at a higher elevation. The reservoir and the surrounding area are underlain by highly fractured high-grade metamorphic rocks. A thick soil overburden is always observed (Cruickshank, 1996). Frequent minor and major landslides and slope failures are common in and around the reservoir due to the presence of this thick overburden and steepness of the slopes. Intensive rainfall is another causative factor aggravating such failures. Since the impoundment of the reservoir in 1982, frequent minor earthquakes (tremors), cracking and bending of houses and other man-made structures, uneven ground settlements, and minor and major earth slips have been recorded. It was observed that most of soil masses resting on the reservoir abutments are moving towards the reservoir at a slow rate (Bandara *et al.*, 1994).

Vaiont dam disaster in Italy is a good example to understand the future failures around a reservoir (Transport Research Board of USA, 1996). At the left abutment of Vaiont reservoir, soil creep was taking place throughout the entire period after its impoundment. Continuous monitoring of the movements was carried out and it was confirmed that slight movements were continuously occurring over a period of 15 years. Later, a massive soil mass at the left abutment moved suddenly into the reservoir on October 09, 1963 replacing a volume of 300Mcm of water when the reservoir water level was lowering after a heavy rain. Reservoir water replaced by this huge mass movement flowed over the structurally sound Vaiont dam killing thousands of people who were living in the downstream area and destroying buildings, houses, cultivated lands and other man-made structures.

Hydro-geological condition, geomorphology and their relationship of the abutments of Kotmale reservoir in Sri Lanka are comparable to those of Vaiont reservoir in Italy. Current mass movements and minor earth tremors in the surrounding area have been recorded throughout the period after the reservoir impoundment. If the rate of mass movements and earth tremors increase, sudden failures will take place and displace a considerable amount of reservoir water. Therefore, the entire downstream area is at a high risk of massive overflow. Detailed geo-technical investigations and monitoring procedures must be undertaken in and around the Kotmale reservoir (Bhandari and Thayalan, 1994).

It is a prerequisite before the embarking on a reservoir construction project to carry out detailed engineering geological investigations. Based on the findings, all unstable soil masses have to be stabilized prior to the impoundment and continuous monitoring procedures have to be adapted. However, in this area, where large areas would have been geologically unstable for eras due to inherent structure and lithology, neither stabilization nor monitoring has been done. While already unstable ground has been left unattended, the impoundment of the reservoir 27 years ago has aggravated the situation with time. Stabilization or monitoring activities are impracticable almost to the point of near impossibility for consideration. Although modern echnology is available for effective stabilization, the anticipated colossal expenditure involved, precludes the use of such technology. In order to prevent deterioration of the situation, diversion and interceptor drains must be put in place in order to avoid groundwater level fluctuation with reservoir water level. The options for remedial measures are very limited and for the present, loosened moving soil masses can be tightened and strengthened by deep-rooted trees, which can offer a similar mechanical effect to that of anchorage, the latter being a much costlier exercise.

METHODOLOGY

Detailed landslide investigations were conducted in order to identify the potential areas for future landslides, possible affected areas, buffer zones, and vulnerable communities etc. All landslide and landslide-prone locations were included in a map. Extensometers, which were assembled locally, were erected perpendicular to some of the already developed tension cracks. Their locations were decided based on the surface area of the moving mass. Readings were taken twice a month from 2002 to 2004. The available boreholes and dug wells situated around the Kotmale reservoir were used for monitoring the fluctuations of groundwater level.

Rate and direction of the mass movement were recorded against monthly and weekly rainfall, reservoir water level fluctuation and fluctuation of groundwater level. In this regard, movement and fluctuation of groundwater level were monitored at regular intervals.

The rate of movement of the moving soil mass was interpreted in the backdrop of rainfall records, sub-slope movements and spatial piezometric variations for the corresponding period in order to establish the causative factors. Landslide hazard zonation maps are available for the entire area of the reservoir periphery (Manual of Landslide Hazard Zonation – NBRO, 1989).

RESULTS

In addition to the above-investigated areas, it was observed that most land segments of the area around the reservoir were highly prone to landslides (Figures 1 and 2). There are some areas where landslides have already taken place. Cracks developed in the floors and walls of the houses, tensional cracks, ground subsidence, tilting and bending of tree trunks and poles and water stagnating areas suggest that some of the soil slopes are creeping towards the reservoir.

Engineering geological investigations proved that surrounding soil masses were highly unstable. It was also noticed that the rate of movement of such unstable soil masses is increased with the lowering of reservoir water level. This happens entirely due to the force created towards the reservoir when the repulsion of pore water pressure increased as a result of rapid draw-down of reservoir level. This force is sufficient to push the whole unstable soil mass towards the reservoir. Fluctuation of the rate of movement has a direct relationship with climatic changes. This relationship could be established with the help of the available observations in the vulnerable areas. Following are major field observations as evidences to support the interpretations.

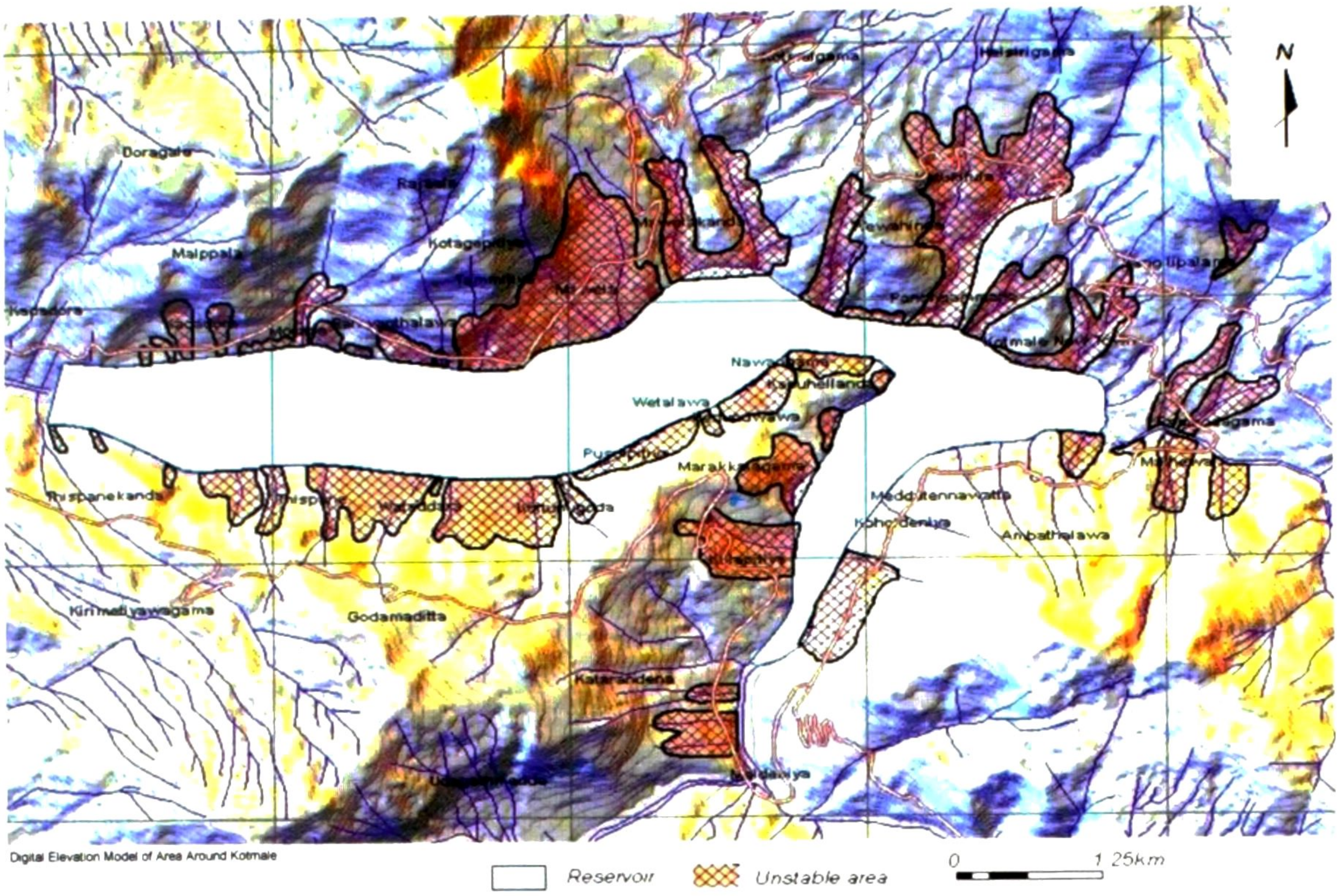

Figure 1: Landslides around Kotmale Reservoir

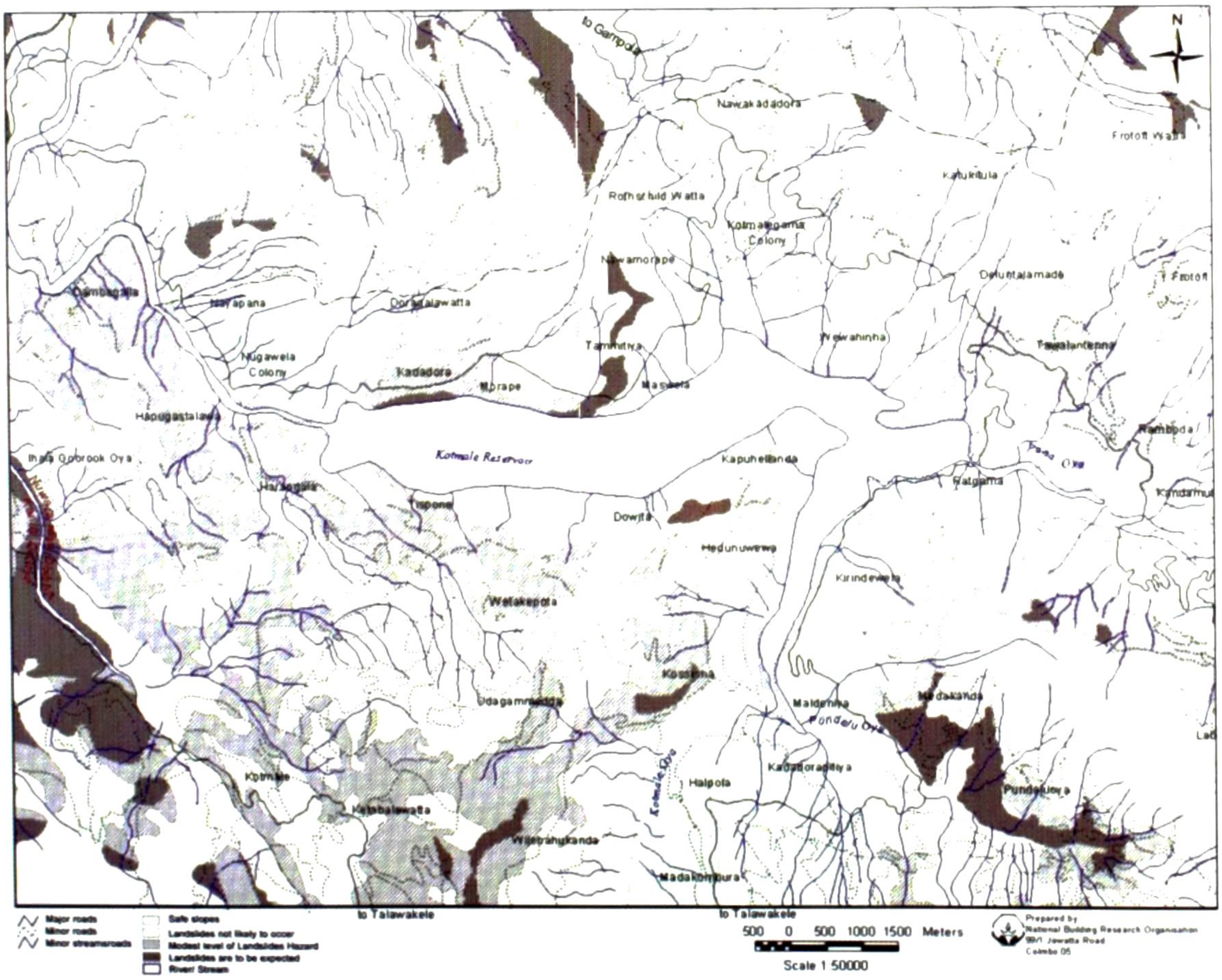

Figure 2: Landslide Hazard Zonation Map around Kotmale Reservoir

(i) Widening of existing tension cracks developed perpendicular to the direction of movements.
(ii) Widening of cracks developed in the walls and floors of houses and other structures.
(iii) Development of subsidence, subsidence of culverts, bridges, roads etc.,
(iv) Tilting of trees, electric poles, buildings and other concrete structures.

Precipitation data in the surrounding area of the reservoir available with the Department of Meteorology were analyzed. The data from rainfall stations namely 101, 156, 266, 371N, 157 and 328 situated near the reservoir were utilized for analysis. According to the records, two heavy rainy seasons could be observed in the area around the reservoir; rains resulting from the North Western monsoon from May to September and the first inter-monsoonal rains from October to December.

Reservoir water level is entirely depending on the patterns of rainfall precipitation. Water level is at its maximum from May to September during the North Western monsoon. Rainfall patterns from year 2000 to 2004 were considered for this study.

Fluctuation of groundwater level was monitored with the help of available dug wells in the area and existing tube wells. Ten experimental stations were selected for the current study as follows:

(a) Four stations, to make a profile of groundwater column within the soil overburden from top to bottom of left abutment of the reservoir.
(b) Three stations, to make a profile of ground water column within the soil overburden from top to bottom of right abutment of the reservoir.

(c) Three locations representing different terrain conditions of the soil slopes surrounded by the reservoir.

Groundwater level varies with the fluctuation of reservoir water level. When the reservoir water level is high, the ground water level gets increased and when the water level is lower, groundwater level gets lowered. In some of the stations groundwater level had gone down below the observation wells.

Rates of Movement at Selected Sites

Four extensometers were installed in the problematic area surrounding the reservoir. They were installed on a line perpendicular to the tensional cracks developed in the area. Table 1 gives a summary of the total displacements which were recorded in four selected stations between 2002 and 2005.

Table 1: Summary of total displacements measured using extensometers

Station Number	Total Displacement (cm) From year 2002-2005	Location	GPS co-ordinates
01	2.90 cm	Left Abutment	183705 E 207503 N
02	2.55 cm	Left Abutment	185515 E 208243 N
03	2.95 cm	Right Abutment	186748 E 205910 N
04	11.15 cm	Right Abutment	184392 E 205604 N

Table 1 indicates that the maximum displacement of 11.15 cm exists within the soil overburden at the right abutment situated near the dam. According to the results of monitoring, the rate of soil; movement increases when the reservoir water level decreased. These observations indicate that the movement of soil overburden is directly related to the fluctuation of reservoir water level.

DISCUSSION

The current situation of the unstable soil masses around the reservoir is listed below.

(i) All unstable soil masses are moving down the slope towards the reservoir. The movements are mainly induced by the fluctuation of reservoir water level. During the drawdown stage of reservoir, groundwater level in the soil slope is lowered at relatively lower rate. Intensive rainwater infiltration, subsurface geological structure, thickness and type of soil overburden support the downward movement.

(ii) One of the soil slopes around the reservoir is situated at the toe region of a rocky escarpment. It is separated from the slope above this rock exposure. It was observed that there were several unstable detached rock fragments hanging from this escarpment. They could cause to frequent rock falls.

(iii) As for the rates of movements, it is revealed that there was a maximum displacement of soil mass (11.15 cm) during the period of monitoring for the rest of the areas; rates of movements were too low. Therefore, further investigations and monitoring activities must be carried out in order to determine whether or not the soil mass moving towards the reservoir will significantly replace reservoir water.

(iv) Under the prevailing conditions, stabilization or monitoring works are impracticable almost to the point of near impossibility for consideration. Although modern technology is available for effective stabilization, In order to minimize the existing situation high expenditures involved preclude the use of such technology. In order to mitigate the deterioration of the situation, diversion drains and interceptor drains must be put in place, especially over the already identified sliding masses in order to avoid the increase of groundwater level.

(vi) The options for remedial measures are very limited, and at present, loosened soil masses can be tightened and strengthened by planning deep-rooting trees. Such action offers a similar mechanical effect to that of anchorage, which is a much costlier exercise.

RECOMMENDATIONS

(i) In order to minimize the rate of settlement of all unstable soil masses, the most effective method of stabilization procedure is the establishment of surface and subsurface drainage systems using appropriate drainage techniques.

(ii)Two types of surface drainage systems could be used as diversion drains and interceptor drains. Diversion drains are used for prevention of any water flowing into the sliding area across its periphery. Interceptor drains are used for prevention of surface runoff from springs and rain within the sliding area. With the help of highly impermeable material such as clay, a well-planned surface drainage system must be constructed. Objectives of this measure are to a) minimize rainwater infiltration, b) to divert the surface runoff from problematic areas and to c) drain rainwater away from the problematic sites.

(iii)Subsurface drainage should be provided to control the groundwater table and/or seepage flows. Subsurface drains should be constructed using flexible pipelines so as to allow movement without structural damage. Maintenance access should be provided at appropriate locations. Drainage tunnels are used for deep-seated landslides where subsurface water is very deep and construction of horizontal drains and drainage wells are difficult.

(iv) The area under threat of sudden rock falls should be covered with a dense tree belt. To select a suitable tree species, the following botanical criteria have to be considered.

(a) *Root system -Deep root system of trees generally fixes the loosened soil overburden to the solid basement rock.*

(b) *Tree trunk- the selected species should have a long, straight and strong tree trunk. In case of a sudden rock fall, these tree trunks will be capable of reducing damages caused by jumping and rolling of rock fragments.*

(v) With the help of deep-rooted tree species, some of the vulnerable soil slopes could be stabilized. Soil anchorage and intensive evaporation are the major expected mechanical processes. Areas that are underlain by thick colluvium soil layers could be strengthened by this eco-friendly technique.

(vi) Construction of suitable retaining structures should be done in order to strengthen the unstable soil masses. Application of soil anchorages, toe supports and strengthening of soil masses are the expected outcomes with the construction of these retaining structures.

It may also be emphasized that any evacuation and resettlement of the victims already identified and resident in the unstable areas (displaced masses) should be hastened considering the significant risks to their life and property. In this regard, public awareness campaigns have already been done. But they should be continued in order to keep the public informed about the prevailing situation. However, it must be mentioned here, that the inherent geology of the Kotmale valley mentioned earlier, is no new development and has been known for several decades

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