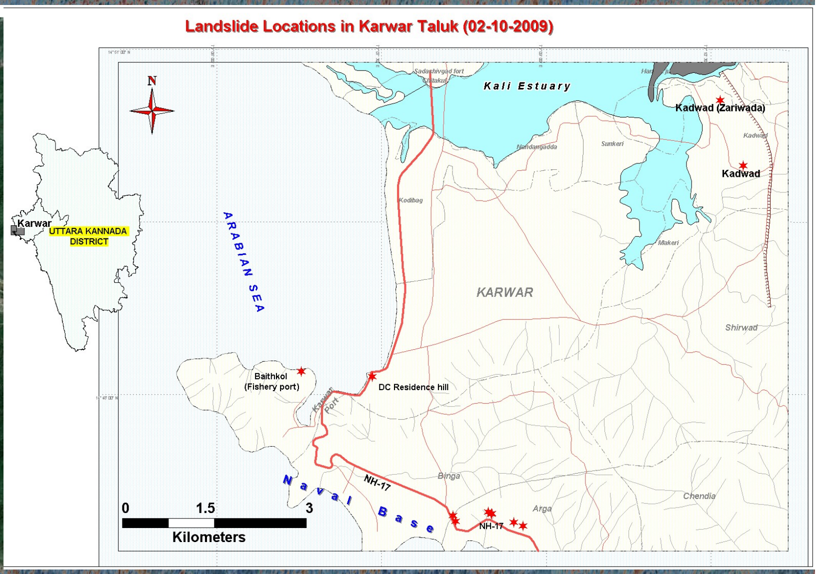
Landslides at Karwar, October 2009: Causes and Remedial Measures



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ENVIS TECHNICAL REPORT: 33
November 2009

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Landslides at Karwar, October 2009: Causes and Remedial Measures

Report
by

The Western Ghats Task Force
Govt. of Karnataka

for
submission to

Sri. B.S. Yeddyurappa

The Hon'ble Chief Minister of Karnataka,

November 2009

Landslides at Karwar: Members of the Expert Committee

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Content

Acknowledgement:

We are grateful to Sri.Gokul, IFS for arranging logistics during the field visit. We thank Mr. G R Rao, Vishnu Mukri and Mr.Pradeep Bhat (for the assistance in vegetation mapping), Mr.Karthick B and Dr.Prakash Mesta (for assisting in GIS analysis) and Mr.Boominathan (cover page design and layout).

Landslides at Karwar: The Expert Committee Report

Executive Summary

The multidisciplinary expert committee, consisting of members from ecology, geology, forestry, Government officials, etc., under the Chairmanship of Sri Ananth Hegde Ashisar, Chairman, Western Ghats Task Force (WGTF), on 14th Oct 2009, visited the locations where landslides occurred during October 2-3, 2009. Members of the expert committee are:

Members	Affiliation	Contact details
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The committee met briefly at the Forest Guest House, Karwar and explored the possible reasons for landslides in Karwar and visited the following locations where landslides had occurred. Latitude and longitude of these locations were recorded using calibrated GPS (Global Positioning System) and Survey of India toposheets.

Locations	Latitude	Longitude	Reference documents
Kadwad (Zariwad)	14.87783	74.17772	Survey of India toposheet No. 48 J/1 of 1:50,000 sc.
Kadwad (Forest Checkpost)	14.83311	74.17989	Forest Sy.No.71 A_1A_1
Agra 1 (NH 17)	14.7815	74.14531	Forest Sy.No.52A
Agra 2 (NH 17)	14.78089	74.14647	Forest Sy.No.52A
Baithkhole (Near port)	14.80369	74.11381	Forest Sy.No.16
Baithkhole (Near port)	14.80272	74.11411	Forest Sy.No.16
Baithkhole (Near port)	14.80447	74.11369	Forest Sy.No.16
Baithkhole (Near port)	14.30458	74.11331	Forest Sy.No.16
Baithkhole (Near port)	14.80206	74.11383	Forest Sy.No.16
Shirwad	14.81075	74.17989	Forest Sy.No.230
Mandralli	14.84728	74.15631	Forest Sy.No.269
Makeri 1	14.82272	74.17156	Forest Sy.No.47
Makeri 2	14.82097	74.17153	Forest Sy.No.47
Makeri 3	14.82092	74.17153	Forest Sy.No.47
Baad (Murlidhramath)	14.80697	74.137	Forest Sy.No.47
Baad	14.80403	74.12289	Forest Sy.No.47
Binga 1 (NH17)	14.79061	74.11486	Forest Sy.No.16A
Binga 2 (NH17)	14.79108	74.11639	Forest Sy.No.16A
Binga 3 (NH17)	14.78164	74.13611	Forest Sy.No.9A
Agra 3 (NH17)	14.78303	74.14144	Forest Sy.No.52A
Agra 4 (NH17)	14.78289	74.14144	Forest Sy.No.52A

Background

Landslides occur when masses of rock, earth or debris move down a slope. Mudslides, debris flows or mudflows, are common type of fast-moving landslides that tend to flow in channels. These are caused by disturbances in the natural stability of a slope, which is triggered high intensity rains. Mudslides usually begin on steep slopes and develop when water rapidly collects in the ground and results in a surge of water-soaked rock, earth and debris. Causes may be of two kinds: 1. Preparatory causes & 2: Triggering causes. Preparatory causes are factors which have made the slope potentially unstable.. The triggering cause is the single event that finally initiated the landslide. Thus, causes combine to make a slope vulnerable to failure, and the trigger finally initiates the movement. Thus a landslide is a complex dynamic system. An individual 'landslide' characteristically involves many different processes operating together, often with differing intensity during successive years.

The main trigger of landslides is heavy or prolonged rainfall. This could be either an exceptional short lived high intensity event, or of a long duration rainfall event with lower intensity, lasting several days, such as the cumulative effect of monsoon rainfall. In the former case it is usually necessary to have very high rainfall intensities, whereas in the latter the intensity of rainfall may be only moderate - it is the duration and existing pore water pressure conditions that are important.

Geological causes	**Morphological causes**	**Physical causes**	**Human causes**
• Weak materials • Sensitive materials • Weathered materials • Sheared materials • Jointed or fissured materials • Permeability contrasts • Material contrasts • Rainfall	• Vegetation change • Slope angle • Uplift • Rebound • Fluvial erosion • Erosion of lateral margins • Subterranean erosion • Slope loading	• Intense rainfall • Prolonged precipitation • Rapid drawdown • Ground water changes • Soil pore water pressure • Surface runoff • Seismic activity	• Excavation - toe cutting, slope cutting • Land use change • Water management • Mining • Quarrying • Vibration • Water leakage • Deforestation

Gravity caused slope instability occur naturally due to earth quakes, etc. Slope failures are also triggered by high degree of human impact on the environment. Land use changes may lead to land degradation, and make hillslopes more susceptible to instability (or mass movement). The past several decades have witnessed intense disruption of forest cover, for alternative land uses (mining, quarrying, monoculture plantations, agriculture, human settlements, roads, railways etc.) or for biomass needs, in the mountains and hills of India. In such events when extreme meteorological events, such as heavy rainfall happen landslide episodes, have increased causing human and cattle deaths and destruction of property and livelihoods.

Susceptibility to landslides may be considered as a natural, tangible process in a landscape, taking into account the rainfall history, as well as the geological and geomorphic setting of the area. Risk levels increase drastically in landslide prone areas whenever human pressures increase. In addition to rainfall, several factors probably contribute to slope failure. These include:

i) Geological structures like shattered, fragmented and highly jointed rocks and topography like steep slopes, interacting to provide the geometry favouring landslides.
ii) Prolonged rainfall certainly produces abnormally high antecedent groundwater levels, more so in places where the ground water level is already high due to the nearness of rivers or estuaries or other water bodies. It is the collective rainfall of many days that enhances the pore water pressure.
iii) Poor drainage network in the hillocks – due to changes in land cover (removal of vegetation or obstruction of drainage channels) alters the drainage.
iv) Steep slopes cut for pathways and residential buildings near the base of the slope further destabilizes the slope by removing the basal support.

Landslide description

Kadwad (Zariwada) land slide: Major landslide was noticed at Kadvad village to the northeast of Karwar, where 8 to 9 houses were washed with earth flow causing 19 deaths of humans. The hill is about 65 m asl and the slope is < 20º. First order streams from this hill drains to Kali river and the hill base bordering the Kali estuarine area, has density human habitation along with plantations of coconut, banana, fruit trees etc. The cutting of slopes for construction of housing and home gardens was observed. Also, large scale soil removal in the recent years, from this mound has been reported. The committee assessed the various factors responsible for the slide - slope angle, human interventions in slopes, apart from assessing the accumulated collapsed debris.

After observing the slip surface and other features on the slope, it was evident that it was a slope failure in the form of a mudslide or debris slide. The length of the slide is about 250 m, the width about 75 m, depth about 30 m in the deepest part and the shape of the slide is concave.

The instability in the slope was mainly due to removal of vegetation (deforestation), of the hill, alteration of slopes (base cutting for construction of houses and household gardens), large scale removal / excavation of soil at the toe of the hill (for developmental works in the region). Deep rooted vegetation provides significant cohesive strength into slope soil, and facilitates good drainage, thereby reducing the chances of landslides. Removal of vegetation or other changes in the natural land cover, such as forests, permanently reduces rooting strength, thus increasing chances of landslide.

The collective rainfall of many days, before the landslide has increased the pore water pressure, which along with lateral pressure due to swelling of oversaturated clay rich soil horizon (layer) have powered (or enhanced) the driving force for the slide resulting in the burial or displacement of houses and human deaths and loss of properties.

It was inferred after the assessment of the instability in the area, that the basement of the hill at Zariwada hamlet in Kadwad is a potential risk zone due to intense human activities. Hence, it is not advisable to rehabilitate this landslide-affected zone till the slope is stabilized to the best possible extent.

Implementation of remedial measures shall include - afforestation of hill tops with native tree species (preferably the ones with tap root systems); trees with specialized root systems to resist water-logging are to be considered especially for base of the hills. Sealing of cracks, slope-grading, proper drainage measures and soil reinforcement (using geo-grid and biotechnical measures) are other measures. However, appropriate selection of these measures along with their design is only possible after an in-depth geological and geotechnical study of the slide area.

Landslides at National Highway (NH 17): The antecedent high intensity rain has triggered the slides. Main causal factors are unscientific road cuts (without proper mitigation measures), building of large compound wall (for naval base) altering/blocking the natural drainages and large scale granite quarrying. Rock and debris fall were noticed around Arga village limits. In the Baitkolgudda, earth flow in larger quantity was seen, just missing the fishing harbour and dense human settlement narrowly. Weathered granites on the hills and weakening of soil due to excessive rains have triggered the landslides near Binaga, National Highway.

On the basis of *prima facie* observations and studies the committee suggests the following and requests the Government to implement these suggestions on priority.

Recommendations of the expert committee (based on the field visit on 14th Oct 2009 and subsequent studies and land use analysis)

1. **Planting of native vegetation on hilltops and slopes**. The roots of the native vegetation, especially of certain specially chosen tree species, can act as good soil binders, thereby providing slope stability. The removal of trees (with deep tap roots) and subsequent taking over of secondary vegetation, planting of cashew trees on the Zariwada hill by removing earlier natural tree cover, most of them with shallow roots has reduced the soil binding properties.

2. **Restoration of natural drainage network.** Alteration in hydrological regime due to changes in drainage network consequent to deforestation - Inappropriate

locations of human habitations on the first and second order streams in Kadwad has also hindered the water movement. Heavy pressure of rain water within the hill removed all the blockages on the way – as evident from mudslide and collapse of houses (in Zariwada)

3. **Discouraging monoculture plantations–** the land given to cashew plantations in the Kadwad hills should be taken back and the afforestation has to be carried out with the native species of flora according to suitably designed planting programmes.

4. **Immediate banning of large scale illegal quarrying of granite stones and mineral mining** considering the hazards proneness of the region (Karwar) and presence of sensitive pockets (Naval base, Kaiga nuclear plant, eco sensitive Anshi-Dandeli tiger reserve). Weathered granites on the hills and weakening of soil due to excessive rains have triggered the landslides near Binaga, National Highway.
5. **Banning soil and rock mining on the hills-** Landslide prone areas should not be leased out for soil or stone removal. All illegal mining and quarrying have to be stopped
6. **Improving drainage connectivity**. The collective rainfall of many days has enhanced the pore water pressure. This with lateral pressure due to swelling of oversaturated clay rich horizon has set the driving force resulting in burial of houses and humans displacement and destruction of houses and loss of properties (at Zariwada, Kadwad).
7. **Need to investigate the suitability of human habitations in regions prone to landslides.**
   (i) The Konkan Railway track connecting Karwar town with Goa and other places passes through this Zariwada paleo-river valley and also crosses the lineaments. The vibration generated by movement of trains is also suspected to have developed the cracks on hill tops resulting in the loosening of the soil (subsequent to soil mining reported to have taken place). Long spell of high intensity antecedent rainfall has triggered the mud slide.
   (ii) Geomorphologically, the valley area was a paleo-river channel that formerly drained into the Kali River that flows in the north of Zariwada/Kadwad. The shift of the river course might have led to the formation of hills/mounds. Composition of this mound which is mainly of laterite clay further confirms the existence of paleo stream in this region. The paleo-river channel is still connected to the Kali River and

the groundwater seepage into the channel increases or decreases rhythmically according to high and low tides in the River.

(iii) Soil formation for centuries on the hillocks and heavy rain might have led to the swelling of clay inside the hillocks resulting in the landslips.

8. **No large scale developmental projects particularly in Karwar taluk and ecologically fragile regions in Central western Ghats.** Considering the implementation of large number of mega projects in Karwar, it appears that the region has exceeded the carrying capacity and further implementation of any mega projects would prove detrimental to the local population. The region has already prone to hazards and could be categorized as hazard hotspot. This also emphasizes the need for carrying capacity study for Uttara Kannada district.
9. **Considering the hazard proneness of the region it is necessary to set up 'Disaster management centre (DMC)'** to assist in regional planning, management of disasters and also to assist the administration in rehabilitation measures in case of eventualities. Also, the region around 25 km radius of Karwar is seismically sensitive and also occurrence of lineaments further emphasizes the need for setting up a **seismic monitoring cell (within DMC)** in the district to assist the district administration in the predication and also mitigation measures. Disaster management centre shall house seismic monitoring cell, and shall have the state of the art gadgets to predict calamities due to natural as well as human induced causes.
10. **Naval authorities should be asked to remodel the protection wall** considering the natural drainages on priority. Construction of the protective wall by the naval authorities without any due consideration to natural drainage systems has resulted in large scale flooding of the region, which also has triggered series of landslides all along the Highway (NH 17). Removal of the protection walls at many locations during the floods, highlights the need for holistic approaches in planning and implementation of large scale projects. Many such projects have seriously impaired the ecology of the region, affected the livelihood of nature people and also have posed serious threats to the existence of local population.

11. **Shifting of all affected families** (located on the hill side) at Madibag/Zariwada to appropriate locations without affecting their current livelihood dependence.

12. **Afforestation with native vegetation** in the region considering the large scale deforestation in recent times. At present many hill tops are barren or with highly inadequate tree cover.

13. **Setting up special Uttara Kannada package to restore ecosystems –** The funding shall be from all developmental projects in the district. **Karwar taluk, in**

all probability, has transgressed its limits of growth, beyond the carrying capacity - Series of landslides consequent human tragedies and property loss is the indication of the lack of integrated approaches in planning and the region has crossed the thresholds of carrying capacity. Large scale land cover changes has resulted in alterations in hydrological regimes evident from the conversion of perennial streams to seasonal streams, enhanced siltation in the catchment evident from increased sedimentation in reservoirs in recent years. The region being one among the global biodiversity hotspots call for immediate measures to restore the ecosystems. Large scale projects such as hydro power plants, project sea bird, Kaiga nuclear plants have played significant role in degradation the ecosystems which have also affected the livelihood of local people. **These projects shall also make provision to provide a recurring grant to sustain the proposed Disaster Management Centre at Karwar and also for Ecological Research in Karnataka part of Western Ghats.**

14. Considering the level of devastations in Karwar, **landslide susceptibility mapping should be carried out to delineate potential zones of instability**, particularly in areas where human lives and properties are involved. If any indication of slope instability is noticed in an area which has major risk elements, the fact should be shared with society in a proper way. This suggestion has two major implications.
    - (i) First, with the increasing large scale environmentally unsound development activities in the region, the risk posed by natural hazard must also be evaluated. This is well-exemplified by a series of natural hazards (landslides) in the region. Considering rainfall-intensity and changes in climate / hydrologic regimes (due to global warming) stochastic relationships have to be developed to assess high-risk areas.
    - (ii) Secondly, with the successful establishment of relationship between rainfall and landslide activity, analysis of palaeo landslides would provide insights based on the past variation in rainfall patterns. Equally, such relationships aid in predicting changes in mass movement activities based on modelled regional impacts of global climate change.

15. Apart from reforestation of barren hill slopes and hill tops, sealing of cracks, slope-grading, proper drainage measures, soil reinforcement using geo-grid and biotechnical measures have to be done. However, appropriate selection of these measures along with their design is only possible after an in-depth geological and geotechnical study of the slide area.

Section 1
Landslides: Introduction

‘Landslide’ is a general term for a variety of downslope movements of earth materials that result in the perceptible downward and outward movement of soil, rock and vegetation under the influence of gravity. The materials may move by falling, toppling, sliding, spreading, or flowing. Some landslides are rapid, occurring in seconds, whereas others may take hours, weeks, or even longer to develop.

It includes various types of slope failure including earth and debris flows, slumps, slides, and soil and rock fall. Landslides are one of the normal landscape building processes in undulating terrain and are common in Himalaya and Western Ghats regions in India. It includes any detached mass of soil, rock, or debris that moves down a slope or a stream channel. They are classified according to the type and rate of movement and the type of materials that are transported. Two types of forces are at work: (1) driving forces combine to cause a slope to move, and (2) friction forces and strength of materials act to stabilize the slope. When driving forces exceed resisting forces, landslides occur. It is one of the common natural hazards with devastating effects. They become a problem when they interfere with human activity resulting in damage to property and loss of life, evident from recent episodes in Karwar. In order to minimise the losses due to landslide it is necessary to identify and analyse the most important determining factors leading to slope failure. They occur as “on-site” hazards and “off-site” hazards, and should be distinguished to effectively plan for future hazard situations.

- On-site hazards occur on or near the development site and are typically the slower moving landslides that cause most of the property damage in urban areas. They include features called slumps, earth flows and block slides.
- Off-site hazards typically begin on steep slopes at distance from homes or developments, and are often rapidly moving.

Different Types of Landslides

Landslides are classified by causal factors and conditions, and include falls, slides and flows, which are described below. There are many attributes used as criteria for identification and classification including rate of movement, type of material and nature of movement. A combination of characteristics can also contribute to an increased risk of landslide hazards.

a. Falls: Falls move through the air and land at the base of a slope. In falls, material is detached from a steep slope or cliff and descends through the air by free fall or by bouncing or rolling down slope. Rock fall, the most common type, is a fall of detached rock from an area of intact bedrock.

b. Slide: Slides move in contact with the underlying surface. Slides include rockslides – the down slope movement of a rock mass along a plane surface; and slumps – the sliding of material along a curved (rotational slide) or flat (translational slide) surface. Slow-moving landslides can occur on relatively gentle slopes, and can cause significant property damage, but are far less likely to result in serious injuries.

c. Flows: Flows are plastic or liquid movements in which mass (e.g., soil and rock) breaks up and flows during movement. Debris flows normally occur when a landslide moves down slope as a semi fluid mass scouring, or partially scouring soils from the slope along its path. Flows are typically rapidly moving and also tend to increase in volume as they scour out the channel.

Causes of Landslides: Causes of landslides can be broadly distinguished in the following two types and the probability of landslide occurrence depends on both the intrinsic and extrinsic variables.

a. Internal factors or Intrinsic variables: Geology, slope gradient; slope aspect, elevation, soil geotechnical properties, vegetation cover, and long-term drainage patterns are intrinsic variables that contribute to landslide susceptibility. The steeping of the slope, water content of the stratum and mineralogical composition and structural features, which tend to reduce the shearing strength of the rocks, are also vital factors for causing landslides.

b. External factors or Extrinsic variables: A slight vibration or jerk to the mass would greatly add up against the frictional resistance and the mass would become unstable. The heavy traffic in a hilly terrain could be a contributing factor towards causing the imbalance of the masses. The extrinsic variables may change over a very short time span, and are thus very difficult to estimate. If extrinsic variables are not taken into account, the term susceptibility could be employed to define the likelihood of occurrence of a landslide event.

Causal Factors: The causal factors that contribute to the landslides in the area are (i) preparatory and (ii) triggering. These mainly consist of:

- **Fissured Materials**- Loose soil, rock and fragmented materials.
- **Mass discontinuities**- Adversely oriented slip control, bedding lineaments, faults, etc.
- **Water and soil erosion of the slope toe**- Due to streams or human anthropogenic activities.
- **Intense short period rainfall-** Heavy rainfall for a shorter duration on a weak plane.
- **Prolonged high precipitation**- High rainfall, dam construction and alteration in river course.

- **Loading of the slope at its crest**- Construction on the top of slope, heavy earthmoving equipments, etc.
- **Shrink and swell of expansive clay**- Soil of clayey or clay loamy with high permeability and porosity.
- **Water leakage**- Seepage of water from any construction or natural resources.

Understanding of these factors in a region helps in adopting at stabilization approaches.

In order to minimise the damage due to landslides, it is required to identify the regions, which are susceptible for landslides. The proneness of the terrain to produce slope failures and susceptibility is usually expressed in a cartographic way is defined as landslide susceptibility. A landslide susceptibility map depicts areas likely to have landslides in the future by correlating some of the principal factors that contribute to landslides with the past distribution of slope failures. This requires spatial and temporal data related to the region. Geospatial technologies such as Geographic Information System (GIS) and Remote Sensing (RS) help in the analysis of spatial and temporal data. Remote sensing provides the spatial data at regular intervals, while GIS helps in the analysis.

The Landslide Hazard Zonation map can be derived through interpretation of satellite imagery and by using the factors leading to the occurrence of the potentially damaging phenomenon. With the increasing availability of high-resolution spatial data sets along with GIS it is possible to partially automate the landslide hazard mapping process that eliminates the need of longer time required in fieldwork and extensive expert input. The essential steps followed in landslide susceptibility zoning are:

- A landslide distribution mapping, differentiated according to type, activity, dimensions, etc., and based on information covering, when possible, a time span as large as possible.
- Spatial mapping of the relevant terrain parameters related to the occurrence of landslides.
- The analysis of the terrain conditions which are responsible for the occurrence of the different types of landslides.
- The assignment of weights to the causal factors, depending on their role in landslides.
- Formulation of decision rules and designation of susceptibility classes.

Landslides: Review

Landslides, around the world, take a heavy toll on life and property every year. Indeed, they are one of the most significant contributors to loss of life and aggregate national losses caused by natural disasters associated with earthquakes, severe storms and heavy rainfall in mountainous terrain **(**Lundgren, 1986; Swiss Re, 2000). Sediment disasters by debris flows, mud flows, and landslides occur almost every year during the rainy and typhoon period of July to October in Japan. In July 1982, a heavy rainfall of 488 mm in a day caused 4300 debris flows in Kyushu Island killing 299 people. Many debris flows caused by intensive rainfall during July 1983, in Honshu Island killed 199 people. Both created also enormous loss of property (Abe and Ziemer, 1999).

Landslides are particularly frequent in active oregenic belts like the Himalayas, which are the youngest, tallest and the most fragile mountains in the world. The North-Eastern Hill regions and the Western Ghats are also landslide prone areas. Scores of human lives are lost in these areas every year, livestock perish, houses and property and agriculture destroyed. Transportation and communication networks are also affected costing enormous loss to the states. Geologists say that seismic movements are constantly taking place in the Himalayas. Thousands of landslides of medium to large dimensions have been occurring in the Himalayas every year. On an average, nearly 200 earthquakes of smaller magnitude occur every year in the Uttarakhand region of mid-Himalayas alone. Most of them are undetected by the local communities. According to V.C. Thakur, then Director of the Wadia Institute of Himalayan Geology, the uncontrolled downhill flow of water after heavy rains, particularly along barren slopes, was an important causative factor in these landslides. Apart from geological reasons, changes in the land use pattern in the mountains have also led to the increase in the frequency and magnitude of landslides. The most obvious of these changes, according to Thakur, is the rapid destruction of forests which has left large tracts in the entire Himalayan region with denuded slopes (Kazmi, 1998).

Many factors contribute to landslides, which include geology, gravity, weather, groundwater, wave action and human actions. Landslide may accompany highway and building excavations, collapse of mine waste piles, and slope failures associated with quarries and open-pit mines. Typically a landslide occurs when several factors converge. **Gravity** works more effectively on steeper slopes, but more gradual slopes may also be vulnerable. **Geological setting** like the presence of permeable sands and gravels above impermeable layers of silt and clay, or bedrock may precipitate landslides. Water seeps downward through the upper materials and accumulates on the top of the underlying units, forming a zone of weakness. **Heavy and prolonged rainfall** is the most common triggering factor for landslides. Slides often occur following intense rainfall, when storm water runoff saturates soils on steep slopes or when infiltration causes a rapid rise in groundwater levels. Groundwater may rise as a result of heavy rains or a prolonged wet spell. As water tables rise, some slopes become unstable. When **earthquakes** occur on areas with steep slopes, many times the soil slips causing landslides. Debris flows caused by earthquakes can also trigger mass movement of soil. Of the various human factors that cause landslides are

- **Destruction of natural vegetation (**including deforestation),
- Inappropriate **drainage systems**,
- Drastic land cover changes - faulty **land use patterns** and
- **Cutting and deep excavations on hill slopes**.

A landslide is a complex dynamic system. An individual landslide characteristically involves many complex processes operating together. Heavy rains, earthquakes and volcanic eruptions alone or in combination are the major reasons for slope failures. The high annual rainfall, steep slopes, high weathering rates and slope material with a low shear resistance or a high clay content are often considered the main preconditions for mass movements in East Africa (Knapen et al., 2006). Rainfall and earthquakes are the most common triggering factors for landslides (Cannon and Ellen, 1988; Corominas and Moya, 2008).

Humans are reported to have precipitated landslides in many areas because of soil removal, quarrying and mining, deforestation, road networks, tunneling etc. The vulnerability to landslides or earthquakes is greater in zones what are geologically termed as active faults and fractures, shear zones, lineaments, joints or folds. Debris flows could be greater along narrow streams on steep areas. If basement of the hills/mountains are cut the chances of landslides increase. Occurrence of highly fractured bedrocks increases landslide susceptibility. Tectonically and seismologically sensitive areas, if not carefully managed by humans, stand greater chance of suffering from landslides, especially from heavy and prolonged rains, vibrations from movement of heavy vehicles, excavation work etc. Wherever drainage density is high the water pressure pushes the slope material and generates pore water pressure along joints. As failure starts the rough joints widen and water pressure pushes slope materials forward causing slides. Younger geological formations with unconsolidated soils stand greater chance for slides. In any case action of water during heavy rains often acts as the main triggering cause (Deoja et al., 1991; Naithani et al., 2000; Meunier et al., 2008).

The main causal factors for slope failures can be divided into preparatory and triggering causal factors (Glade and Crozier, 2004). **Preparatory causal factors**, i.e. factors making slopes susceptible to movement over time without actually initiating it, often reported for the East African region include the increasing population pressure with slope disturbance and deforestation as a consequence and the reduction in material strength by weathering. **Triggering causal factors** on the other hand can be seen as external stimuli responsible for the actual initiation of mass movements. The triggering causal factors in the region can be earthquakes, excessive rainfall events and human disturbance such as slope excavation and terracing, inconsiderate irrigation and water leakage (Knapen et al., 2006).

Rainfall and slope instability: Slope instability due to rainfall is a common geotechnical problem in tropical and subtropical areas. Many slope stability studies have indicated that the infiltration of rainwater into a slope decreases the stability of the slope. The mechanism that leads to slope failures is that the negative pore–water pressures start to increase when water starts to infiltrate the unsaturated soil. (Tsaparas et al., 2001; Gasmo et al., 2000). Slope failures in the tropical regions like Malaysia are commonly triggered by frequent rainfall (Lee et al., 2009). Analysis by Dahal and Hasegawa (2008) of 193 landslides in the Himalayan locations, where rainfall data was available, showed that when the daily precipitation exceeded 144 mm, the risk of landslides was high. However, rainfall alone cannot be taken in isolation as various other factors are involved in causing landslides during rainfall. They include hydraulic, physical and mechanical properties of the terrain and other geomorphological factors such as slope, vegetation cover, micro-climatic characteristics of the area, and perhaps other factors.

Vegetation clearing by fires and logging favours slope failures. Changes in the vegetative cover on steep slopes have increased debris-flow frequency (DeGraff, 1991; Guthrie, 2002). Deforestation is reported to have reduced slope stability on the densely populated Mount Elgon region of Uganda (Knapen et al., 2006).

Vulnerable places in India: Hill-side instability is a common problem in the geo-dynamically sensitive belts of Himalayas. Several major landslides have occurred in the recent past resulting in large-scale damages to life and property. Cloudburst occurs in areas where the mountains are high. As the floating clouds cannot find a passage, after some time a thick layer of clouds accumulate and one day it bursts creating landslides (Deoja et al., 1991; Naithani et al., 2002).

Largely made up of Precambrian geological formations with variable cover of Jurassic to Quaternary sedimentary rocks and Cretaceous-Eocene volcanics, the peninsular Indian shield was long held to be immune from seismicity. Nevertheless, many earthquakes have been recorded from the coastal margin of the Indian peninsula during the last 200 years. Geologists ascribe point out various reasons for such disturbances:

1. The continental fragment is being pushed northeastward by the Carlsberg and Central Indian ridges;
2. The Indo-Myanmar subduction zone is exerting vigorous slab pull towards the east;

3. Repeated cycles of sea level change during the Quaternary have also induced continuing hydro-isostatic adjustment due to variable melt water loading in the Bay of Bengal and the Arabian sea. All these forces produce space-time fluctuations of strain around many small to large faults, which occur in the upper crust of the shield (Banerjee *et al.*, 2001).

Karwar landslides

The landslides which took place in the Karwar taluk on 2nd October 2009 may be categorized as a **mudflow.** Also known as **debris flows** mudflows are fluid mass of rock, earth and other debris saturated with water. A mudflow develops when water rapidly accumulates in the ground, such as during heavy rainfall changing the earth into a flowing river of mud or slurry.

Of the several causes that can be attributed for the landslides are:

- **Very heavy rainfall:** Most important triggering cause for landslides. Antecedent rainfall over a longer time period is considered, as well as the geological and geomorphic setting of the area, landsliding susceptibility can be easily regarded as a natural tangible landscape process.
- **Earthquakes:** In mountainous regions all over the world earthquakes toll a heavy toll of human lives through house collapse and landslides.
- **Human actions impeding drainage of storm water**: The high wall of INS Kadamba is reported to have blocked the surge of storm water towards the sea, because of insufficient outlets provided in the wall. The wall itself collapsed in many places and in one place the local people broke the wall to pave way for fast drainage.
- **Slope cutting and deep excavations:** Natural slope of hills have been cut to make the roads like NH-17, and the Baithkol fisheries port road. Toe support of the most vulnerable Zariwada hill has been cut by the local residents for housing. There has been also digging of the hill for soil.
- **Deforestation** is widespread in the coastal areas. Tree cutting amounts to removal of a protective mantle. Moreover, after interval of some years when the root network disintegrates the compaction of soils and rocks by root mass weakens causing slope failure. The hollows created by stump and root disintegration become a major cause for water seepage into the soil and trigger off landslides during spells of heavy rainfall.
- The entire city of Karwar is situated on beach ridges formed due to the influence of Kali River and Arabian Sea confluence during the past. It seems during the formation of these beach ridges at Majali and Karwar the accumulation of sediment as ridges, the above processes played major role compared to the Holocene sea level fluctuation (regression).

SECTION 2
LANDSLIDES AT KARWAR, October 2009

On October 2, 2009, on a day of very heavy rains, the coastal tract of Karwar taluk in Uttara Kannada witnessed a spate of landslides. The most catastrophic landslide took place in the Zariwada (Jarivada) hamlet of Kadwad village, in the outskirts of Karwar town, when a part of a hill overlooking the Kali River estuary, came crashing down at around 4.30 pm, killing 19 people. The people were buried alive and their houses destroyed totally. In the same village part of another hill also slid down, but the people escaped unhurt and their houses were just spared from the fury of nature. There was also a series of other landslides all along the hills to the east of INS Kadamba Naval Base obstructing the NH-17 in several locations. Loosened soils and granite boulders came crashing down the hill slopes, destroying the wall of the Naval Base in many places. As the rain waters flooded parts of the NH, stated to be due to the obstruction created by the compound wall of the Naval Base, some of the local people are reported to have broken the wall to release the flood waters to flow seawards through the Base. Landslides also happened on the steep hill close to the Karwar Port, (on the summit of which Deputy Commissioners' residence is located). Yet another slide happened in the Baithkol hill overlooking the Fisheries Port. The locations of all major landslides are shown in Figure-2.1.1 (map of coastal Karwar) and (overlaid on Google imagery) in Figure 2.2. Streams of Kali river at the location is given in Figure 2.1.2. The Google Imagery of Kadwad village showing the locations of the two landslides that happened on two different hills the same day is shown in Figure 2.3.1. Lineaments of Karwar is given in Figure 2.3.2. The two landslide areas of Kadwad are shown overlaid on Google Imagery separately as Kadawd-1 (without any casualities) and Kadwad-2 (at Zariwada) where the 19 deaths happened, in Figures-2.4 and 2.5 respectively. Landslides in various pockets of Karwar are listed in Table 2.1.

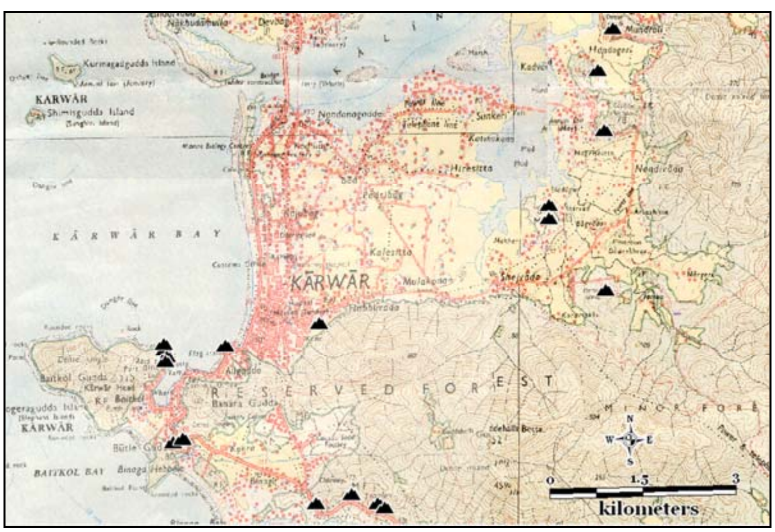


Table 2.1: Landslide locations visited by the Committee on 14th Oct 09

Locations	Latitude	Longitude	Reference documents
Kadwad (Zariwad)	14.87783	74.17772	Survey of India toposheet No. 48 J/1 of 1:50,000 sc.
Kadwad (Forest Checkpost)	14.83311	74.17989	Forest Sy.No.71 A_1A_1
Agra 1 (NH 17)	14.7815	74.14531	Forest Sy.No.52A
Agra 2 (NH 17)	14.78089	74.14647	Forest Sy.No.52A
Baithkhole (Near port)	14.80369	74.11381	Forest Sy.No.16
Baithkhole (Near port)	14.80272	74.11411	Forest Sy.No.16
Baithkhole (Near port)	14.80447	74.11369	Forest Sy.No.16
Baithkhole (Near port)	14.30458	74.11331	Forest Sy.No.16
Baithkhole (Near port)	14.80206	74.11383	Forest Sy.No.16
Shirwad	14.81075	74.17989	Forest Sy.No.230
Mandralli	14.84728	74.15631	Forest Sy.No.269
Makeri 1	14.82272	74.17156	Forest Sy.No.47
Makeri 2	14.82097	74.17153	Forest Sy.No.47
Makeri 3	14.82092	74.17153	Forest Sy.No.47
Baad (Murlidhramath)	14.80697	74.137	Forest Sy.No.47
Baad	14.80403	74.12289	Forest Sy.No.47
Binga 1 (NH17)	14.79061	74.11486	Forest Sy.No.16A
Binga 2 (NH17)	14.79108	74.11639	Forest Sy.No.16A
Binga 3 (NH17)	14.78164	74.13611	Forest Sy.No.9A
Agra 3 (NH17)	14.78303	74.14144	Forest Sy.No.52A
Agra 4 (NH17)	14.78289	74.14144	Forest Sy.No.52A

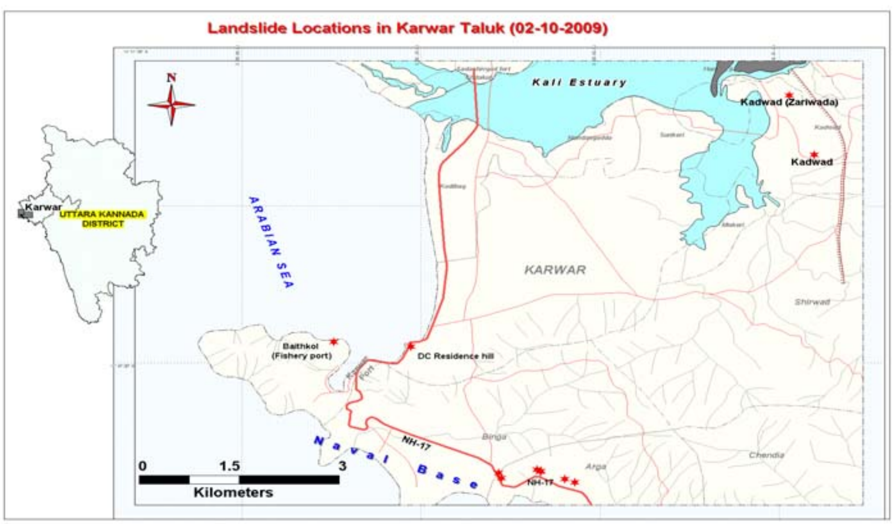


Fig. 2.1.1. Locations of major landslides in coastal Karwar (shown by star symbols)

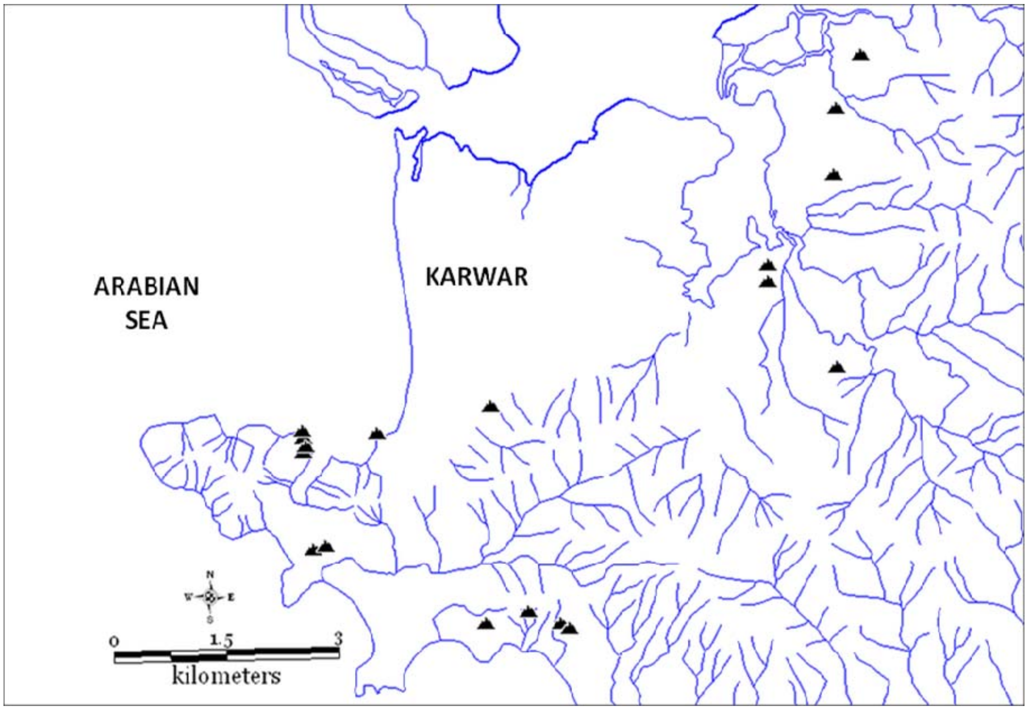


Fig. 2.1.2: Locations of major landslides in coastal Karwar (shown by trainagle symbols)

Figure 2.2. Locations of major landslides in Karwar (overlaid on Google Imagery by star symbols. Note also the drainage network intensity in the hills. The shore of Arabian Sea all along from south of Baithkol hill is the Sea Bird Naval Base. The habitations are situated between the steep hills, the Arabian Sea and the Kali River estuary)

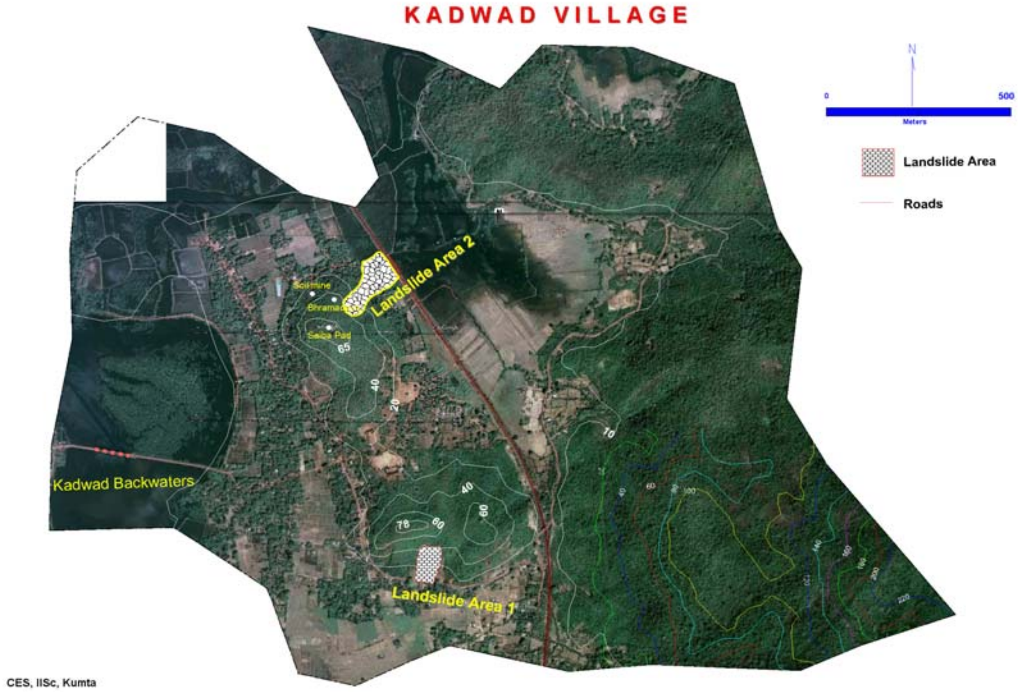


Fig. 2.3.1: Google Imagery of Kadwad village showing two landslide locations (major settlements of the village are around the two hills of -65 m & 78 m. Railway track passes through close to the hills through backwaters of Kali, prawn farms and low lying paddy fields. Human casualties took place in Landslide Area 2.

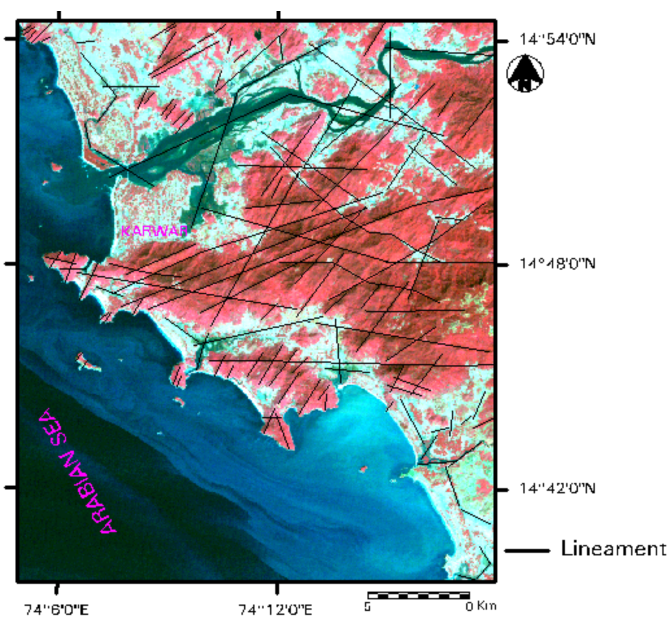


Figure 2.3.2: Lineaments of Karwar coast (Landsat TM+, 2000).

The linear features forming the hill ridges (intrusions such as granite or graniticgneiss, amphibolite, dolerite, etc.) are quite conspicuous and extend to the western margin that some times run along the headlands peaks. The linear trends along the headlands which run shorter distance can be basic dykes or amphibolites which are quite significant and conspicuous all along the central west coast. A lineament passes right across the summit of the hill along the Saiba Pad and another through base of the hill, along south, in east-west direction. A lineament is also found starting close to Landslide Area 1, passes across the railway track in somewhat SW-NE direction).

Geomorphologically, the valley area was a paleo-river channel that formerly drained into the Kali River that flows in the north of Zariwada/Kadwad. The shift of the river course might have led to the formation of hills/mounds. Composition of this mound which is mainly of laterite clay further confirms the existence of paleo stream in this region. The paleo-river channel is still connected to the Kali River and the groundwater seepage into the channel increases or decreases rhythmically according to high and low tides in the River. The Konkan Railway track passes through this Zariwada paleo-river valley connecting Karwar town with Goa and other places.

The soils of the Uttara Kannada district are basically derivatives of the Dharwad system- the most ancient metamorphic rocks in India- which are rich in iron and manganese. Most of the coastal hills are covered with exposed laterite rocks. These are very unproductive rocks, most of the top-soil already washed off. Peninsular gneiss containing granite occurs towards south of the district. Table 2.2.1 gives the soil texture details. In the zone of accumulation and depletion, debris consists of laterite clay, sand and weathered granite material. Topography and drainage conditions exert considerable influence on the nature of laterite profiles. Drained upland soils are brown-red colour denoting a non-hydrated iron oxide ($Fe\sim O_3$) in the soil. In middle and lower slopes, soil drainage is poorer than in the upper slope and summit and, hydrated iron oxides mainly goethite ($Fe_20_3.H_20$) and limonite ($Fe_20_3.5H_20$) with reddish brown to brown yellow clay. Lower-slope colluvium is typically brown yellow in colour, as are the better drained soils developed in the alluvium. Table 2.2.2 lists the physical and chemical constituents of the soil.

Table 2.2.1 : Texture of soil samples collected from various locations

Place details	Sample	lat	long	%Sand	%Silt	%Clay
				(Texture)		
Station-01Extra soil	Sam-5B			37.50	31.25	31.25
Baithkal fishing point	Sam-01 bottom	14.8035	74.114	62.50	21.88	15.63
Kadwad-02	Sam-02, 5 ft ht.			32.00	31.67	36.33
Kadwad-02	Sam-04, 15 ft ht.			40.00	6.00	54.00
Kadwad-02, Hill top slope	Sam-05,	14.8422	74.177	55.56	27.78	16.67
Kadwad-02 , saiba Pada, Hill Plane Top	Sam-06	14.842	74.176	55.26	28.95	15.79
Karwar, Below DC Bunglow		14.8039	74.123	73.33	6.67	20.00
Baithkal	Sam-02, Top	14.3038	74.113	60.00	11.67	28.33
Kadwad, Station-04, Extra soil	Sam-5A			52.67	10.00	37.33
Kadwad-02	Sam-03, 10 ft. ht.			62.50	25.00	12.50
Kadwad-02, Bottom	Sample-01			88.33	11.33	0.33

Table 2.2.2: Select physico-chemical parameters of soil samples from landslide sites

Sample	**pH**	**Conductivity (µS/cm)**	**Ca (mg/100 g)**	**Mg (mg/100 g)**	**% TOC (g/100g)**	**% Org Matter (g/100 g)**
Sam-5B	5.97	31.40	59.25	65.69	0.39	0.67
Sam-01 bottom	5.71	16.10	18.03	57.96	0.31	0.54
Sam-02, 5 ft	5.80	13.10	25.76	151.98	0.20	0.34
Sam-04, 15 ft	5.50	15.50	2.58	28.34	0.18	0.30
Sam-05,	6.53	24.80	28.34	56.67	3.06	5.28
Sam-06	5.79	18.20	33.49	48.94	2.44	4.20
	6.35	94.00	61.82	61.82	0.75	1.29
Sam-02, Top	6.12	14.50	43.79	77.28	0.42	0.72
Sam-5A	5.65	12.70	2.58	10.30	0.12	0.20
Sam-03, 10 ft.	5.60	9.00	5.15	51.52	0.12	0.20
Sample-01	6.06	16.30	12.88	113.34	0.14	0.24

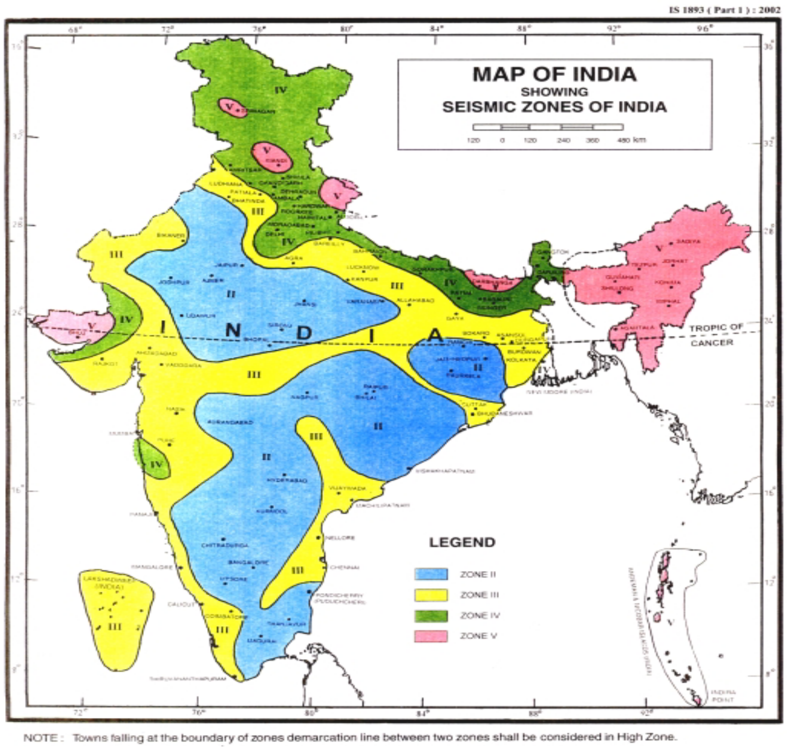


Figure 2.3.3: seismic zones of India (Karwar comes under the high seismic risk zone; As per BMTPC, 2006 Karwar falls under Zone III)

Fig.2.4: Kadwad Landslide Area 1 (no casualties happened here. Note the lineament starting from right of Landslide Area 1 in the NE direction)

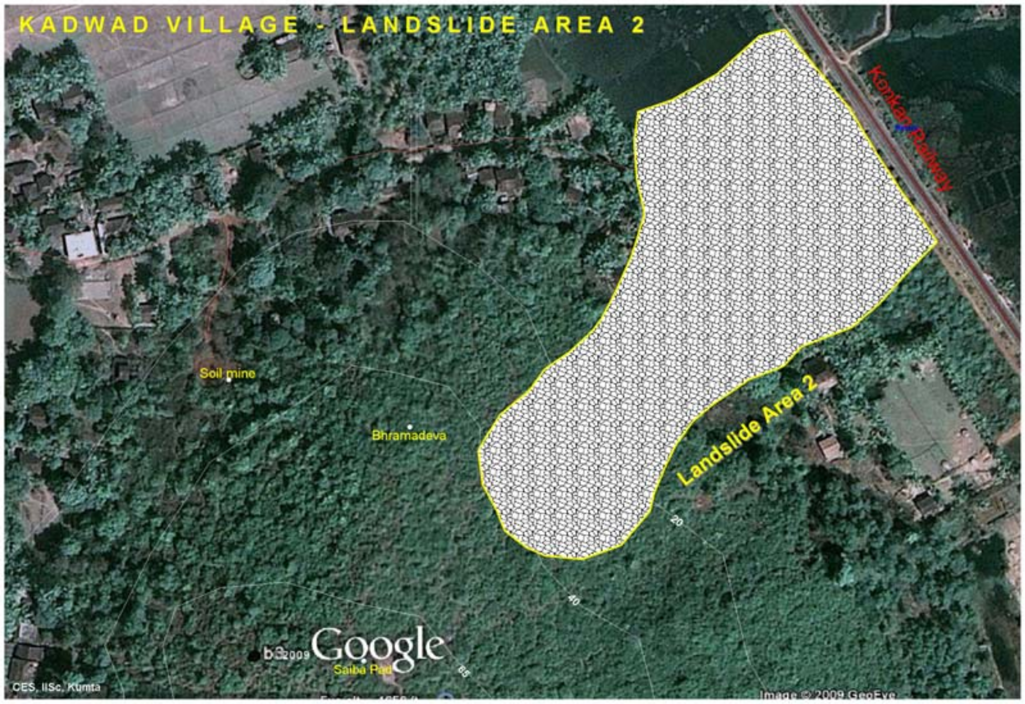


Fig. 2.5: Kadwad-2 (Zariwada) landslide area (where 19 deaths happened)

Descriptions of landslides

1. Landslides at National Highway-17

The locations of landslides alongside NH-17 (Figures-2.1 & 2.2) took place in the Arga village, and to the area to the immediate south of Binga village. These locations are along the steep hillsides overlooking the INS Kadamba Naval Base. Many local people suspect that quarrying for for granites, by blasting, along with rainfall could have been a major reason for destabilization of hill slopes. The debris of rock and soil blocked the NH-17 and in many places entered the Naval Base, breaching its compound wall (Figures 2.6-2.8). A landslide of potentially dangerous nature took place from the steep hill (atop which is situated the Deputy Commissioner's residence- marked as 'DC residence hill' in Figures 2.1-2.2). The slide materials, huge granite boulders and soil fell on the NH and even crossed into Arabian Sea across the road. However, no casualties happened as the road was already blocked to traffic due to flooded conditions and landslides.

Fig.2.6: Rock and soil that slid into the Project Seabird Naval Base

Fig. 2.7: Breach in the wall of the Naval base. Fig. 8: NH-17 cleared of debris; on the right compound wall of Naval Base

Fig.2.8: Landslide close to NH-17 on steep hill atop which DC's residence is located

2. Landslide at Baithkol

Baithkol is situated towards the left of a very narrow creek of the Arabian Sea, to the immediate left of the Karwar Port. Baithkol is a promontory at 14.8° N, protruding into the sea. It has created conditions that made Karwar an all weather natural port (Figures 2.1-2.2). Almost triangular in shape, the promontory has its broader base facing the Karwar Port and its acumen jutting into the open sea. Most of this promontory is covered with a steep hill furnished with a good network of natural drainage channels that run in all directions towards the sea. The hill base towards south of fisheries port is a high density human settlement, except towards. However, as the landslide happened towards the north-eastern tip (Figures 2.9-2.10), at the entry point into the creek, free from habitation, the residents were spared from the calamity, or the fisheries port proper affected.

Fig.2.9: Baithkol landslide

Fig. 2.10: Clearing debris at Baithkol landslde (Karwar Bay in the backdrop)

3. Landslides at Kadwad

Kadwad village is situated towards the east of Karwar town and south of the Kali River estuary; a large inlet of the estuary could be seen separating the town and Sunkeri village towards its north-east from Kadwad (Figures 2.1-2.2). Towards its north, north-east and west are mangrove swamps, prawn farms, low lying rice fields, marshes and small inlets of the estuary. The two hills, one of 78 m elevation to the south and the other of 65 m towards the north constitute the major landscape features of the village. The zone between lowlands and the hills is densely populated, the houses zoning the normal floodline, and many abutting the slower slopes of the hills.

The landslide-1 happened taking away roughly about 100 m wide swathe of a scrub-covered hill. The slide started at about 45 m height in the 78 m hill, towards its southern slope, and the rubble, mostly of soil and mud, moved towards the habitation below, almost crossing the road skirting the hill. The direction of slide was from north-east to south-west. The landslide covered nearly an area of about one hectare (Figures 2.11-2.12). No human casualty happened here, nor any significant loss of property. Preventive measures should be taken forthwith to shelter people and their houses from recurrence of such hazards in the future.

Figs. 2.11-2.12: Images of Landslide-1 in Kadwad, soil and mud predominating

In the landslide-2, the most vicious of all the landslides that ever happened in the history of Uttara Kannada district in which19 people lost their lives. The slide occurred in the Zariwada hamlet towards the north of Kadwad village, on the north-east face of a 65 m hill. The hill ruptured at about 40 m height and the soil, mud and water rushed towards the habitation below at around 4.30 pm on October 2. Horrified on hearing the rumble and seeing the mudslide rushing towards them along with uprooted trees and palms most residents ran for safety along the flooded road. However, unfortunately, eight houses were totally destroyed, with 19 of their inmates buried alive. Eight members of Talekar family lost their lives according to *Deccan Chronicle* (Oct. 5, 2009). One of the RCC houses (Figure 2.14, the building was constructed on load bearing columns) was carried away from its original location to about 15 m away, where it stood collapsed at the time of our survey. Here also the hill that split is covered with dense scrub with isolated, stunted cashew trees. The rubble of the slide, mainly clayey soil, soft mud, and partially formed, soft laterite from the inside of the hill covered an area of about 1.3 ha. The advance of the slide was checked by the Konkan Railway embankment passing through the mangrove swamps and fields (Figures 2.13-2.17).

Fig. 2.13: Landslide-2 in a scrub Kadwad village

Fig. 2.14: A building that has been carried away by about 15 m in the landslide

Fig.2.15: Soft laterite in the slide materials at Kadwad Landslide-2

Fig. 2.16: The slide materials at Kadwad Landslide-2 stopped at the railway Embankment


Fig. 2.17: The densely settled Kadwad village at the foot of the hill, bordered by mangrove swamps and prawn farms

LANDSLIDE RELATED PRESS REPORTS AND OTHER LOCAL ACCOUNTS

The Deputy Director of the Department and Mines and Geology of Uttara Kannada, in his report to the Deputy Commissioner of the district blamed the Konkan Railway for the Zariwada (Jariwada) tragedy as the latter had “unscientifically” dug the hill for laying the Konkan Railway track through the adjoining lowlands, thereby disturbing the natural gradient of the hill. According to a news item in *The Hindu*, October 10, 2009 Santosh Uma Vengankar (51) and many others are reported to have concurred with such allegation. Mr. Vaingankar, who lost everything in the calamity, says that a small landslip occurred on the same hill over ten years ago, “…just a few days after the Railways excavated a portion of this hill.” However, other residents, like Satir Belurkar alleged that the “the real culprits of the October 2 tragedy are the several unauthorised miners operating in the area.” Ullas Govekar, another resident conferred to *The Hindu* that the blasting conducted in the mines here created tremors in a radius of several kilometers.

The Hindu report continues that the local residents of Binaga village, close to the INS Kadamba Naval Base, attributed the reasons for landslides in the village (at several places on National Highway 17) to the torrential downpour compounded by illegal blasting and mining in the hills. The compound wall of the Naval Base is also reported to have impeded drainage, creating flooded conditions that prompted village youth to demolish part of the wall to make way for the flood waters.

During our survey also the matter was confirmed by the local people, who also said the compound wall of INS Kadamba collapsed in several places due to the force of the blocked water. The flooding of Karwar city during those October first week days was attributed by locals to poorly engineered drainage system and choking of drainage canals due to inaction of the Municipality. A minor landslide in Canacona in South Goa, that took place at 5.30 am on 2 October, 2009 halted the trains on the Konkan Railway. Railway tracks, south of Karwar were already flooded (http://www.indianews.com/business/2009/1002/224517.htm). Dakshina Kannada had also reported floods and landslides on October, 2. Landslides happened in Venur and Laila of Belthangidi taluk (http://www.daijiworld.comnews)

Fig. 2.18. Karwar flooded during October first week, 2009

During the meeting convened on landslides in the Deputy Commissioner's office at Karwar some of the experts concurred with the local representatives that the compound wall of INS Kadamba should not obstruct the drainage of the hills and should make adequate drainage channels at proper intervals. According to *Times of India* 12, October, 2009 "as the survivors of the landslides are still recovering from the shock of the tragedy, there is a mad race between some contractors to appropriate the soil and rocks" from the landslide areas. The amount of soil in the killer landslide at Kadwad was stated to be six lakh tonnes. The contractors are reported to have sold soil at rates ranging from Rs. 800 to Rs. 950 per truckload. The soil and rocks in the landslide area stated to have been separated by the district administration at the cost of Rs.50 lakh, to facilitate rescue operations, which the contractors considered a boon for them. People resented this move by greedy persons to make money out of the tragedy and urged the district authorities to dispose of the soil through auction so as to recover the money spent on rescue operation.

According to the Chief Minister of Karnataka, 18 districts of Karnataka, received between 28^{th} September to 4^{th} October, 2009 abnormally high rainfalls due to low pressure weather system. The departure from normal rainfall in these districts were between 98% high in Chikmagalur to 924% in Bagalkote. The departure for Uttara Kannada district was 435% (http://yeddyurappa.in/news-and-events-report-on-the-losses-and-damages-due-to-floods). The Naval team played important role in recovering the bodies trapped in the debris at Kadwad (http://news.indiaid.com/blog/_archives/2009/10/10/4346356.html). Quoting a member of the Kadwad Village Panchayat a report says: "some illegal miners had moved substantial chunk of mud from the hillock a couple of weeks before the rains started lashing the region. The illegal miners in league with powerful politicians and officials in the district.." (http://www.3dsyndication.comshowarticlerss.aspx?nid). A picture of the relief operations in Kadwad village was contributed by Vinayak Patgar, Kumta (Figure 2.19). Figure 2.20 is of a body being removed from the site.

Fig. 2.19: The body of landslide victim taken out by the rescue team in Kadwad village

Fig. 2.20: Yet another body being removed from landslide site at Kadwad.

SECTION 3:
VEGETATION AND LANDSLIDES: APPLICABILITY TO COASTAL KARWAR

Introduction

Shallow rapid landslides are important erosion processes in steep terrain. The hill slope failures begin frequently in slightly concave depressions (Johnson and Sitar, 1990). These depressions are believed to be former landslide scars which have gradually filled with soil and organic materials through time (Shimokawa, 1984; Reneau *et al.*, 1989). As soil depth in these depressions increases with time, the stability of the site decreases. This coupled with episodic occurrence of heavy precipitation (or snow melt) can sufficiently decrease soil strength resulting in another slope failure (Sidle and Terry, 1992).

The effect of changing root strength caused by vegetation management is another factor influencing slope stability in forested areas. When trees are cut, live roots begin to decay and there is generally a lag time before the root systems of newly planted or invading trees contribute substantial root strength to the site. Field studies in many parts of the world have shown that sites are most susceptible to landsliding about 2 to 12 years after forest cutting (Endo and Tsuruta, 1969; Megahan *etal.*, 1978). This lag period corresponds to the time of minimum rooting strength as determined in several independent studies (Sidle and Terry, 1992). Vegetation conversion and range improvement practices on steep slopes can have a profound impact on site stability. In many areas, brush species are periodically removed by fire, herbicide or mechanical means to promote increased productivity of grasses. More dense grass cover offers resistance from surface erosion, the rooting strength of the grasses is negligible compared to most shrub or tree species (-ibid-).

Forest vegetation, especially tree roots, helps stabilize hillslopes by reinforcing soil shear strength. Root reinforcement is important on slopes where roots can extend into joints and fractures into bedrock or into a weathered transitional layer between the soil and bedrock. The stabilization of slopes by vegetation depends on the depth to which the roots grow. The more the roots penetrate a potential a shear plane, the greater is the chance that the vegetation will increase slope stability (Abe and Ziemer, 1990). Proper management of vegetation in steep forested areas can influence site stability by modifying rooting strength. Rooting strength is important factor in cohesion of substratum.

Bruijnzeel (2004) states that whereas a well developed tree cover can prevent shallow landslides up to about 1 m in depth due to the stabilizing forces of the root network, deep landslides of >3 m are not appreciably affected by forest cover. In cases of extreme climatic events such as hurricanes, trees may actually increase slope instability due to the trees' weight and the susceptibility of particularly high trees to uprooting due to extreme storms, damaging the soil matrix. Bruijnzeel's observations need not be universally applicable. In the context of Uttara Kannada district, which is for most part covered with the forest clad hills of Western Ghats, killer landslides are very unusual phenomenon. The removal of forest cover increases rapidly soil erosion and might trigger of landslides, especially in soft soils (as it happened in Kadwad and Baithkol) and soils with fractured granite rocks as in the Arga hills.

According to van Noordvijk (2005) forest or vegetation can potentially attenuate downstream effects of landslides. If the vegetation cover of the slope is in tact, vegetation downhill can act as a filter for dislodged soil, preventing the sediment entry into river channels. However, during rainstorms which exceed the water holding capacity of the soil, or earthquakes, such natural filter mechanisms may fail. Noordvijk states that, in contrast, clear-felling of slopes will increase the probability of landslides occurring, particularly after a few years when the roots are decomposed and loose their stabilizing force.

This could have been true with Karwar landslides. At Kadwad the hills were deforested already due to dense human population and nearness of Karwar city. Moreover the last trees were reported to be cut or uprooted some years ago for planting with cashew. With the passage of years root network would have decomposed. Their slope stabilizing force gone eventualities like exceptionally high rainfall, which could occur every few years at least, could trigger of landslides. Any ecologist would observe at the outset that the forest cover is very poor in all the hills where landslides have happened, as in Kadwad, Baithkol, Arga and DC's residence hill. Therefore a rapid vegetational assessment was carried out in the region so as to find out whether impoverishment of vegetation could have also contributed to the landslides.

Thousands of landslides of medium to large dimensions have been occurring in the Himalayas every year. On an average, nearly 200 earthquakes of smaller magnitude, most of them undetected by local communities, occur every year in the Uttarakhand region of mid-Himalayas alone. According to V.C. Thakur, then Director of the Wadia Institute of Himalayan Geology, the uncontrolled downhill flow of water after heavy rains, particularly along barren slopes, was an important causative factor in these landslides. Apart from geological reasons, changes in the land use pattern, most obvious of these being the rapid destruction of forests which has left large tracts in the entire Himalayan region with denuded slopes (Kazmi, 1998). A study conducted in 1984 on the relationship between the building of the Mussoorie-Tehri road and landslides revealed that landslides caused more devastation in deforested rather than forested areas (-ibid-).

Deforestation and landslides in Karwar coastal hills

Vegetational status, almost all along the coastal hills of Uttara Kannada has been poor to very poor from historical times, although the climatic conditions are favourable for growth of multi-canopied evergreen forests that can be considered most ideal for slope protection. Slash and burn cultivation, or shifting cultivation (known as 'kumri' of 'hakkal') was widely practiced along the coastal hills during the pre and early British period. This was once considered the only suitable cultivation system for the hilly terrain receiving high seasonal rainfall. But as there were long gaps between two cycles of slash and burn, forest recovery to certain degree would happen during the fallow period. Landslides of vicious nature were, therefore, practically unknown, in coastal Uttara Kannada. Notable of the kumri cultivators were Kumri Marattis, Kunbis, Halakki Vokkals, Karivokkals etc. Taking note of the destruction this system of cultivation brought to forests, the British prohibited it by the close of the 19th century (Chandran, 1998). Passage of over 100 years since this ban on shifting cultivation could have been time enough for forest recovery through natural succession along the coastal hills of Karwar. But, to this day, though the hills appear to be under a green mantle of vegetation, there is *prima facie* insufficiency of tree growth. Therefore, we have studied the vegetation in some representative sample hills using a sampling method called 'point-centred quarter'. The method is useful especially for estimating tree density and basal area. As forest cover has critical linkages to slope stability in many places such study would be useful in interpreting the landslides in the area and establishing linkages with vegetation.

To know the status of vegetation we sampled three representative areas as shown below:

1. Zariwada hill in Kadwad village (Fig 3.1 and 3.2), the location of the fatal landslide
2. Arga hill parallel to NH-17, and INS Kadamba, where several small landslides took place. The hill has vegetation somewhat similar to Baithkol and DC's residence hill, the locations of other landslides
3. Amdalli hill as a control sample, representative of the potential landslide prone granite-soil hills of coastal Karwar, undergoing the same pressures, but to a lesser degree. No landslides happened here so far, but caution has to be exercised to prevent further degradation of vegetation. The details of the study are given in Table 3.1.

Table 3.1: Vegetation analysis

Study locality	Estimated trees/ha	Estimated basal area/ha (sq.m)	% evergreen trees	Mean ht (m)
Zariwada hamlet Kadwad	76	2.356	3	3.8
Arga hill	44	5.92	20	5.9
Amdalli hill	435	26.84	87	10

Vegetation of Zariwada hill, Kadwad

The natural tree cover was stripped off (we do not know of the kind of secondary vegetation that prevailed prior to start of cashew plantation by the KCDC). Cashew was planted in a total area of 20 Ha. The hill, probably, as rest of the coastal hills of Karnataka had a shifting cultivation history. According to a local resident, before the arrival of present residents, the area had population mainly of Kunbis, who moved away from the place to interior areas (probably because of stoppage of Kumri cultivation). The locality was known to the elderly persons as 'kumri-jaga' meaning slash and burn cultivation area. The salient features of vegetation are as follows:

- The vegetation is of dense scrubby nature
- The tree density (76/ha) and basal area (2.35 sq.m) are extremely low. A terrain of this kind, with soft and moist soil, with soft laterite inside, should have over 350 trees/ha and basal area of over 25 sq.m/ha. Most trees (82%) belong to *Anacardium occidentale* (cashew), which have been planted many years ago by the Karnataka Cashew Development Corporation. *Olea dioica* is the lone evergreen tree in the sample. This relic species shows that there could have been more evergreen species before cashew was planted
- The tree density being low mean tree height is also very low at 3.8 m.
- A small sacred grove on the same slope that suffered landslide has some more remnants of past evergreen forest. These trees (outside the sample study area) has few large evergreens like *Mammea suriga, Mangifera indica* and *Mimusops elengi.* There is also a lone *Sterculia guttata.*
- Thorny bushes, herbs, grasses and climbers are many in the vegetation. More details of species are given in Tables 32. to 3.8.

Insufficiency of vegetation: Good tree cover would have been an effective insurance against erosion and landslides, especially on small hills. Whereas a good forest in Uttara Kannada normally has 350 plus trees, density of mere 76 trees/ha is too poor a protective cover. Whereas a multi-canopied vegetation is desirable as in most natural vegetation elsewhere there are only low, stunted and isolated cashew trees. Most trees bear marks of cutting and lopping. Coppices of *Terminalia paniculata, Tectona grandis, Odina wodier* etc are also found sparingly. That the slope instability, to a major extent, could have been caused by poor tree cover can be assumed from the fact in the split part of the hill hardly had any deep going dicot tree roots. Most plants are of shallow rooted shrubs and climbers and palms like *Caryota urens.* The lower slope bordering human habitation has very poor natural tree growth. Combined and cumulative impact of soil removal, toe cutting and torrential rains was in the form of the major landslide that destroyed homes and killed 19 people.


Fig: 3.1. Surveying vegetation of Zariwada hill in Kadwad
Fig: 3.2. View of the scrubby vegetation of the Zariwada hill

Arga hills

A steep series of hills running close to the Arabian Sea these are promontories of the Western Ghats. In this part of Karwar the NH-17 mostly passes through the base of these hills. The narrow strip of coast below is occupied by INS Kadamba. The high wall separating the naval base from NH-17 has been breached in many places due to landslides and storm waters. A series of landslides have taken place along this range of hills obstructing the NH-17. Granite quarries are found in these hills. Although the hill sides are covered with a dense mantle of vegetation the trees are very sparse, just 44/ha, whereas their number should have been over 350/ha to provide more stable conditions, as most forests of Uttara Kannada elsewhere are. The salient features of vegetation (Fig. 3.3) are as follows:

- Dense scrubby vegetation with short bamboos (*Oxytenanthera stocksii*)
- Very low tree density (44/ha) and low basal area (5.92 sq.m). The ideal would have been over 350 trees/ha and basal area of over 25 sq.m
- The tree density being low mean tree height is also low at about 6m. To develop multi-storied vegetation for greater soil protection and stability to the ground the general canopy height should be at least 10 m.

- Most trees are of deciduous type, whereas the ideal would be multi-storied evergreen forest affording more effective soil protection. Notable of the trees are *Ficus arnottiana* (Kallaswatta), *Holarrhena antidysenterica* (Kodasa), *Ixora brachiata* (Gurani), *Schleischera oleosa* (Sagadi), *Syzygium cumini* (Neerlu) and *Terminalia paniculata* (Kindal). Occasionally small teak trees and *Sterculia urens* also are found. The nature of the tree vegetation is indicative of repeated fires (at least until the immediate past); eroded and stony soils indicate continuing ongoing human impacts which can be deciphered from dense growth of thorny bushes and entanglement of climbers (Table 3.2-3.8 for more details on speices).

Fig: 3.3. Vegetation of Arga hills (note stone quarry inside forest)

Amdalli hill

This hill is further south, high and steep, bordering the Ankola taluk. Bordering the coastal zone and yet merging with the Western Ghats the hill is to the east of the NH-17 and is not affected by road cutting unlike the Arga hills. No landslides occurred here, may be due to lower population of the village and less of soil disturbances or quarrying. The rocks in this hill are also of granitic nature. We studied this hill to compare the vegetation with that of landslide localities, and to know whether vegetation can provide greater stability to hill slopes. The tree number estimated is much higher at 435/ha, and also the basal area (26.84 sq.m/ha). A greater proportion of trees (87%) are evergreen. The vegetation however seems to be on fast decline due to rising human pressures. The salient features of the vegetation are as follows:

- The forest is denser but degradation process is rampant due to rising human pressures. Illegal cutting of small timber and removal of firewood have been noticed during our study
- The tree density at 435/ha is much healthier than the coastal hills nearer to Karwar that have suffered from landslides. The degradation of vegetation is higher closer to the habitation in the valley. The basal area of 26.84 sq.m/ha is very good for

any of the coastal hills of Uttara Kannada district. At the same time geological composition of the hill (mainly of granite rock masses and soil not forming a consolidated substratum) requires that the any further vegetational degradation can destabilize the slopes and create landslides here too under conditions of episodical heavy rains and even mild seismicity.

- The present vegetation indicates that the forest would have been fully evergreen forest. The presence of Western Ghat endemics like *Diospyros candolleana*, *Holigarnagrahamii* are indicators of such past. Human interference could be the reason for a mix of deciduous and secondary evergreen species like *Terminalia tomentosa, Flacourtia montana, Syzygium caryophyllata* etc.
- Forest degradation is ongoing as can be judged from commoner occurrence of thorny species and climbers, from firewood and poles collection and even traces of illegal sawing of timber (Figure 3.4).

Figs: 3.4. Forest degradation in Amdalli hill

Landslide prevention to be considered environmental service of forests

Control of landslides should be today a matter of great concern for all the residents living alongside and below hill slopes. For that matter, Karwar city itself is strategically close to the steep hills of Western Ghats. The landslide in the Baithkol fisheries port area, fortunately happened just missing the fisheries port proper as well as the densely populated colony itself. Huge sized granite boulders along with thousands of tonnes of soil came rushing down the steep hill slopes onto the NH-17 and beyond in several places. As the road was blocked human casualties did not happen on the NH. The people of Zariwada were unlucky, with 19 buried alive and several houses destroyed or damaged.

A striking factor here is the impoverished vegetational cover on the hills. Coastal and Malnad taluks of Uttara Kannada receive every year over 3000 mm of rainfall. Either episodically or continuously for several days at a stretch during the monsoon months, heavy rains pound the region. Whereas a healthy tree cover is of paramount necessity the situation of coastal Karwar is precarious. Added to that there is also high degree of human impact on the hills in the form of toe cuttings, to expand their holdings, both for houses and agriculture, stone quarrying and soil mining. The road cuttings are also improper in most places and attention paid to drainage is scanty as well. Compounding to the causes are willful removal of natural vegetation for planting cashew trees on the hills of Kadwad, by the Karnataka Cashew Development Corporation. Cashew trees are poorly grown on those hills, shallow rooted and insufficient to hold together soil and rocks in a region battered by torrential seasonal rains. Landslide prevention is to be considered as an environmental service of forest vegetation, especially in the hilly terrain of coastal Karwar, where the dominating rock type is granite which does not form a consolidated mass with soil. This is unlike in other coastal taluks like Kumta, Honavar or Bhatkal where the main rock type is laterite. Even underneath degraded vegetation laterite forms a conglomerate with the loamy soil, preventing landslides, except when hillside is cut too deep or unscientifically. However, as pressures rise unregulated on natural ecosystems their carrying capacities are transgressed, more so in the fragile evergreen forest belt of Uttara Kannada.

Table 3.2: Sahibapad-Kadwad landslide area: Trees in sampled plots

Sl	Family	Species	Habit	Distribution
1	Meliaceae	*Aglaia elaeagnoides*	Shrub	Oriental-Indomalaysia
2	Sapindaceae	*Allophylus cobbe*	Shrub	Oriental-South India, Sri Lanka, South East Asia
3	Liliaceae	*Asparagus racemosus*	Climber	Paletropics
4	Euphorbiceae	*Bridelia scandens*	Shrub	Oriental-Western Ghats
5	Combretaceae	*Calycopteris floribunda*	Climber	Oriental-Indomalaysia
6	Apocynaceae	*Carissa carandus*	Shrub	Oriental-Peninsular India
7	Lauraceae	*Cassytha filiformis*	Climber	India, Sri Lanka, old world Tropics
8	Verbenaceae	*Clerodendrum viscosum*	Shrub	Oriental-Indomalaysia
9	Menispermaceae	*Cyclea peltata*	Climber	Oriental-Western Ghats
10	Fabaceae	*Dalbergia climber*	Climber	
11	Dioscoriaceae	*Dioscorea spp*	Climber	
12	Myrsinaceae	*Embelia tsjeriam-cottam*	Shrub	Oriental-India, Myanmar, Sri Lanka
13	Myrtaceae	*Eucalyptus sp*		
14	Asteraceae	*Eupatorium odoratum*	Shrub	Neotropical
15	Euphorbiaceae	*Gymnosporia rothiana*	Shrub	
16	Asclepiadaceae	*Hemidesmus indicus*	Climber	Oriental-Peninsular India, Sri Lanka
17	Apocynaceae	*Holarrhena antidysenterica*	Shrub	Oriental-Indomalaysia
18	Rubiaceae	*Ixora coccinea*	Shrub	Oriental-Western Ghats, Sri Lanka

19	Euphorbiaceae	*Jatropha gosypifolia*	Shrub	Neotropics-Brazil
20	Anacardiaceae	*Lannea coromandelica*	Tree	Oriental-South Asia, Indomalaysia
21	Leeaceae	*Leea indica*	Shrub	Oriental to Australia
22	Melastomaceae	*Memecylon edule*	Shrub	India, Sri Lanka, Myanmar, Malasia, Thailand
23	Passifloraceae	*Passiflora sp*	climber	
24	Verbenaceae	*Premna obtusifolia*	Shrub	Oriental-Indomalaysia
25	Cyperaceae	*Scleria sp*	Shrub	
26	Euphorbiaceae	*Sepium insigne*	Tree	
27	Myrtaceae	*Syzygium caryophyllatum*	Tree	Oriental-South India, Sri Lanka
28	Combretaceae	*Terminalia paniculata*	Tree	Oriental-Peninsular India
29	Rhamnaceae	*Ziziphus oenoplia*	Shrub	Pantropics
30	Rhamnaceae	*Ziziphus rugosa*	Shrub	Oriental-India, Sri Lanka

Table 3.3: Sahibapad-Kadwad landslide area: Plants in sampled shrub layer

Sl	Family	Species	Habit
1	Fabaceae	*Acacia auriculiformis*	Tree
2	Rubiaceae	*Adina cordifolia*	Tree
3	Verbenaceae	*Avicennia officinalis*	Tree
4	Poaceae	*Bambusa spp*	
5	Acanthaceae	*Blepharis asperrima*	herb
6	Cyperaceae	*Cyperus malacensis*	herb
7	Fabaceae	*Derris spp*	Climber
8	Convolvulaceae	*Evolvulus aslinoides*	herb
9	Euphorbiaceae	*Excoecaria agallocha*	Shrub
10	Cyperaceae	*Fimbristylis ferrugenia*	herb
11	Tiliaceae	*Grewia microcos*	Tree
12	Poaceae	*heteropogon contortus*	herb
13	Apocynaceae	*Ichnocarpus frutescens*	Climber
14	Poaceae	*Ischemum indicum*	herb
15	Poaceae	*Ischemum semisagittatum*	herb
16	Verbenaceae	*Lantana camara*	Shrub
17	Euphorbiaceae	*Macaranga peltata*	Tree
18	Clusiaceae	*Mammea suriga*	Tree
19	Anacardiaceae	*Mangifera indica*	Tree
20	Santalaceae	*Osyris quadripartita*	Tree
21	Fabaceae	*Pongamia pinnata*	Tree
22	Rhizophoraceae	*Rhizophora apiculata*	Tree
23	Sonneratiaceae	*Sonneratia alba*	Tree
24	Sonneratiaceae	*Sonneratia caeseolaris*	Tree
25	Rutaceae	*Zanthoxylum rhetsa*	Tree

Table 3.4: Saihibapad:Kadwad landslide area-Other opportunistic plants

Sl	Family	Species	Habit	Distribution
1	Meliaceae	*Aglaia elaeagnoides*	Shrub	Oriental-Indomalaysia
2	Sapindaceae	*Allophylus cobbe*	Shrub	Oriental-South India, Sri Lanka, South

				East Asia
3	Sapindaceae	*Anacardium occidentale*	Tree	Native to South America
4	Euphorbiaceae	*Aporosa lindleyana*	Tree	Oriental-Peninsular India, Sri Lanka
5	Combretaceae	*Calycopteris floribunda*	Climber	Oriental-Indomalaysia
6	Rubiaceae	*Canthium parviflorum*	Shrub	Oriental-Western Ghats
7	Apocynaceae	*Carissa carandus*	Shrub	Oriental-Peninsular India
8	Lauraceae	*Cassytha filiformis*	Climber	India, Sri Lanka, old world Tropics
9	Verbenaceae	*Clerodendrum viscosum*	Shrub	Oriental-Indomalaysia
10	Menispermaceae	*Cyclea peltata*	Climber	Oriental-Western Ghats
11	Fabaceae	*Dalbergia climber*	Climber	
12	Myrsinaceae	*Embelia tsjeriam-cottam*	Shrub	Oriental-India, Myanmar, Sri Lanka
13	Asteraceae	*Eupatorium odoratum*	Shrub	Neotropical
14	Tiliaceae	*Grewia microcos*	Shrub	Oriental-Tropical Asia
15	Rubiaceae	*Ixora coccinea*	Shrub	Oriental-Western Ghats, Sri Lanka
16	Melastomaceae	*Memecylon edule*	Shrub	India, Sri Lanka, Myanmar, Malasia, Thailand
17	Passifloraceae	*Passiflora sp*	climber	
18	Euphorbiaceae	*Sepium insigne*	Tree	
19	Combretaceae	*Terminalia paniculata*	Tree	Oriental-Peninsular India
20	Rhamnaceae	*Ziziphus oenoplia*	Shrub	Pantropics
21	Rhamnaceae	*Ziziphus rugosa*	Shrub	Oriental-India, Sri Lanka

Table 3.5: Plants in Kadwad 1 landslide area

Sl	Family	Species	Habit	Distribution
1	Poaceae	*Bambusa spp*		
2	Combretaceae	*Calycopteris floribunda*	Climber	Oriental-Indomalaysia
3	Apocynaceae	*Carissa carandus*	Shrub	Oriental-Peninsular India
4	Dioscoriaceae	*Dioscorea spp*	Climber	
5	Moraceae	*Ficus arnottiana*	Tree	Oriental-India, Sri Lanka
6	Apocynaceae	*Holarrhena antidysenterica*	Shrub	Oriental-Indomalaysia
7	Rubiaceae	*Ixora brachiata*	Tree	Oriental-Western Ghats
8	Anacardiaceae	*Lannea coromandelica*	Tree	Oriental-South Asia, Indomalaysia
9	Melastomaceae	*Memecylon edule*	Shrub	India, Sri Lanka, Myanmar, Malasia, Thailand
10	Sapindaceae	*Schleichera oleosa*	Tree	Oriental-Indomalaysia
11	Myrtaceae	*Syzygium cumini*	Tree	Oriental-Indomalaysia
12	Verbenaceae	*Tectona grandis*	Tree	Oriental-Indomalaysia
13	Verbenaceae	*Tectona grandis*	Tree	Oriental-Indomalaysia
14	Combretaceae	*Terminalia paniculata*	Tree	Oriental-Peninsular India
15	Rhamnaceae	*Ziziphus oenoplia*	Shrub	Pantropics

Table 3.6: Plants in Binaga granite quarry landslide sampled area

Sl	Family	Species	Distribution
1	Euphorbiaceae	*Aporosa lindleyana*	Oriental-Peninsular India, Sri Lanka
2	Rutaceae	*Atalantia racemosa*	Oriental-India, Sri Lanka

3	Rubiaceae	*Canthium diciccum*	Oriental-South India, Myanmar
4	Arecaceae	*Caryota urens*	Tropical Asia
5	Ebenaceae	*Diospyros candolleana*	Oriental-Western Ghats
6	Ebenaceae	*Diospyros montana*	India-Tropical Australia
7	Flacourtiaceae	*Flacourtia montana*	Oriental-Western Ghats
8	Anacardiaceae	*Holigarna grahamii*	Oriental-Western Ghats
9	Rubiaceae	*Ixora brachiata*	Oriental-Western Ghats
10	Oleaceae	*Olea dioica*	Oriental-Western Ghats, Deccan plataeu
11	Myrtaceae	*Syzygium caryophyllatum*	Oriental-South India, Sri Lanka
12	Myrtaceae	*Syzygium spp*	
13	Combretaceae	*Terminalia alata*	Oriental-India

Table 3.7: Trees in Amdalli non-landslide sampled area

Sl	Family	Genera	Species	habit	Distribution
1	Lauraceae	*Actinodaphne*	*hookeri*	Tree	Oriental-Western Ghats
2	Meliaceae	*Aglaia*	*elaeagnoides*	Tree	Oriental-Indomalaysia
3	Euphorbiaceae	*Aporosa*	*lindleyana*	Tree	Oriental-Peninsular India, Sri Lanka
4	Rutaceae	*Atlantia*	*racemosa*	Tree	Oriental-India, Sri Lanka
5	Ebenaceae	*Diospyros*	*candolleana*	Tree	Oriental-Western Ghats
6	Ebenaceae	*Diospyros*	*buxifolia*	Tree	Oriental-Indomalaysia
7	Ebenaceae	*Diospyros*	*paniculata*	Tree	Oriental-Western Ghats
8	Rutaceae	*Glycosmis*	*pentaphylla*	Shrub	Oriental-South India, Sri Lanka
9	Rubiaceae	*Ixora*	*brachiata*	Tree	Oriental-Western Ghats
10	Myristicaceae	*Knema*	*attenuata*	Tree	Oriental-Western Ghats
11	Leeaceae	*Leea*	*indica*	Shrub	Oriental to Australia
12	Euphorbiaceae	*Macaranga*	*peltata*	Tree	Oriental-Western Ghats, Sri Lanka
13	Melastomataceae	*Memecylon*	*talbotianum*	Shrub	Oriental-Western Ghats
14	Lauraceae	*Neolitsea*	*scrobiculata*	Tree	Oriental-Western India
15	Anacardiaceae	*Nothopegia*	*colebrookeana*	Tree	Oriental-Western Ghats
16	Oleaceae	*Olea*	*dioica*	Tree	Oriental-Western Ghats, Deccan
17	Rubiaceae	*Psychotria*	*dalzellii*	Shrub	Oriental-Western Ghats
18	Myrtaceae	*Syzygium*	*sp*	Tree	
19	Flacourtiaceae	*Flacourtia*	*montana*	Tree	Oriental-Western Ghats
20	Lauraceae	*Litsea*	*laevigata*	Tree	Oriental-Western Ghats
21	Anacardiaceae	*Mangifera*	*indica*	Tree	Oriental-Western Ghats
22	Rutaceae	*Acronychia*	*pedunculata*	Tree	India, Sri Lanka, Laos, Cambodia, Vietnam, Taiwan, Sumatra, Borneo, Phillipines, Java
23	Anacardiaceae	*Holigarna*	*grahamii*	Tree	Oriental-Western Ghats
24	Sapotaceae	*Mimusops*	*elengi*	Tree	Oriental-Indomalaysia
25	Arecaceae	*Calamus*	*thwaitesii*	Shrub	Oriental-Western Ghats
26	Clusiaceae	*Garcinia*	*morella*	Tree	Oriental-India, Sri Lanka, Malesia
27	Annonaceae	*Sageraea*	*laurifolia*	Tree	Oriental-Western Ghats

SECTION 4
LANDSLIDES: GEOLOGICAL FACTORS

A graphic report of Kadwad landslides is found in *Geo Karnataka* (October 19, 2009), along with a plausible explanation. Zariwada as the name suggests is a low-lying valley region characterized by seepage of ground water. Geomorphologically, the valley area can be recognized as an old stream (paleo-river) channel that formerly drained into the Kali River that flows in the north of Zariwada. The paleo-river channel is still connected to the Kali River and the groundwater seepage into the channel increases or decreases rhythmically according to high and low tides in the River. Zariwada colony of houses was located beside a huge clayey-laterite hill. The hill consists largely of reddish clays and was topped by thin cap of laterite. Granitic material underlies the clayey hill as can be seen in some cuttings. The clayey material from the hill was in demand for using as filler material in construction sites. The removal of clays from the eastern flank of the hill had created a vertical scarp on the eastern flank of the hill that increased the instability of the hill flank.

On 2-10-2009, due to rains, people in the Zariwada colony were inside their houses Around 4.15pm, the eastern scarp flank of the Zariwada suddenly gave up and ruptured with a thud of sound. The massive quantity of loose clayey material abruptly rolled down the gradient and settled on the 9 houses burying the 19 inmates alive. The whole process of landslide ended by 4.30 pm.

On 3-10-2009, early morning about 3.30 am, another clayey hill on the western side of Zariwada also collapsed blocking the road leading to Kadwad. However there were no human casualties since the houses were located at a distance from the affected hills. It is reported that similar landslides had occurred in the Kadwada area, during the year 1959.

Mechanism of landslide (as given in *Geo Karnataka*, October 19, 2009): The laterite capped clayey material in the Zariwada hill were densely soaked in water due to persistent rains in the area. The basic character of the clays allows them to absorb water easily into their intergranular pore spaces, but the inherent nature of poor permeability prevent them from discharging the excess water held in the pore-spaces. Added to this, the seepage of water into the Zariwada paleo-river valley from the Kali River backwaters render the area excessively saturated with water, preventing any discharge from the equally saturated clayey hills of Zariwada.

The excessive pore-water pressure in the clayey material of Zariwada hill when crossed the optimum limit led to disruption of unstable scarp slope leading to the massive landslide. The massive landslide brought down huge quantity of clayey soils from the hill with landslide collapsed area measuring about 90 m wide, 150m long and 10 to 30 m high along the eastern flank of the Zariwada hill.

The derived huge quantity of loose material covered the bottom of the hill where there were several houses with people inside. The sudden fall of the massive material that lasted barely 15 minutes between 4.15 to 4.30 pm on 2-10-2009 buried alive the people inside the doomed houses. The direction of flow of the fallen clayey soil material was blocked by the Railway track in the east and was diverted towards north. One house was dragged northwards for some 10 meters along with the moving material derived from the landslide. Lesson from the Zariwada disaster is that clayey hills beside river zones in Coastal Karnataka are susceptible for sudden landslides during the rainy season and the people should be prevented from constructing houses or living near the susceptible clayey hills located near the rivers.

Note on laterites and other rocks of Karwar landslides

Two types of terrain along the Karwar coast were affected by landslides during the first week of October, 2009. In the Kadwad village the landslide consisted of massive movement of soil and mud with partially formed soft laterite (Refer figures in section 2). This laterite is different from the laterite formed from the basalt rocks of Deccan trap. The latter is considered a later formation after the cessation of Deccan volcanism in the Early Tertiary period. According the Geological Survey of India (2006) the majority of the rock sequences of Karnataka are lateritised due to their exposure to suitable climatic conditions for a prolonged period. These laterites occur as extensive cappings in the Western Ghats and in coastal plains. Their thickness ranges from a few cm to as much as 60 m. Based on their elevation level, two types are identified, one at +600 m elevation confined to Western Ghats and the other fringing the coastal lines along the west. The latter type is gravelly to sandy in texture and appears to be transported, whereas those confined to Ghats are homogenous and less sandy. In the Uttara Kannada district the generalised laterite profile displays reddish brown lateritic soil on top underlain by hard, concretionary and pisolitic laterite, underlain by 0-3 m thick aluminous laterite and 0-4 m thick bauxite zone. Kumta, Honavar and Bhatkal laterites are good examples.

Laterites and laterite genesis are highly complex issues (Ollier and Sheth, 2008). There are conflicting theories on laterite formation and it is not in the purview of this report to dwell on those. The Zariwada hill surface has a thin interrupted mantle of highly weathered laterite blocks (Figure 4.1). On the contrary such hard, mature, eroded and honey-combed laterite structure does not exist in the interior of the hill, which is a mass of soil, deep-yellowish red to dark red or reddish brown clayey loam type. Soft laterite, is seen in the interior as shown in the Figures 4.2-4.3. The reason for immaturity of laterite could be the lack of erosion and weathering. There is excessive wetting during the monsoons but probably not followed by dryness because of the fact the Zariwada hill is within the backwater zone of Kali River, and probably in a palaeo river valley, as reported to in *Geo Karnataka.* The name Zariwada itself suggests a low lying valley, characterized by seepage of ground water. Water table is very high in the village and even during summer months well water level is within few meters. Immaturity of the laterite could be precisely due to this factor, as the clay fraction is not washed out of it nor the buried prototype subjected to drying effect of the prolonged post-monsoon period. This situation is quite contrary to the laterite of southern taluks like Kumta, Honavar or Bhatkal where the rain washed laterite, is exposed to months of dryness. On exposure, with the leaching away of clay and soil and soluble fractions of minerals the laterite presents typical honey comb appearance and vermiform tubules.

The landslide chances of lateritic hills of southern coast (Kumta to Bhatkal) are slim because of the hardness of the exposed surface. A road cutting in Kumta taluk shows such hardened surface with least chances of landslide (figures 4.4-4.5)unlike the granite-soil complex of Karwar hills along the NH-17 where several slides have happened. Note that the picture of road cutting is in contrast to the collapsed hillside of same NH-17 in the Arga hill of Karwar (Figure 4.6).

Granite and other related rocks derived from Peninsular gneisses are the predominant rock types in Karwar, and could be seen all along the coastal hills.

Fig 4.1: Highly weathered laterite on top of Zariwada hill, Kadwad

Fig: 4.2. Partially formed soft laterite in Zariwada landslide at Kadwad (lack of erosion due to water logging may be the cause of this formation)

Fig: 4.3. Imperfectly evolved soft laterite in the Zariwada landslide at Kadwad

Fig: 4.4. A stable road cutting on NH-17 in Kumta showing hardened lateritic surface


Fig: 4.5. Hardened lateritic surface of road cutting in Kumta – close view


Fig 4.6: NH-17 landslide at Arga hill- unconsolidated mass of soil and granite rocks

Increase in soil erosion

In the recent years Karwar coast has experienced severe soil erosion due to more of anthropogenic factors. During 1989-2000 period (11 years) the erosion of land was estimated to be 174.4 hectares, whereas during 2000-2003 (just three years) the erosion of land increased by almost one and half times. This sudden rise in erosion may be due to the enhanced human interference along the coast owing to urbanisation, harbour development, naval base establishment, desiltation in the bays, estuaries and creeks; effects of dams constructed along Kali river, sand mining from beach ridge-dune system and river beds (Hanamgond and Mitra, 2007).

Lineaments: Karwar

Lineament studies have become an important step in analyzing the structural and tectonic aspects of an area. A lineament is a regional scale linear or curvilinear feature, pattern or change in pattern that can be identified in a data set and attributed to a geologic formation or structure. Lineaments may represent fractures, faults, joint sets, shear zones etc. Karnataka State has thousands of lineaments of varying length of which 69 lineaments are over 100 km long. In general, it is believed that these lineaments might have formed due to tectonic activities, plate movement etc. some of the major lineaments correspond to faults. Lineament zones often yield valuable minerals, oil etc. Lineaments representing fractures and faults are in general classified as high ground-water potential zones. Generally, it is believed that seismicity is also associated with major lineaments (Raj, 1994).

Using remote sensing data Hanamgond and Mitra (2007) identified 131 lineaments in coastal Karwar. The presence of highly folded granitic gneiss The intensive igneous activity by way of dyke intrusions, presence of ptygmatic, criss-cross pegmatite intrusions and highly folded granitic gneiss (all forming lineaments) are evidences of high shear along this stretch. Based on the lineaments study and the known tectonic trends identified by earlier workers on regional scale, it has been opined that the Karwar coast is structurally controlled and the tectonic processes control the lineament pattern (Nayak, 1993; Hanamgond and Mitra, 2003;).

SECTION 5:
Rainfall: Triggering Factor for Slope Failures

Worldwide statistics shows that 89.2% of landslide deaths were due to slope failures triggered by intense and prolonged precipitation. The rest were due to construction leading to undercutting of slopes, mining and quarrying, earthquakes etc. Rainfall of course is mainly the final factor to act upon slopes destined to fail, the causes for which are physico-chemical properties of the rock mass, topography relief, slope, aspect, geological structure, land use land cover, vegetation cover, anthropogenic causes etc. Peak occurrence of landslides in South Asia in July suggests their strong linkages with Asian monsoon (*South Asian Disaster Report*, 2007). The Himalayas are the worst affected by landslides in the country, followed by the North-Eastern States and the Western Ghats.

Rainfall triggered most of the major landslides that occurred in India during 2009 (up to early November) as the Table 5.1 based on details provided by Geological Survey of India shows. It may not be single slope failure in each locality shown. Associated with heavy rainfall, often, a series of landslides have taken place. Most landslides are in the Himalayas; the Uttarakhand region leading in rainfall triggered slope failures. The latest to happen after the Kadwad village tragedy in Karwar is that in Ooty region of Nilgiris during early November, 2009, which claimed 43 human lives. Widespread destruction of houses, crops and other property, disruption of road and rail traffic and communication systems compound to the miseries caused by floods in the same regions. In the higher altitudes of Himalayas heavy snowfall also causes landslides as in Jammu and Kashmir and Himachal Pradesh.

Rain threshold

Heavy rains in one or few days or incessantly happening for several days cause saturation of overburden on hill slopes, increase in pore pressure in overburden, and in underlying weathered rocks triggers landslides. Often multiple landslides happen in the same region due to reduction in the shear strength of material. Amount of daily precipitation as well as cumulative antecedent rainfall are important in causing slope failures. It is difficult to say exactly what amount of rainfall causes landslides. It could be locality specific, linked to the degree of slope and other geo-morphological and geological factors as well as anthropogenic causes. Analyzing rainfall history Dahal and Hasegawa (2008) found that in the Himalayan mountain slopes, when the daily precipitation exceeds 144 mm the risk of landslides is high. Cumulative rainfall antecedent to slope failure is also important factor. Prolonged or intense rainfall or a combination of both and the resultant pore pressure developed result in landslides in the Western Ghats of Kerala. Majority of landslides happened on steep slopes of >20 degrees (Kuriakose et al. 2008).

Table 5.1: Notable landslide occurrences in India during July to early November, 2009, (as reported by the Geological Survey of India, Government of India).

Localities	State	Month	Human deaths	Major cause
Syara village, Pithoragarh dt	Uttarakhand	July	3	Heavy rains
Jumma	-do-	-do-	3	-do-
Chamoli dt	-do-	-do-	2	-do-
Pittoragarh dt., Champavat	-do-	August	--	-do-
Champavat	-do-	-do-	1	--
Pithoragarh dt	-do-	-do-	46 (3 villages washed away)	-do-
-do-	-do-	-do-	1	Construction site
Almora dt	-do-	September	3	Heavy rains
Badrinath NH	-do-	-do-	--	-do-
Kedarnath Road & Rishikesh	-do-	-do-	--	--
Uttarakhand	-do-	-do-	3	--
-do-	-do-	October	--	--
Lahul & Spiti	H. Pradesh	August	--	--
Mandi-Dharampur Highway	-do-	-do-	2	--
Brahmor-Dharnmashala Road	-do-	-do-	1	Heavy rains
Spiti valley	-do-	September	--	Heavy snowfall
Bilaspur-Mandi	-do-	-do-	1	Heavy rains
Kyongsala	Sikkim	August	1	-do-
Sanbaria & Daramdin	-do-	-do-	2	-do-
Darjeeling hills	W. Bengal	-do-	3	-do-
Darjeeling & Kalimpong	-do-	-do-	7	-do-
Vaishnodevi shrine route	Jammu & Kashmir	July	5	--
Balipura-Tawang Road	Arunachal Pradesh	-do-	--	-do-
Assam highway	Meghalaya	August	--	Heavy rains
Lumding-Badarpur	Assam	-do-	--	-do-
Assam highway	Meghalaya	-do-	--	-do-
Andheri, Mumbai	Maharashtra	September	13	-do-
Canacona	Goa	October	--	-do-
Kadwad, Karwar	Karnataka	-do-	19	-do-
Ujjire	Karnataka	-do-	1	--
Mantada, Nilgiris	Tamil Nadu	November	5	Heavy rains
Ooty, Nilgiris	-do-	-do-	39	-do-
Kozhikode	Kerala	October	--	-do-

Note: Table based on data from GSI: http://www.portal.gsi.gov.in.postdis.htm

Rainfall factor in Karwar

Annual rainfall in coastal and malnad Uttara Kannada, is mostly in excess of 3000 mm. Most of the rainfall is received during the peak monsoon period of June to September. There has been very heavy rainfall in the coastal regions of Karnataka during 2009, and that too extending into early October. Heavy rainfall in the Western Ghats region contributed substantially towards the floods, particularly in northern Karnataka. Incessant rains started pounding Karwar from 29th September and continued up to 3rd of October, creating serious flooding problems. Rainfall of nearly 800 mm was received during these five days (118 mm recorded on 30th September, 40 mm on 1st October, 179 mm on 2nd October and 423 mm on 3rd October), when water started rising everywhere in Karwar city and neighboring villages. The compound wall of the naval base INS Kadamba that was blocking the storm waters rushing down the hills collapsed in many places and was reported to be demolished at one spot by the youth of the flooded Binaga village to facilitate seaward drainage. The cumulative antecedent rainfall for the year on October 2nd morning had already reached 3370 mm and the addition of yet another heavy fall exceeding 400 mm on that day triggered of massive landslides not only in Kadwad village but also in Arga, Binaga, Baithkol and on the port road.

According to a report in *Geo Karnataka* (October 19, 2009), at around 4.15 pm the eastern scarp flank of Zariwada hamlet in Kadwad village "suddenly gave up and ruptured with a thud sound. The massive quantity of loose clayey material abruptly rolled down the gradient and settled on the 9 houses burying the 19 inmates alive. The whole process ended by 4.30 pm."

"On 3-10-2009, early morning around 3.30 am, another clayey hill on the western side of Zariwada also collapsed blocking the road leading to Kadwada. However there were no human casualties since the houses were located at a distance from the affected hills. It is reported that similar landslides had occurred in the Kadwada area, during the year 1959." The rainfall data collected from Dy. Commissioner's office, Uttar Kannada Dist., Karwar for 1st September 2009 to 13th October 2009, as recorded at Karwar rain gauge station is given in Table 5.2. The analysis of antecedent and precedent rainfall pattern indicate an unprecedented rise in the quantum of rainfall from 30th September 2009 to 4th October 2009. As per the information from the local authorities, all the landslides occurred on 2nd October 2009 even though the maximum daily rainfall received was on 3rd Oct 2009 which is nearly 2.5 times more than the rainfall received on previous day. The immediate trigger for all the slides is observed to be the high rainfall.

Heavy rainfall: a matter of grave concern

In the Himalayas, as mentioned earlier, Dahal and Hasegawa (2008) associated heavy daily rainfall of >144 mm as a threshold for risk of landslides. We do not have such threshold rainfall studies linked to landslides in Western Ghats, particularly so in Karnataka. Spells of heavy rainfall lasting for several days together happen almost every year in Karwar, especially in the months June and July and occasionally in August. Daily rainfall data for Karwar for the past 16 years (including 2009) shows that the city had rainfall in excess 0f 3000 mm during 12 years (Figure 5.1). The current year already received 3840 mm by October 31. The annual rainfall exceeded 3500 mm in 1998, 1999, 2000, 2006, 2007 and 2009. What cannot escape our attention is that daily rainfall exceeded 140 mm on 37 times during these 16 years. Maximum was in the current year when it happened five times during June-October 2009 period (3^{rd} October recording 423 mm). In 1999 there was a similar spell with four records of >140 mm, including 469 mm on 12^{th} June. But fortunately there were no landslides or human deaths.

Table 5.2: Rainfall during Sept-Oct 2009

Date	**Rainfall (in mm)**	**Date**	**Rainfall (in mm)**	**Date**	**Rainfall (in mm)**
1-Sep-09	19.9	16-Sep-09	4.7	1-Oct-09	39.5
2-Sep-09	57.9	17-Sep-09	0	2-Oct-09	179.6
3-Sep-09	30	18-Sep-09	0	3-Oct-09	423.6
4-Sep-09	38.4	19-Sep-09	8.2	4-Oct-09	34.9
5-Sep-09	64	20-Sep-09	0	5-Oct-09	1
6-Sep-09	49.6	21-Sep-09	4.4	6-Oct-09	10.4
7-Sep-09	26.4	22-Sep-09	0	7-Oct-09	0
8-Sep-09	8.8	23-Sep-09	0	8-Oct-09	0
9-Sep-09	1	24-Sep-09	2.5	9-Oct-09	0
10-Sep-09	17.3	25-Sep-09	0.7	10-Oct-09	0
11-Sep-09	2.4	26-Sep-09	4.4	11-Oct-09	0
12-Sep-09	41.8	27-Sep-09	0.6	12-Oct-09	0
13-Sep-09	0	28-Sep-09	0	13-Oct-09	0
14-Sep-09	0	29-Sep-09	6		
15-Sep-09	10.7	30-Sep-09	118.2		

A look at rainfall data for the months June to November for the last 51 years (Figures 5.2-5.8) reveals that 18 times during these years, monthly rainfall had exceeded 1200 mm. Rainfall for July 1991 was 1436 mm, and for July 1999 it was 1421 mm. The fact that a monthly total of 690 mm rainfall for October 2009 created such havoc in the city and many other coastal villages raises a grave issue for immediate concern and precautionary action plans. **Karwar taluk, in all probability, has transgressed its limits of growth, beyond the carrying capacity**. The landslides and floods are warning signals of nature about the fragility of the region. Considering the high density of coastal population, the hilly nature of terrain and the fast pace of development, Karwar's future will be at stake if timely steps are not taken to plan for future more meticulously and avert the recurrence of such calamities. Already as the headquarters of Uttara Kannada district, hosting India's largest naval base, a nuclear power plant in Kaiga, a large port and a fisheries port, Karwar is brimming with population. Human settlements have come up everywhere, including in reclaimed backwater swamps of Kali, as well as dangerously close to fragile and geologically unstable hills. Kadwad village, the seat of two major landslides and 19 deaths, at the time of 2001 Census had 961 households and 4408 people.

Why the landslides have not happened in the past and why should they all happen in early October this year? There is no single answer for this. Geologists consider Karwar as situated on a seismic zone. The vibrations due to blasting in the granite quarries of coastal hills and the passage of trains of the Konkan Railway through the fault lines and lineaments are believed to have contributed to the instability of the region. According to them the occurrence of minor seismic activity on October 2nd could not be ruled out. At the same time we have no seismographic records available for the fateful day; nor did people of Karwar experience any tremor.

But one major causal factor for landslide that could be asserted with certainty is the abundance of global data, linking heavy and incessant rainfalls triggering off landslides. More of such landslides happen on deforested hill slopes that lose the shear strength as root entanglements stabilizing soil and rocks deteriorate in some years following tree cutting. Forest degradation is rampant in the coastal hills due to the pressures from rising population. The tree density and basal area, the vital indicators of the health of the hills and their ability to be immune from slope failures during spells of incessant rains, are far below standards for coastal hills of Karwar affected by landslides. The granitic base rocks, predominant in the hills, (granites which is fractured with joints)**,** do not form a conglomerate with the soil matrix, unlike the laterites of the southern coast of Uttara Kannda. Despite the fact scores of these laterite covered southern hills are quarried for building stones, or their bases dug for roads, habitations and fields, landslides hardly happen here. Soils covering the lateritic hills, or the lateritic soils, harden on exposure to the hot sun, their clay part washed out in heavy rains from cut surface leaving behind vermiform tubules on an iron rich surface. Such stability is lacking for the Karwar hills with granite type rocks, which remain separate from the soil. During incessant rains, when great quantities of water seep into the hill soils, especially through stone and soil quarries, and hollows created by deterioration of root systems of cut trees the pore pressure increases and steep slopes especially lose their shear strength resulting in slope failures causing debris flows. Cutting the toes of hills for roads, housing and extension of holdings, widely being carried out all over Karwar, create weak points susceptible to debris flows. A look into the vegetational history of the coastal hills reveals that these belonged to what is administratively referred to as ‘minor forests’ set aside for meeting the biomass needs of the local population. Yet the vegetation was sufficient to maintain the integrity of hills by binding rocks and soils together, even during the peak rainy months subjected to incessant torrential rains that last through days. Sudden upsets in the traditional harmony of nature and humans got strained due to various factors. The establishment in 1980’s of INS Kadamba, the largest naval base of India, covering substantially the coastline of Karwar-Ankola, resulted in the evacuation of people from hundreds of houses, who had no place to move out but live in resettlement colonies or independent dwellings at the foot of hills, or in reclaimed backwaters which otherwise would have been washing the bases of the hills of Western Ghats that extend seaward, particularly in Karwar. The Kaiga atomic power plant also increased substantially pressure on Karwar, especially for housing. It was during this period of human settlement at Baithkol hill base, on the southern side of Kali River mouth, proliferated causing severe degradation of the hills, including tree cutting and cutting the hill base for housing sites.

Removal of natural tree cover, however poor it was, from Kadwad hills, for raising cashew plantation, is to be considered unsuitable for local ecology. The hills are of very fragile nature, composed of soil, and soft laterite. Moored in the backwaters of Kali River the bases of these hills have water logging through most of the year. Water table is quite high in Kadwad, as evident from the local hills. The Zariwada hamlet is so named because of rich underground springs at the base of the hill. It takes some years for the root systems, that stabilized the substratum to disintegrate in the deforested hills. Such disintegrated spots become vulnerable to seepage of water into the hills during rains.

Reviewing landslide susceptibility of Kerala Western Ghats, Kuriakose et al. (2008) conclude that initiation zone of most of the landslides was typical hollows generally having degraded natural vegetation. Here too the imminent cause is prolonged and intense rainfall and the resultant pore pressure variations. Despite the heavy rainfall in the highlands of Kerala, the past had reduced rates of slope instability. Landslides were activated due to anthropogenic activity, such as deforestation since early 18th century, terracing and obstruction of ephemeral streams, and cultivation of crops lacking capability to add root cohesion in steep slopes. According to a report in *Geo Karnataka* (October 19, 2009), Zariwada as the name suggests is a low-lying valley region characterized by seepage of ground water. Geomorphologically, the valley area can be recognized as a old stream (paleo-river) channel that formerly drained into the Kali River that flows in the north of Zariwada. The paleo-river channel is still connected to the Kali River and the groundwater seepage into the channel increases or decreases rhythmically according to high and low tides in the River. Zariwada colony of houses was located beside a huge clayey-laterite hill. The hill consists largely of reddish clays and was topped by thin cap of laterite. Granitic material underlies the clayey hill as can be seen in some cuttings. The clayey material from the hill was in demand for using as filler material in construction sites. That Zariwada is situated on a paleo-river channel is probable because the two hills and the lowlands that constitute Kadwad village itself, in satellite imagery, appear so. The village is in the course of streams draining the high hills of Western Ghats that slope towards Kali estuary. As such the hills are to be considered deposits of soils brought down from the Western Ghats by erosion, trapped and grown into the present form through millennia, between the tides of estuary and water-flow in the archaic streams, and stabilized by the growth of vegetation, mangroves at the base, and presumably, the tropical evergreen forests higher up, which have vanished today without a trace due to anthropogenic pressures. It is water-logging that has caused the looseness of soil and immaturity of laterite embedded in the interior of the hills. Such hills are very fragile, a fact demonstrated by torrential rains that pound the region seasonally, when human actions are not in agreement with basic geology and vegetation.

Figure 5.1: Daily rainfall analysis (1984-2009)

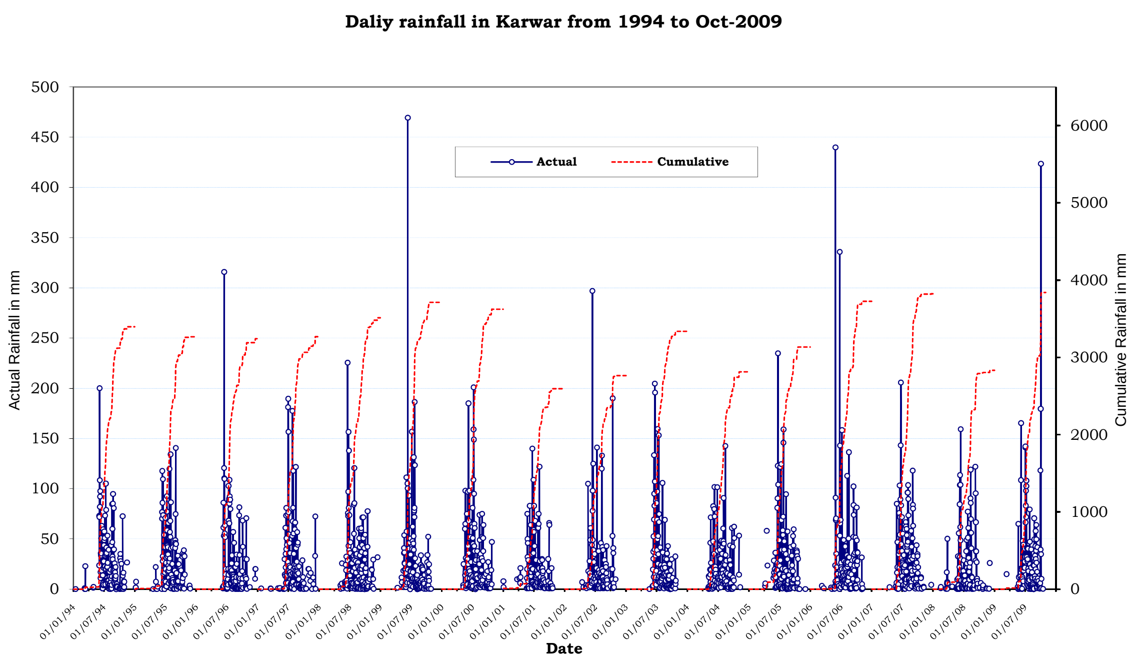


Figure 5.2: Rainfall variability during 1959 to 2009 in June

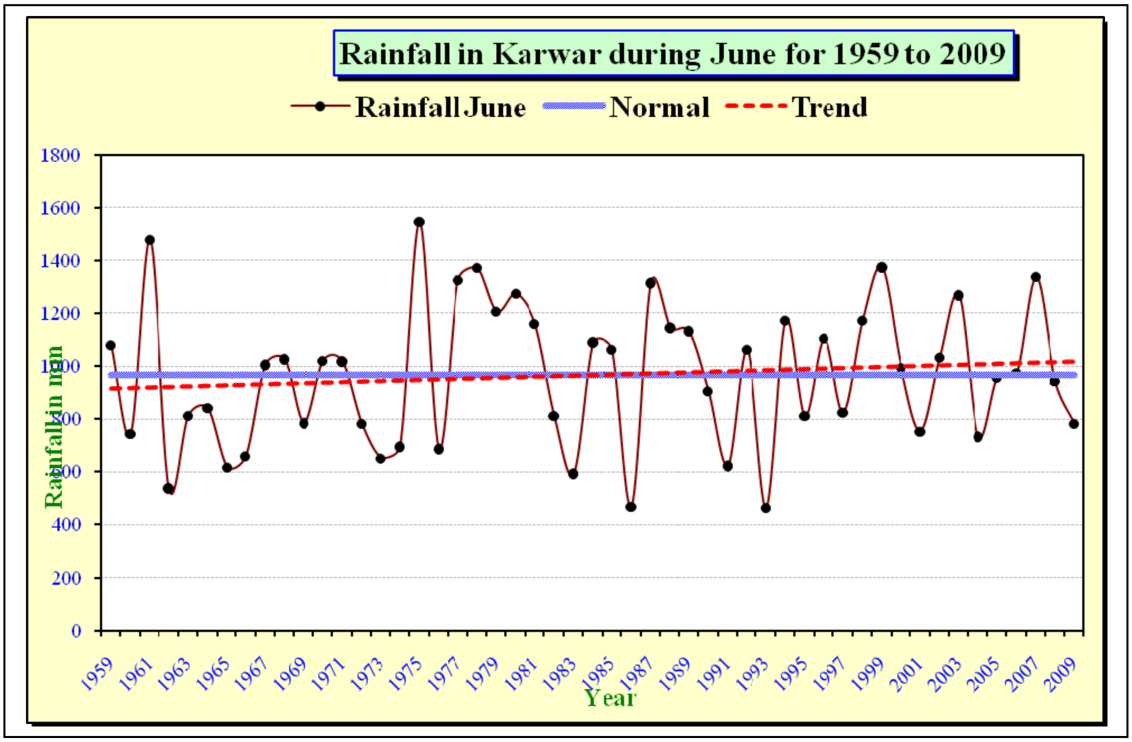


Figure 5.3: Rainfall variability during 1959 to 2009 in July

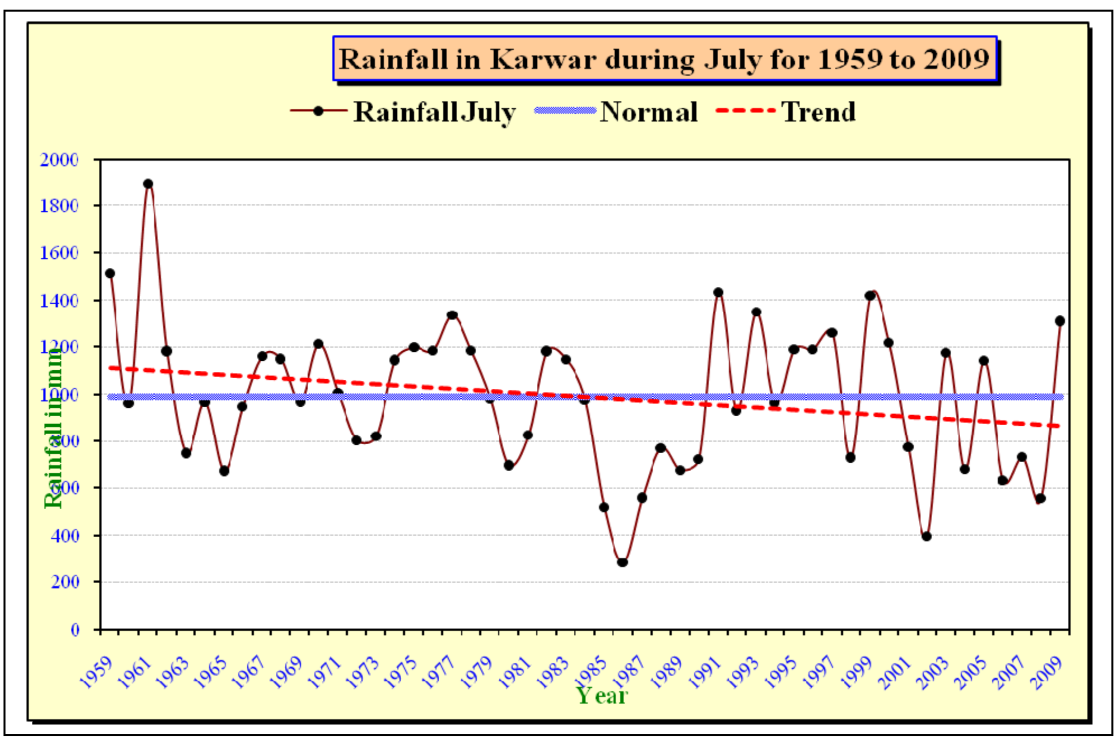


Figure 5.4: Rainfall variability during 1959 to 2009 in August

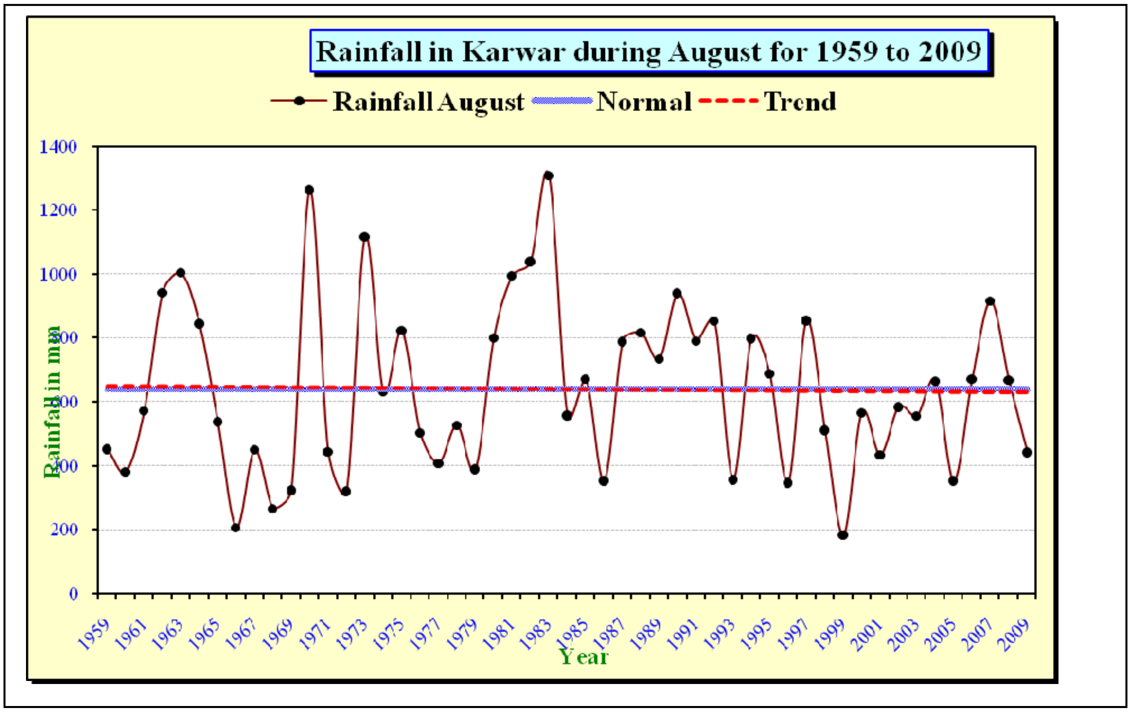


Figure 5.5: Rainfall variability during 1959 to 2009 in September

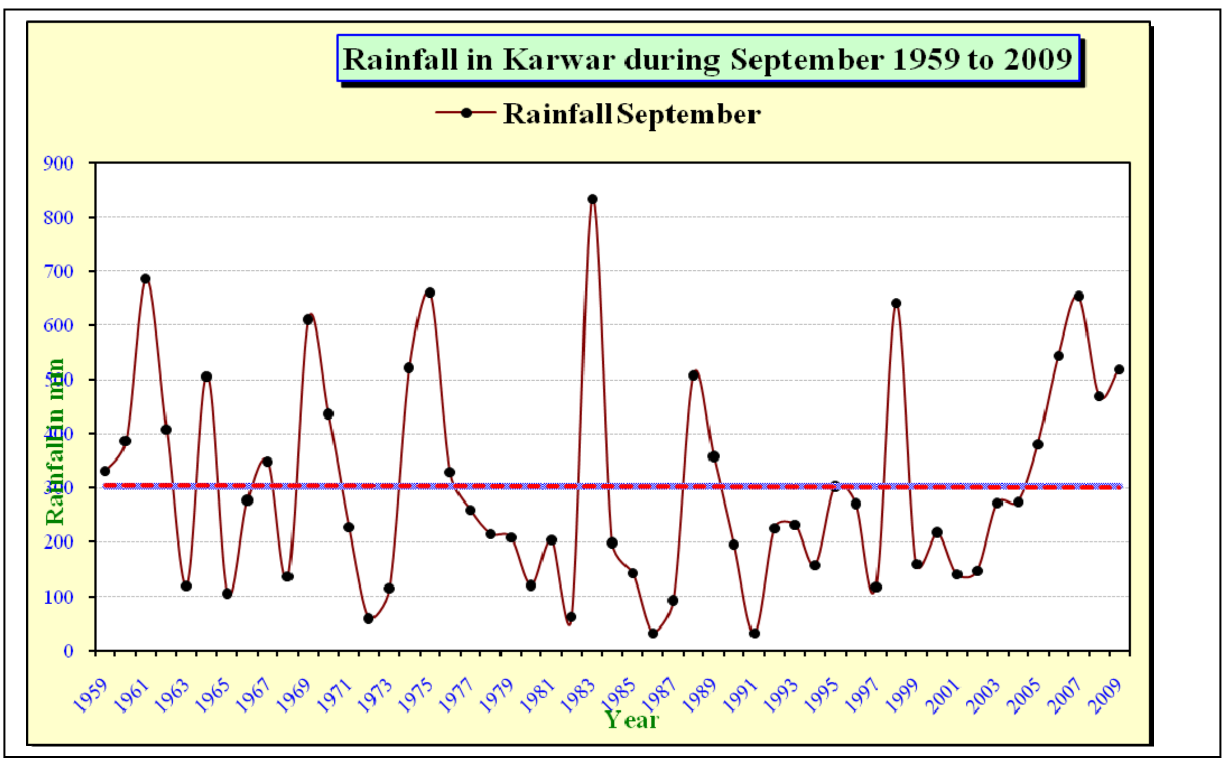


Figure 5.6: Rainfall variability during 1959 to 2009 in October

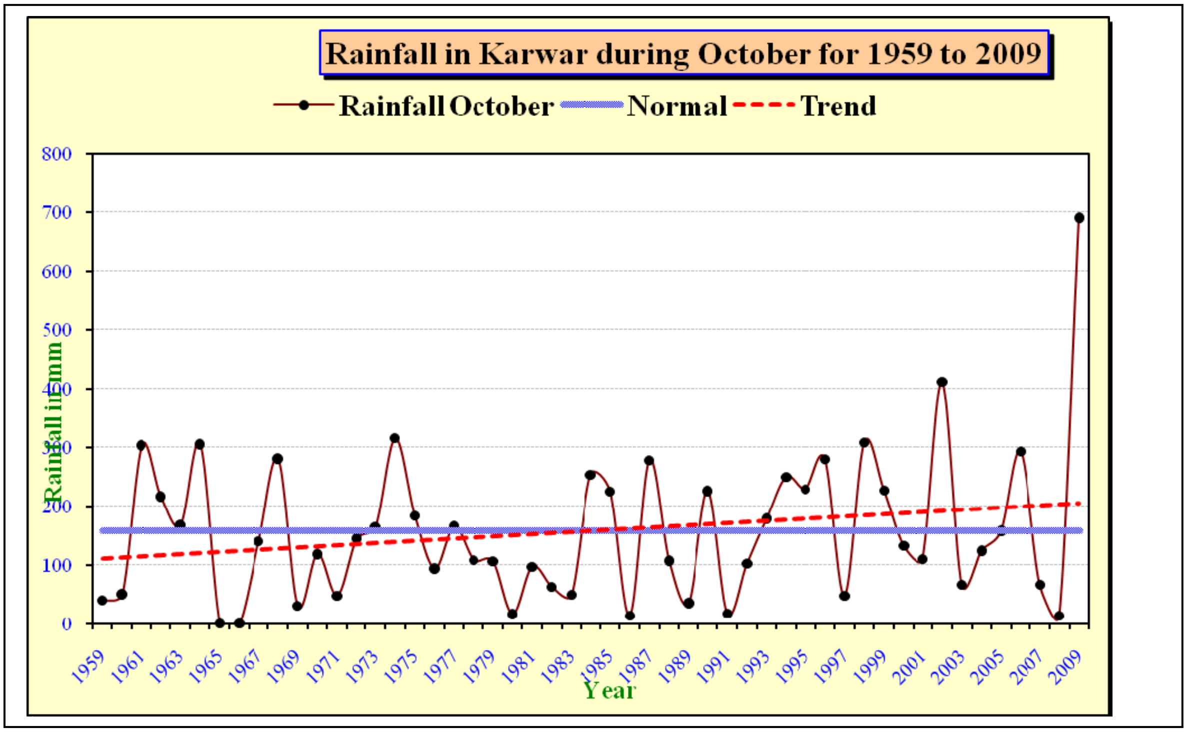
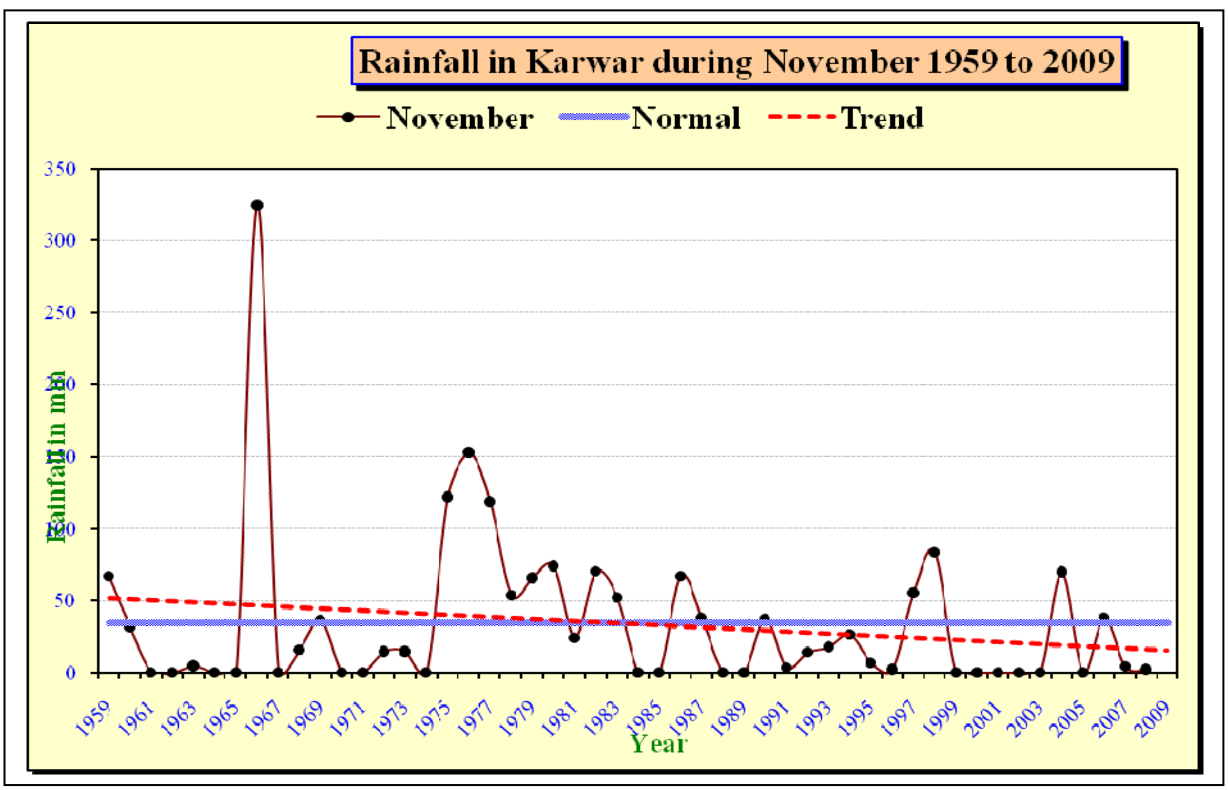


Figure 5.7: Rainfall variability during 1959 to 2009 in November



SECTION 6
PREVENTION AND MANAGEMENT OF LANDSLIDES

Experiences in Japan, Hongkong, and USA, has shown that proper management of slopes on sound scientific principles can lead to mitigation of landslide hazard to a large extent

Drainage correction: The most important triggering mechanism for landslides is the water infiltration during heavy rains and consequent increase in pore pressure within the overburden. Poor drainage density in heavy rainfall areas has been correlated to higher landslide incidence. This is due to less surface runoff, which results in high infiltration and increased pore-water pressure (Kumar, 2005). The author has identified more than 250 cm of annual average precipitation in the Western Ghats of central Kerala as a triggering factor for landslides in the region. Hence the natural way of preventing this situation is by reducing infiltration and allowing excess water to move down without hindrance. As such, the first and foremost mitigation measure is drainage correction. This involves maintenance of natural drainage channels both micro and macro in vulnerable slopes. Drainage channels should be identified in all vulnerable areas, properly widened if necessary and pavements built wherever strengthening is required.

Regulations on building constructions: In all identified, potential hazard zones no fresh permission should be granted for construction of new buildings, at least until such time when foolproof safety measures are implemented.

Engineering solutions: Remedial techniques such as buttresses, shear keys, well designed surface and sub-surface drains, soil reinforcement, retaining structures along the toe of the hills, etc. to be adopted in existing and potential landslide areas.

Landslide hazard zonation maps: LHZ mapping, at 1:50,000 scale, has been carried out for parts of Western Ghats. A micro-level geological and landslide zonation mapping at 1:1000 scale is necessary for all potential hazard zones. The methodology has been already evolved through participation of various scientific-technical institutions by the Department of Science and Technology, Government of India, under the Natural Resources Data management System. Karwar taluk hills with habitations and roads needs to be delineated into high hazard, moderate hazard and landslide free zones.

Study needs: More attention needs to be paid to some critical aspects of landslide studies. These studies with micro-level focus on **geotechnical aspects** and **soil mechanics** need to be specially be carried out for all apparently vulnerable areas of Karwar taluk. Slope stability analysis needs to be carried out for all hillside human habitations of the taluk. In co-ordination with **landuse zonation maps** and **carrying**

capacity studies it would be possible to better planning for the taluk to prevent and mitigate landslide hazards. Various terrain parameters to be studied for landslide risk evaluation, estimation, assessment and management using geoinformatics.

Restoration of vegetation cover: Post disaster studies on bio-restoration have been proposed by the Geological Survey of India for overburden slopes (http:www.gsi.gov.in/landslide/postdis.htm). All the landslide areas, although they appear to be covered with a mantle of vegetation, have extremely poor tree cover. The hills of Kadwad are almost bereft of any notable trees except for poorly grown cashew. A replanting programme should be undertaken, preferably using also the soil spread area after the landslide. Soil removal from the landslides of Kadwad has to be minimal, so as to provide a healthy and raised surface for afforestation. Only very site specific and erosion and water logging resistant trees should be used for afforestation of the lower parts of Zariwada landslides. These could be mangrove species for the soil spread close to the brackish water swamps. Mangroves are very tolerant of water logging and salinity. Their efficient root systems will protect any further rush of loose soils into the Kali River estuary.

At next higher level may be planted in alternative rows mangrove associates. Some of these associates like *Pongamia pinnata* (Hongay), and *Ficus racemosa* (Atthi) are tolerant of water logging as well as desiccation. Their efficient root systems enable them to grow close to water courses and can tolerate periodical rise in water levels and strong currents. These trees would provide excellent binding for loose soils and can be planted at any height in the denuded hills. *Calophyllum inophyllum*, is also an excellent tree for planting at the lower slope of the hill. As it is a large and heavy tree when full grown, it should not be used for upper slopes and hill tops. It cannot also stand the dryness of the hill top during summer months. Planting of all large sized tree species in the upper slopes and summit should be avoided so as to minimize the weight on the hill to avoid any gravity triggered landslide in future. Under proper management and absolute protection in about ten years time the hill could covered with reasonably good vegetation, specially designed for landslide prevention. The Baithkol hill also should be brought under proper vegetational cover almost on the same lines as Kadwad hills.

The hills bordering the NH-17 are presently under poor cover of trees. Most plants there are shallow rooted shrubs, climbers and bamboos. These surface rooted plants cannot stabilize the hill slopes efficiently. There should be minimum of 400 hundred trees/hectare on these hills, whereas at present hardly 50 trees/ha are found here. The basal area/ha is much less than 10 sq.m, whereas what is ideal would be over 25 sq.m/ha. It is notable that landslides have taken place only in those hills bordering the NH-17. It should be therefore borne in mind that the landslides are the result of general deforestation and unscientific slope cutting for the sake of road. The interior hills, though under biomass extraction pressure from coastal people, still have adequate tree numbers and biomass to stabilize their slopes. A choice of native leguminous trees and pioneer evergreens could be considered for revegetation. Revegetation has to be carried out with site specific plans and not by any centralized designs.

Regulation of human activities in sensitive and buffer zones: Many studies point out human activity in unfavourable slopes is the real causative factor triggering landslides. Buffer zone areas are to be identified between steep hill slopes and human settlements at the toe of the slopes. Awareness programmes on landslides may be conducted for the inhabitants here especially highlighting the aspects of care that they need to take of the buffer zone, such as: participation in vegetational development; desist from toe cutting for expansion of holdings; hazards of soil removal from sensitive slopes. The District Administration should not permit soil or stone quarrying from sensitive slopes and buffer zones. Any new developmental projects involving physical structures have to be avoided in such areas.

Recommendations: Based on the field visit on 14th Oct 2009 and subsequent land use analysis, We suggest the following to mitigate landslides in the region.

1. **Planting of native vegetation on hilltops and slopes**. The roots of the native vegetation aid as a good soil binding and provide slope stability. The removal of trees (with deep tap roots) and subsequent taking over of secondary vegetation with fibrous or shallow roots has reduced the soil binding properties.
2. **Restoration of natural drainage network.** Alteration in hydrological regime due to changes in drainage network consequent to deforestation - Inappropriate locations of human habitations on the first and second order streams in Kadwad has also hindered the water movement and water has removed all the blockages – evident from collapse of houses (in Zariwada)
3. **Discouraging monoculture plantations–** the land given to cashew plantation should be taken back and the afforestation has to be carried out with the native species of flora
4. **Banning Illegal soil mining on the hills** (especially in places like Zariwada).
5. **Improving drainage connectivity**. The collective rainfall of many days has enhanced the pore water pressure. This with lateral pressure due to swelling of oversaturated clay rich horizon has enhanced the driving force resulting in displacement and collapse of human habitations resulting in trapping of humans and loss of properties (at Zariwada, Kadwad).

6. **Need to investigate the suitability of human habitations in regions prone to landslides.**
   (i) The Konkan Railway track connecting Karwar town with Goa and other places passes through this Zariwada paleo-river valley and also crosses the lineaments. The vibration generated by movement of trains has devepeloped the cracks on hill tops and also has resulted in the loosening of the soil (subsequent to soil mining). Long spell of high intensity antecedent rainfall has triggered the mud slide.
   (ii) Geomorphologically, the valley area was a paleo-river channel that formerly drained into the Kali River that flows in the north of Zariwada/Kadwad. The shift of the river course might have led to the formation of hills/mounds. Composition of this mound which is mainly of laterite clay further confirms the existence of paleo stream in this region. The paleo-river channel is still connected to the Kali River and the groundwater seepage into the channel increases or decreases rhythmically according to high and low tides in the River.
   (iii) Soil formation for centuries on the hillocks and heavy rain might have led to the swelling of clay inside the hillocks resulting in the landslips.
7. **Immediate banning of large scale illegal quarrying of granite stones, soil mineral mining** considering the hazards proneness of the region (Karwar) and presence of sensitive pockets (Naval base, Kaiga nuclear plant, eco sensitive Anshi-Dandeli tiger reserve). Weathered granites on the hills and weakening of soil due to excessive rains have triggered the landslides near Binaga, National Highway.
8. **No large scale developmental projects in Uttara Kannada district that are likely to harm the ecology and biodiversity of the Western Ghats.** Considering the implementation of large number of mega projects in Karwar, it appears that the region has exceeded the carrying capacity and further implementation of any mega projects would prove detrimental to the local population. The region has already prone to hazards and could be categorized as hazard hotspot. This also emphasizes the need for carrying capacity study for Uttara Kannada district.
9. **Considering the hazard proneness of the region it is necessary to set up 'Disaster management centre (DMC)'** to assist in regional planning, management of disasters and also to assist the administration in rehabilitation measures in case of eventualities. Also, the region around 25 km radius of Karwar is seismically sensitive and also constitution of lineaments further emphasizes the need for setting up a **seismic monitoring cell (within DMC)** in the district to assist the district administration in the predication and also mitigate measures. Disaster management centre shall house seismic monitoring cell, and shall have

the state of the art gadgets to predict calamities due to natural as well as human induced.

10. **Naval authorities should be asked to remodel the protection wall** considering the natural drainages on priority. Construction of the protective wall by the naval authorities without any due consideration to natural drainage systems has resulted in large scale flooding of the region, which also has triggered series of landslides all along the Highway (NH 17). Removal of the protection walls at many locations during the floods, highlights the need for holistic approaches in planning and implementation of large scale projects. Many such projects have seriously impaired the ecology of the region, affected the livelihood of nature people and also have posed serious threats to the existence of local population.
11. **Shifting of all affected families** (located on the hill side) to appropriate locations without affecting their current livelihood dependence.
12. **Afforestation with native vegetation** in the region considering the large scale deforestation in recent times. At present many hill tops are barren. The hanging crown part of the current landslides need to be graded on priority, as cracks were observed at the crown apart from subsidence.
13. **Setting up special Uttara Kannada package to restore ecosystems –** The funding shall be from all developmental projects in the district. **Karwar taluk, in all probability, has transgressed its limits of growth, beyond the carrying capacity** - Series of landslides consequent human tragedies and property loss is the indication of the lack of integrated approaches in planning and the region has crossed the thresholds of carrying capacity. Large scale land cover changes has resulted in alterations in hydrological regimes evident from the conversion of perennial streams to seasonal streams, enhanced siltation in the catchment evident from increased sedimentation in reservoirs in recent years. The region being one among the global biodiversity hotspots call for immediate measures to restore the ecosystems. Large scale projects such as hydro power plants, project sea bird, Kaiga nuclear plants have played significant role in degradation the ecosystems which have also affected the livelihood of local people. **These projects shall also make provision to provide a recurring grant to sustain the proposed Disaster Management Centre at Karwar and also for Ecological Research in Karnataka part of Western Ghats.**
14. Considering the level of devastations in Karwar, **landslide susceptibility mapping should be carried out to delineate potential zones of instability**, particularly in areas where human lives and properties are involved. If any indication of slope instability is noticed in an area which has major risk elements, the fact should be shared with society in a proper way. This suggestion has two major implications.

(i) First, with the increasing large scale environmentally unsound development activities in the region, the risk posed by natural hazard must also be evaluated. This is well-exemplified by a series of natural hazards (landslides) in the region. Considering rainfall-intensity and changes in climate / hydrologic regimes (due to global warming) stochastic relationships have to be developed to assess high-risk areas.

(ii) Secondly, with the successful establishment of relationship between rainfall and landslide activity, analysis of palaeo landslides would provide insights based on the past variation in rainfall patterns. Equally, such relationships aid in predicting changes in mass movement activities based on modelled regional impacts of global climate change.

15. Apart from forestation of barren hill slopes and hill tops, sealing of cracks, slope-grading, proper drainage measures, soil reinforcement using geo-grid and biotechnical measures have to be done. However, appropriate selection of these measures along with their design is only possible after an in-depth geological and geotechnical study of the slide area.

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BRIEF REPORT ON STUDIES OF LANDSLIDE AROUND KARWAR, UTTARA KANNADA DISTRICT.

ABSTRACT: Landslides usually occurs during the monsoon seasons along the hill slopes of Western Ghats. These are one of the natural disasters endangerous to life and property. The present study is aimed to know the cause of landslides. Field visit was conducted around the landslide areas. It revealed that the factors which caused the landslides are: slopes, landuse, lithology, structures, climate, geomorphology and soil. Field investigation was carried out during 13.10.2009 to 14.10.2009. During the course of investigation number of landslide occurred areas were examined.

INTRODUCTION: Landslides are simply defined as the mass movement of rock, debris or earth down a slope and have come to include a broad range of motions whereby falling sliding and flowing under the influence of gravity dislodges earth material. They often take place in conjunction with earthquakes, floods and volcanoes. The objective of the present study is identification of landslides areas around Karwar taluk of Uttara Kannada district.

STUDY AREAS:

1) The Kadwad (Zariwada) area lies between 75°05'35" to 75°10'45" East longitudes to 14°46'10" to 14°50'55" North latitudes falls in the survey of India toposheet No. 48 J/1 of 1:50,000 scale.
2) The Kadwad (Near Forest Naka) area lies between 74°10'47.6" East longitudes to 14°49'59.2" North latitudes falls in the Forest Sy.No.71 A_1A_1.
3) The Shirwad area lies between 74°09'22.7" East longitudes to 14°48'38.7" North latitudes falls in the Forest Sy.No.230.
4) The Mandralli area lies between 74°10'57.3" East longitudes to 14°50'50.2" North latitudes falls in the Forest Sy.No.269.
5) The Makeri area lies between 74°10'17.6" East longitudes to 14°49'21.8" North latitudes falls in the Forest Sy.No.47.
6) The Makeri area lies between 74°10'17.5" East longitudes to 14°49'15.5" North latitudes falls in the Forest Sy.No.47.
7) The Makeri area lies between 74°10'17.5" East longitudes to 14°49'15.3" North latitudes falls in the Forest Sy.No.47.
8) The Baad (Murlidhramath) area lies between 74°08'13.2" East longitudes to 14°48'25.1" North latitudes falls in the Forest Sy.No.47.
9) The Baad (NH 17) area lies between 74°07'22.4" East longitudes to 14°48'14.5" North latitudes.

10) The Binaga (NH 27) area lies between $74^o06'53.5"$ East longitudes to $14^o47'26.2"$ North latitudes falls in the Forest Sy.No.16A.
11) The Binaga (NH 17) area lies between $74^o06'59.0"$ East longitudes to $14^o47'27.9"$ North latitudes falls in the Forest Sy.No.16A.
12) The Binaga (NH 17) area lies between $74^o08'10.0"$ East longitudes to $14^o46'53.9"$ North latitudes falls in the Forest Sy.No.9A.
13) The Arga (NH 17) area lies between $74^o08'29.2"$ East longitudes to $14^o46'58.9"$ North latitudes falls in the Forest Sy.No.52A.
14) The Arga (NH 17) area lies between $74^o08'29.2"$ East longitudes to $14^o46'58.4"$ North latitudes falls in the Forest Sy.No.52A.
15) The Arga (NH 17) area lies between $74^o08'43.1"$ East longitudes to $14^o46'53.4"$ North latitudes falls in the Forest Sy.No.52A.
16) The Arga (NH 17) area lies between $74^o08'47.3"$ East longitudes to $14^o46'51.2"$ North latitudes falls in the Forest Sy.No.52A.
17) The Baithkhol (Near Port) area lies between $74^o06'49.7"$ East longitudes to $14^o48'13.3"$ North latitudes falls in the Forest Sy.No.16.
18) The Baithkhol (Near Port) area lies between $74^o06'49.3"$ East longitudes to $14^o48'16.1"$ North latitudes falls in the Forest Sy.No.16.
19) The Baithkhol (Near Port) area lies between $74^o06'47.9"$ East longitudes to $14^o48'16.5"$ North latitudes falls in the Forest Sy.No.16.
20) The Baithkhol (Near Port) area lies between $74^o06'50.8"$ East longitudes to $14^o48'09.8"$ North latitudes falls in the Forest Sy.No.16.
21) The Baithkhol (Near Port) area lies between $74^o06'49.8"$ East longitudes to $14^o48'07.5"$ North latitudes falls in the Forest Sy.No.16.

PHYSIOGRAPHY: Study area forms a part of Western Ghats comprises of hilly terrain . The hilly ranges having elevation from 65 mtr. to 552 mtr. above mean sea level.

DRAINAGE: Study area No.1 comprises of camping denetritic pattern. Northern part of the drainage joins Kali River. The other areas comprising denetritic drainage. These drainages joins valleys and Sea.

ROAD NETWORK: A study area contains a well laid road network connecting different parts of Karnataka State.

LANDSLIDE AREAS: Landslide is noticed in several parts of the Karwar taluk. The region where rock and debris fall are noticed around Arga village limits. In the Baitkalgudda, earth flow in larger quantity is seen, causing sea food loss (Fishes). Major landslide was noticed at Kadvad village to the northeast of Karwar, where 8 to 9 houses were washed with earth flow causing 21 deaths of humans.

FACTORS FOR LANDSLIDES: Important factors that caused landslides are: Slope, landuse, litholoty, structure (joints, faults, etc.), climate (Rainfall), geomorphology (Weathering), and soil and man made causes like: excavation (Particularly at the toe of slope), loading of slopes crest, draw down (of reservoir), deforestation, irrigation, mining / quarrying, artificial vibrations, water impoundment and leakage from utilizes. An overall evaluation of the pattern and nature of landslide occurrences around karwar taluk of Uttara Kannada District reveals the following.

1. Almost all mass movements occur during monsoon.
2. There seems to be a relation between intensity of rainfall and slope facilities.
3. Majority of the catastrophic mass movement is confined to the overburden.
4. Improper landuse practices such as agricultural practices and settlement patterns have contributed to creep and withdrawal of toe support in many cases.
5. A common factor noticed in most of these vulnerable slopes deforestration in the recent past, cultivation and increase in settlements.
6. In some areas developmental activities like construction of buildings, road cutting, embankments, cut and fill structures caused modification of natural slopes, blocking of surfaces drainage, loading of critical slopes and withdrawal to toe support promoting vulnerability of critical slopes.

SOME MITIGATIONS FOR LANDSLIDES: In general, the important mitigatory measures to be adopted for such areas are:

1. Drainage correction;
2. Proper land use measures;
3. Reforestation for the areas occupied by degraded vegetation;
4. Creating of awareness among local population.

CONCLUSION: The most important triggering mechanism for mass movement is the water infiltrating into the overburden during heavy rains and consequent increase in pork pressure within the over burden. When this happens in steep slopes the safety factor of the slope material gets considerably reduced causing it to move down. Hence natural way of preventing this situation is by reducing infiltration and allowing excess water to move down without hindrance. That is the drainage correction. As many as 25 land slides have taken place in Uttara Kannada District, on the particular date, i.e., 2nd October 2009, such a large scale land slide points to an after effect of possible mild tremor in the area. Hence the seismic data particularly from 1st October to 3rd October 2009 is to be collected from Bhabha Atomic Research Centre to understand, whether there is any tremor on these days. Based on that data, further studies can be taken up. The afforestation programme should be properly planned. The selection of suitable plant species should be such that can withstand the existing stress condition in their study area.

Annexure II: ENGINEERING GEOLOGY DIVISION, OPERATIONS KARNATAKA AND GOA GEOLOGICAL SURVEY OF INDIA, BANGALORE

A NOTE ON THE PRELIMINARY POST DISASTER INVESTIGATION OF LANDSLIDES OCCURRED DURING OCTOBER 2009 IN KARWAR TALUK, UTTAR KANNADA DISTRICT, KARNATAKA

(Lateral priority Item – I)
FS 2009-10

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Introduction

The landslides occurred during the monsoon showers of September and October 2009 in Karwar taluk, Uttara Kannada dist., Karnataka claimed 19 lives, destroyed properties and affected communication lines. The Preliminary investigation of the landslides was taken up on priority as per the instruction received from the Dy.Director General, Op: Karnataka and Goa, Geological Survey of India, Bangalore to assess the nature, causes, the future risk and vulnerability at the sites. Communications were also received from LHIM Division, New Delhi, Chairman, Western Ghat Task Force and telephonic request of Addl. Dy.Commissioner, Uttar Kannada Dist, Karwar to Director (CT), Op: Karnataka and Goa, regarding the urgency of the investigation. The preliminary investigation was carried out at the following sites on 13.10.2009 and 14.10.2009.

A) Landslide at Kadvad village, Karwar Taluk, Karwar
B) Landslide near Forest Naka, Kadvad village, Karwar Taluk, Karwar
C) Landslides along NH17 between Ankola and Karwar:
   Landslide 1, Landslide 2 and Landslide 3
D) Landslide near Karwar port
   Landslide 4, Landslide 5 and Landslide 6

Location of landslides

Landslides of different magnitudes were reported at 21 locations, two slides in the vicinity of Kadvad village, fifteen slides along NH 17 between Ankola and Karwar and five slides along the road connecting to the Port at Baithkhol. The details of the landslides as provided by the forest officials of Karwar are listed below. All the slides are located in Karwar taluk and fall in toposheet no 48J/1 and occurred on 2nd October 2009 (as per local authorities).

Sl no	**Slide location**	**Latitude and Longitude**	**Approximate volume of slide material**
1	Kadvad (Zariwada)	14^{o}52'40.2"N 74^{o}10'39.8"E	750,000 Cu.m
2	Kadvad (Near Forest Naka)	14^{o}49'59.2"N 74^{o}10'47.6"E	400,000 Cu.m
3	Agra (NH 17)	14^{o}46'53.4"N 74^{o}08'43.1"E	6000 Cu.m
4	Agra (NH 17)	14^{o}46'51.2"N 74^{o}08'47.3"E	4000 Cu.m
5	Baithkhol (near port)	14^{o}48'13.3"N 74^{o}06'49.7"E	10,000 Cu.m
6	Baithkhol (near port)	14^{o}48'09.8"N 74^{o}06'50.8"E	15,000 Cu.m
7	Baithkhol (near port)	14^{o}48'16.1"N 74^{o}06'49.3"E	25,000 Cu.m
8	Baithkhol (near port)	14^{o}48'16.5"N 74^{o}06'47.9"E	30,000 Cu.m
9	Baithkhol (near port)	14^{o}48'07.4"N 74^{o}06'49.8"E	8,000 Cu.m
10	Shirwad	14^{o}48'38.7"N 74^{o}10'47.6"E	100,000 Cu.m
11	Mandralli	14^{o}50'50.2"N 74^{o}09'22.7"E	45,000 Cu.m
12	Makeri	14^{o}49'21.8"N 74^{o}10'17.6"E	5,000 Cu.m
13	Makeri	14^{o}49'15.5"N 74^{o}10'17.5"E	4,500 Cu.m
14	Makeri	14^{o}49'15.3"N 74^{o}10'17.5"E	3,800 Cu.m
15	Baad (Murlidhramath)	14^{o}48'25.1"N 74^{o}08'13.2"E	5,000 Cu.m
16	Baad	14^{o}48'14.5"N 74^{o}07'22.4"E	3,000 Cu.m
17	Binga (NH 17)	14^{o}47'26.2"N 74^{o}06'53.5"E	500 Cu.m
18	Binga (NH 17)	14^{o}47'27.9"N 74^{o}06'59.0"E	1500 Cu.m
19	Binga (NH 17)	14^{o}46'53.9"N 74^{o}08'10.0"E	35,000 Cu.m
20	Agra (NH 17)	14^{o}46'58.9"N 74^{o}08'29.2"E	50,000 Cu.m
21	Agra (NH 17)	14^{o}46'58.4"N 74^{o}08'29.2"E	10,000 Cu.m

Rainfall: The investigated area falls in Western Ghat and receives a high average annual rainfall. The antecedent and precedent rainfall pattern shows an unprecedented rise in the quantum of rainfall from 30th September 2009 to 4th October 2009. As per the information from the local authorities, all the landslides occurred on 2nd October 2009 even though the maximum daily rainfall received was on 3rd Oct 2009 which is nearly 2.5 times more than the rainfall received on previous day. The immediate trigger for all the slides is observed to be the high rainfall. The rainfall data from 1st September 2009 to 13th October 2009, as recorded at Karwar rain gauge station is as follows:

Date	**Rainfall (in mm)**		**Date**	**Rainfall (in mm)**		**Date**	**Rainfall (in mm)**
1-Sep-09	19.9		16-Sep-09	4.7		1-Oct-09	39.5
2-Sep-09	57.9		17-Sep-09	0		2-Oct-09	179.6
3-Sep-09	30		18-Sep-09	0		3-Oct-09	423.6
4-Sep-09	38.4		19-Sep-09	8.2		4-Oct-09	34.9
5-Sep-09	64		20-Sep-09	0		5-Oct-09	1
6-Sep-09	49.6		21-Sep-09	4.4		6-Oct-09	10.4
7-Sep-09	26.4		22-Sep-09	0		7-Oct-09	0
8-Sep-09	8.8		23-Sep-09	0		8-Oct-09	0
9-Sep-09	1		24-Sep-09	2.5		9-Oct-09	0
10-Sep-09	17.3		25-Sep-09	0.7		10-Oct-09	0
11-Sep-09	2.4		26-Sep-09	4.4		11-Oct-09	0
12-Sep-09	41.8		27-Sep-09	0.6		12-Oct-09	0
13-Sep-09	0		28-Sep-09	0		13-Oct-09	0
14-Sep-09	0		29-Sep-09	6			
15-Sep-09	10.7		30-Sep-09	118.2			

Data Source: Dy. Commissioner’s office, Uttar Kannada Dist., Karwar

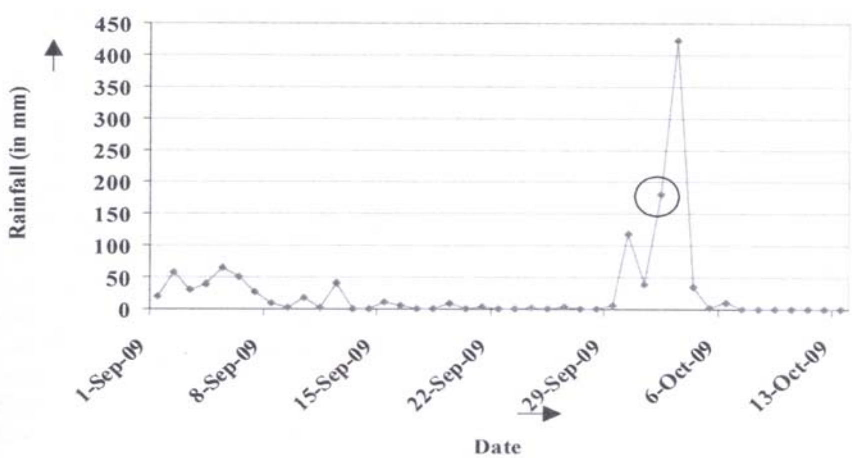


Figure1: The antecedent and precedent rainfall pattern for the landslides (Karwar rain gauge station)

ASSESSMENT OF INDIVIDUAL LANDSLIDE

A) Landslide at Kadvad village, Karwar taluk, Karwar (Photo: 1-11)

The Kadvad landslide occurred at 1615hrs on 2nd October 2009 killing 19 people and completely destroying nine houses, coconut plantation and livestock.

Location and Physiography: The slide is located in toposheet no 48J/1 at latitude $14^{o}50'35.6''$N and longitude $74^{o}10'36.4''$E, nearly 6 km northwest of Karwar town. The landslide occurred in the northeast slope of the NW-SE trending mound. The maximum height of the mound is 65m above msl with a slope angle of ~20^{o}. The foot hill is habitated all round. The spur of the mound runs into the marshy land near the bank of Kali River on its three sides. The original hill profile shows small depression/streams draining into Kali River from northeast and southwest direction.

Land use and Land cover: The slope has been modified for making formations for habitation and plantation for a long time. The modification includes (as data gathered from local residents and inferred from the site condition) three levels of benching with construction of houses and plantation of coconut trees. The slope is moderately vegetated with shrubs and cashew plants both having low root and shoot ratio.

Geology at site: The litho units exposed at the site includes vesicular laterite with predominantly tubular cavities, clayey soil, saprolite (weathered granite) and granite. A small lensoid body of lithomarge clay layer occurs near the head scarp at the left flank.

Slide morphometry: The slide is a large (>20,000 m^2 area in plan), very fast, deep seated (depth of failure more than 20m) rotational debris slide. The different morphometric parameters of the slide are as follows:

a) Length of slide: 250-300m
b) Width of slide: 60 m
c) Depth of slide: ~30m
d) Scarp width: ~60m
e) Scarp depth: ~20m
f) Scarp angle: ~vertical to concave
g) Crown cracks observed
h) Run out distance: ~300m
i) Cut slope angle near the toe: 90^{o}
j) Cut slope height near the toe: 20m
k) Slide direction: N36^{o}E
l) Slope prior to failure: 20^{o}
m) Slope after failure: 10^{o}- 15^{o}

Photo1: The geological set up at the site.

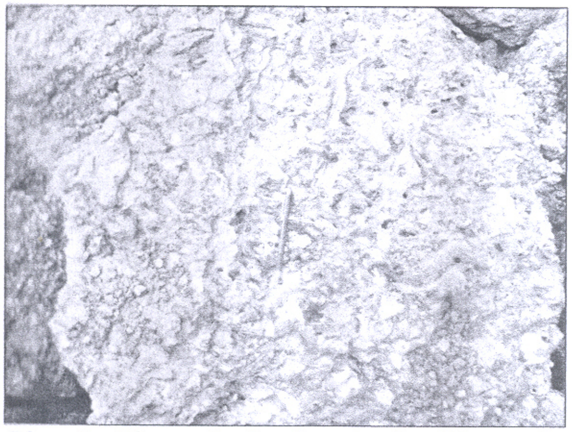


Photo2: The vesicular laterite boulder in the debris in the mid slope.

Photo3: The weathered granite (saprolite) in the slide debris in the mid slope (right flank).

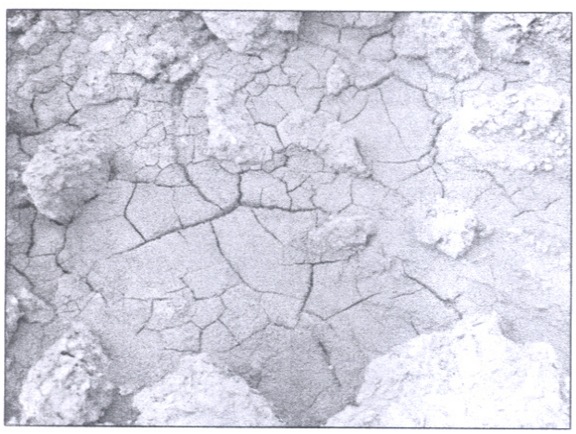


Photo4: The clayey soil with mud cracks in the debris.

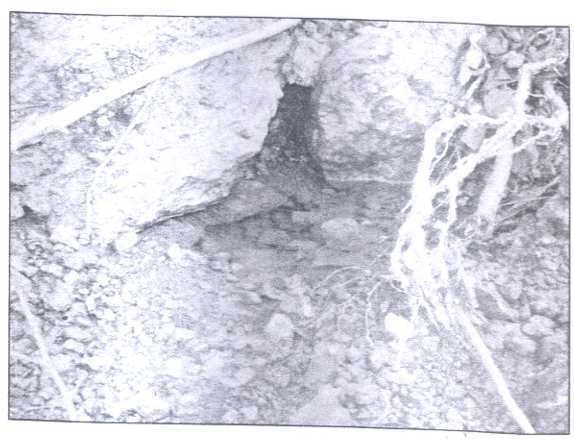


Photo5: The natural stream formed in the zone of depletion.

Slide material: The slide material in the zone of accumulation and depletion is debris comprises of different fraction of laterite, sandy lateritic soil, clayey soil and weathered granite material. The size of different fractions varies from huge lateritic bloulders to clay size, with dominant finer material.

Causes of the slide: The causes of the slide as observed during the investigation are as follows:

a. The original slope angle being very low ~20^o, the slope was stable prior to human interference. The modification of the slope by cutting 15-20m vertical slope (as observed in the left and right flanks of the slide zone) for settlement and plantation increased instability.
b. The 10-15m thick clayey soil layer, between laterite and saprolite layers, being impervious was oversaturated during the antecedent rainfall and was responsible for development of high pore pressure. The pore pressure cumulatively with lateral pressure due to swelling of oversaturated clay rich horizon may have increased the driving force.
c. Even though the slope was moderately vegetated with shrubs and cashew plants, the vegetation added dead weight on the failed slope as these plants do not have deep penetrating root system to hold the slope material intact (as the plane of failure of the slide is more than 20m).
d. As per information received from local authorities and some local residents there was an excavation in front of the slope for providing soil for the construction of the embankment for Konkan Railway alignment. Even though the excavation depth could not be confirmed but its location was somewhere near the front of the slide slope. The instability was induced due to the excavation (toe cutting into the slope) which has increased the relative slope height, the volume and weight of material above the toe.
e. The rise in the stagnated water level in the marshy area in front of the mound during the ensuing rainfall might have decreased the volume of water drained out of the mound thus increasing the water content of the slope forming material with subsequent rise of water table.
f. Even though percolation through vesicular laterite is high the drainage facility in the area was poor to drain out the excess infiltrating water from the slope.

Photo6: View of the crown cracks and the ponding of water in the slide zone

Photo7: The remnant cut slope exposed in the left flank of the slide

Triggering mechanism: The trigger for the slide was the continuing high rainfall and subsequent increase in the pore pressure due to impermeable clayey soil horizon.

Recommendations: As per the site condition the following measures are recommended:

a. The houses in the vicinity of the slide zone are to be shifted to safer places.
b. The hanging crown part needs to be graded as it is still unstable (as subsidence and crown cracks were observed). The major part of the intact slope exposed is either laterite or clayey soil hence the vertical, 20m high crown scarp should be graded to 35^o-45^o.
c. The water logged areas and rills present in the slope (ponding of water in the midslope and the rills developed near the head scarp) are to be diverted or suitably drained out of the slope.

d. Plantation in the slide zone with deep rooted plants in staggered manner is essential to stop future landslides of local nature in the slide debris. It is to be noted that deep seated slides cannot be protected with biogeotechnical measures.
e. For long term stability at the site of landslide and the adjoining slopes of the mound, detail study of the whole area as a single unit should be taken up for landslide microzonation.
f. The long term remedial measures is to be proposed after detail investigation at the site of landslide and it will depend on
    i. The type of future landuse contemplated for the area.
    ii. Development plans envisaged for such type of landuse pattern.
    iii. Cost/economics

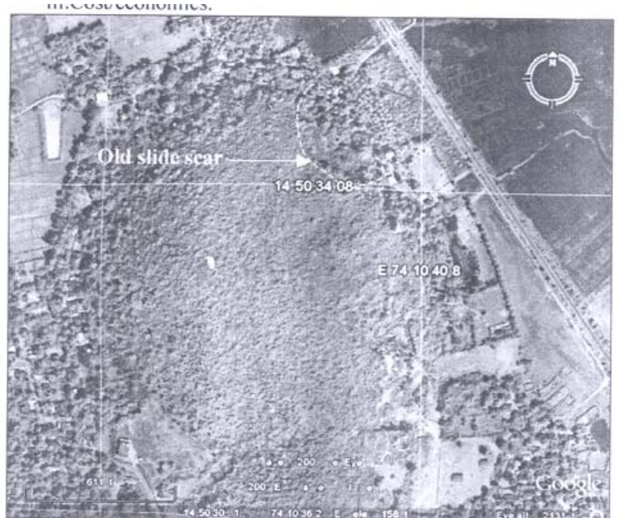


Photo8: The google image showing the slope prior to failure and the probable old slide scar.

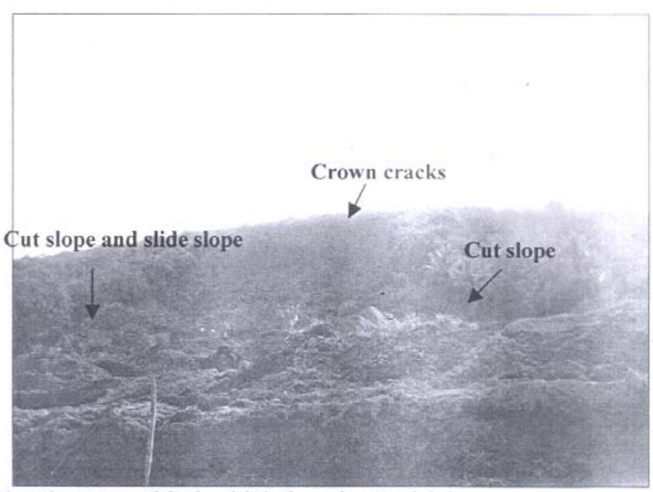


Photo9: A view of the landslide from the tip of slide.

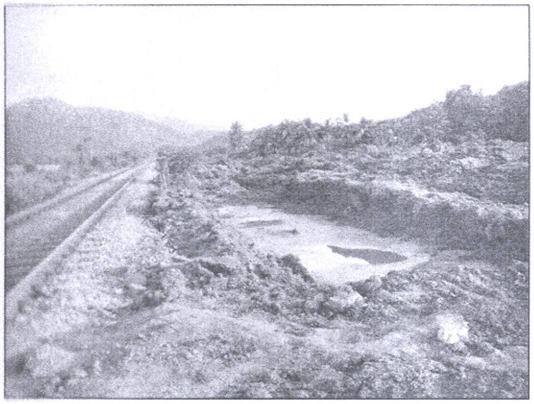


Photo10: View of the toe of the slide blocked by the embankment of Konkan railway

Photo11: The damaged house near the left flank of the slide

B) Landslide near Forest Naka, Kadvad village, Karwar taluk, Karwar (Photo: 12-14): The Landslide near Forest Naka, Kadvad village occurred on 2nd October 2009 and blocked the road.

Location and Physiography: The slide is located in toposheet no 48J/1 at latitude 14^o49'59.2"N and longitude 74^o10'47.6"E, nearly 5km northwest of Karwar town. 400,000 Cu.m volume of debris and soil moved down slope blocking the road connecting to Kadvad village from SH6. The landslide occurred in the southeast slope of the E-W trending hill. The maximum height of the area is 78m above msl with a slope angle of ~30^o. The foot hill is habitated in the south and south east slopes. The original hill profile shows small streams running into Kali river from northeast and southwest direction.

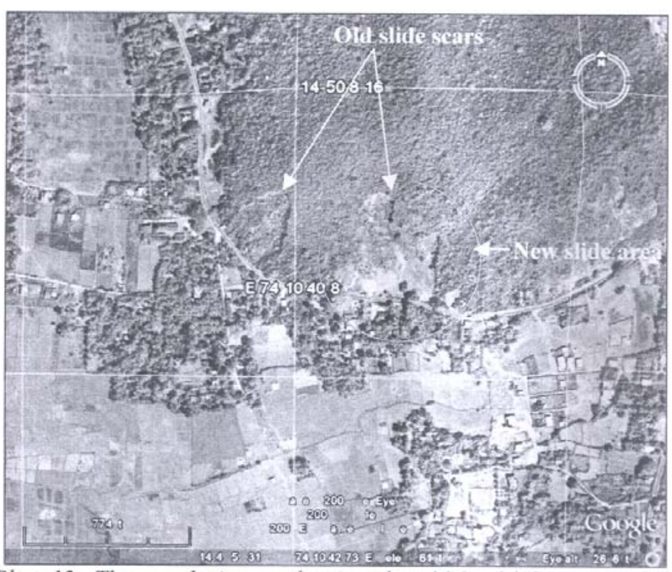
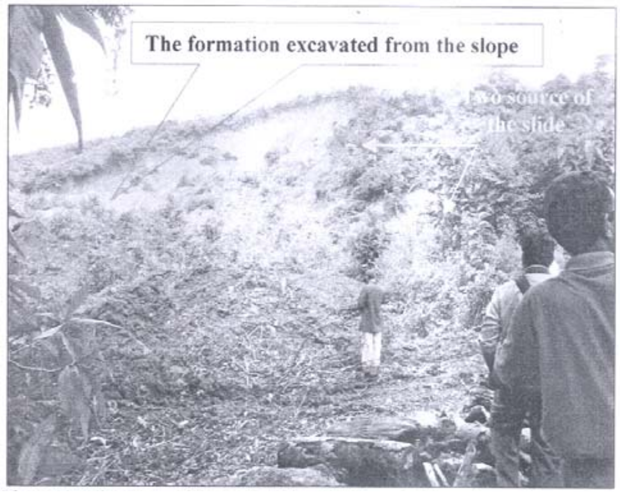


Photo12: The google image showing the old landslide scars in the mound where the slide occurred near the Forest Naka, Kadvad village.



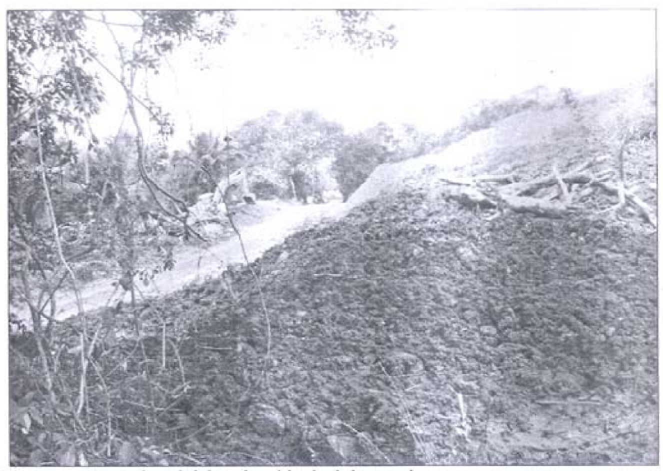


Photo14: The soil and debris has blocked the road

Slide morphometry: The slide is very fast, large, deep-seated rotational soil slide. The morphometric parameters of the slide are as follows:

Length of slide:250-300m, Width of slide: 100m, Depth of slide: ~15-20m, Scarp width: ~75m, Scarp depth: ~15m, Scarp angle:~50^{o} to vertical, Run out distance: ~ 300m, Cut slope angle near the toe: Vertical, Cut slope height near the toe: 10m, Slide direction: S15^{o}E, Slope prior to failure: ~20^{o}, Slope after failure: 10^{o}-15^{o}

Slide material: The slide material in the zone of accumulation and depletion is soil and debris comprises of different fraction of lateritic soil (sand to clay size), and weathered granite.

Causes of the slide: The causes of the slide as observed during the investigation are as follows:

a. The cut slope for the road formation
b. As per the information provided by local authorities there was excavation at the

c. midslope to flatten the slope. This has increased the driving force due to the removal of material from the toe.
d. As the slope forming material is mostly lateritic soil, clayey soil and overburden. The over saturation of the slope material decreased the resisting force.
e. The satellite image of the site prior to the present slide shows presence of an old slide scar thus the slope was already in distress and there was a debris accumulation in the slope. The slope material was thus partly unconsolidated.
f. Due to the blockage of natural drainage in the area there was a decrease in quantum of the drain out of the water from the slope.

Recommendations: As per the site condition the following measures are proposed:
a. Removal of the slide debris/ soil from the slope.
b. The material that is heaped up at the side of the road towards the slide zone should be removed as low rainfall can trigger this unconsolidated soil to slide/flow damaging the houses below.
c. Landslide microzonation of the whole area is essential for providing longterm remedial measures. As one old landslide scar was exist near to the site as observed in the satellite picture. Detailed investigation for the whole area in toto is essential.

C) Landslides along NH17 between Ankola and Karwar (Photo 15-23)

i) Landslide 1:
The slide is located near Agra along NH17 at latitude 14^o 46’ 51.2” N and longitude 74^o 08’ 47.3”E and falls in toposheet no 48J/1. Approximately 4000 Cu.m of debris material moved down slope and blocked NH17.

Slide morphometry: The slide is a multiple slide (a part of rockslide with planer failure and the other is a shallow rotational debris slide). The overburden/debris towards southeast failed along the contact of the granite and overburden. The debris slide seems to be a base failure along the joint plane. The slide material moved along S25^{o}W direction onto the road and blocked traffic along NH17. The rock type exposed in the area is granite. The length and width of slide is 20m. The slope forming material is weathered blocky granite with two sets of joints.

Cause: The causes of this slide are as follows
a. The joint plane has been daylighted due to slope cut for road formation.
b. The planer failure occurred along the daylighted joint plane trending N75^{o}E-S75^{o}W dipping 70^o southwesterly in granite. The overburden material with granite slipped along this plane.

c. High rainfall removed the material along this plane by infiltrated water which also acted as lubricant in reducing the resisting force.

Recommendations

a. The slide debris is to be removed from the slope.
b. The material above the exposed granite base should be removed/graded.
c. The granite is to be rock bolted as per appropriate spacing after detail study of the site.

ii) Landslide 2:

The slide is located near Agra along NH17 at latitude 14^o 46’ 53.3”N and longitude 74^o08’42.9”E and falls in toposheet no 48J/1. Approximately 6000 Cu.m of debris material moved downslope and blocked NH17.

Slide morphometry: The slide had taken place along the contact of a fractured dyke and weathered granite. The slope material (boulders, cobbles of granite and dyke, the overburden soil) moved along a shallow dipping joint plane in granite and the contact plane of granite and dyke. The slide moved in $S20^oW$ direction upto the road. With a length of 30m, width 15m and depth 4-5m, the slide can be classified into a complex slide with both rock and debris component.

Causes: The slope failed due to the following causes:

a. Blockade of natural stream.
b. The weak contact between the weathered granite and weathered dyke.
c. The prevailing shallow dip daylighted joint and orientation
d. Highly fractured rock mass
e. Toe cutting due to slope modification.

Recommendations: As the relative relief of the slope is low with a low original slope angle, the retrogression of the slide is not expected but the lateral widening is pertinent. The concave crown scarp is vulnerable to failure. Hence the following measures are proposed at the site for stabilizing the slope

a. The removal of slide debris.
b. Grading of the crown scarp by excavation.
c. A retaining wall of 2m height is to be constructed at the toe
d. Backfilling the slope with stone pitching at 1:1 slope angle.

Photo15: View of the slide with exposed shallow dipping plane (right arrow) and mafic dyke boulders (left arrow)

iii) Landslide 3:

The landslide along the cut slope of the NH17 occurred on 2nd Oct 2009. The slide is located near Agra along NH17 at latitude 14^{o} 46’ 57.9”N and longitude 74^{o} 08’29.9”E and falls in toposheet no 48J/1. Approximately 50,000 Cu.m of debris moved downslope and blocked NH17.

Slide morphometry: The slide is a multiple debris slide. The debris includes boulders, cobbles and overburden soil and granite. The slide material moved in S25^{o}W direction and blocked the road. Three slides occurred adjacent to each other. The slides from S70^{o}E direction toward N70^{o}W direction along the road have length of 10m, 100m and 30m, width 10m, 20-30m and 15m and depth 2m, 5m and 5m respectively. The slides appear to have occurred independently and coalesced together at their flanks. Old slide scar was observed near the new slides indicating an earlier failure. The widening of the slide is discreet yet it seems continuous. The scarps are vertical to concave into the slope. The slope forming material is lateritic soil and weathered granite. Vegetation on the slope is moderate to sparse.

Causes: The following causes can be attributed to the failure:

a. The slope modification for road formation and highly weathered granite material on the slope.
b. The presence of old slide with previous unconsolidated slide debris on the slope.
c. Sudden increase in the rainfall volume.

Recommendations: The original slope angle is gentle with a very low relief. Lateral widening of the slide is suspected. The slides may coalesce together in future. Hence the following measures are recommended at the site:

a. A retaining wall at the toe of the slide as the slide toe lies very near to the road cutting
b. Benching of the slope with grading of the crown, as the slope relief is low and slope angle is gentle
c. Increasing the land cover with deep rooted plants.

Photo16: The old slide scar (left arrow) and the new slide (right arrow)

Photo17: The middle of the three coalesced slides and is the longest slide

Photo18: The source of the maximum debris on to the road

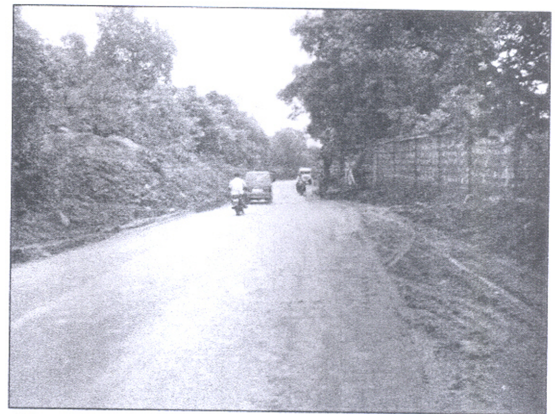


Photo19: The view of the road from where debris has been removed

D) Landslide near Karwar port

iv) Landslide 4:

The slide is located near Port in Baithkhol at latitude 14^o 48’13.3”N and longitude 74^o06’49.7”E and falls in toposheet no 48J/1. The slide occurred on 2nd October 2009 in the eastern slope of the N-S trending spur. Approximately 10,000 Cu.m of debris material moved down slope and blocked the road.

Slide morphometry: The slide is a moderate translational debris slide. The debris include boulders, cobbles of weathered granite and soil. The slide with a length of 30-40m, width of 8-10m and depth of 5-6m moved in N75^{o}E direction upto the road. Lateritic soil and weathered granite is the slope forming material. The slide was controlled by the shallow dipping joint plane in granite.

Causes: The causes of the slope failure are:

a. The toe cutting of the slope for road.
b. The unfavorable joint orientation in granite along which the material slide.
c. The blockage of natural stream, no drainage. The slide occurred along the earlier depression/small water outlet.
d. High rainfall.

Recommendations: The original slope angle is gentle with a very low relief. As the cause is road cutting the debris is to be removed from site and retaining wall with weep holes at the toe should be provided at the site.


Photo20: The movement of the debris along a joint plane

v) Landslide 5

The slide is located near Port in Baithkhol at latitude 14^{o} 48' 16.5" N and longitude 74^{o}06'47.9"E and falls in toposheet no 48J/1. The slide occurred on 2nd October 2009 in the northern slope of the N-S trending spur. Approximately 30,000 Cu.m of debris material moved down slope into the sea and blocked the road.

Slide morphometry: The slide is a multiple and multisource debris slide. The debris consisting of boulders, cobbles of weathered granite and mafic dyke, laterite and lateritic soil. The slide with a length of 200m, width of 100m and depth of 10m moved in N65^{o}E direction into the sea.

Causes: The following causes can be attributed to the failure:

a. The slope modification for making the road. The cut slope height is inferred to be >5m at the site with vertical slope angle.
b. The presence of moderately dipping joint plane in the granite day lighted toward the free face.
c. Immediate cause was the high precipitation

Recommendations: As the original slope angle is gentle with a very low relief, lateral widening of the slide is suspected hence the measures recommended are as follows:

a. Retaining wall at the base of the slide after removing the debris.
b. Removal of the crown scarp from the left flank of slide.

Photo21: The slide debris slammed into the sea.

Photo22: The view of the slide zone with both joint controlled (left arrow) planer failure and rotational failure (right arrow).

vi) Landslide 6

The slide is located near Port in Baithkhol at latitude 14^{o}48' 09.8"N and longitude 74^{o}06'50.8" and falls in toposheet no 48J/1. The slide occurred on 2nd October 2009 in the eastern slope of the N-S trending spur. Approximately 15,000 Cu.m of debris material moved down slope and blocked the road.

Slide morphometry: The slide is a complex slide with both rock and debris component. Both rational and translational component caused this slide. The slide material includes boulders and cobbles of weathered granite and lateritic soil and laterite. The slide with a length of 30m, width of 10m and depth of 5m has moved in S50^{o}E direction.

Causes: The causes of the slope failure are:

a. The toe cutting of the slope for road.
b. The unfavorable joint orientation in granite along which planer failure occurred and the overburden/soil failed towards the northern side.
c. High rainfall

Recommendations: The original slope angle is gentle with a very low relief. As the main cause is road cutting the debris is to be removed and retaining wall with weep holes at the toe should be provided.

Photo23: The structures near the crown of the slide are in danger.

Few long term strategies to be adopted for Landslide mitigation in this area:

1. The landslide hazard zonation of the cut slope along the road cutting along NH 17 in particular and the road network in the hilly areas in general should be carried out to demarcate high vulnerable areas so as to take up preventive measures.
2. Assessment of the cut slope stability in the hilly area should be carried out for predicting instability which will be helpful for town planning and developmental activities.
3. Landslide awareness programme should be conducted for residents and officials of the hilly region so as to make people aware of the failure patterns, causes and other attributes of slope instability so that they can take precautions at individual level as well as at community level.

ACKNOWLEDGEMENTS

The author is thankful to Shri R.Panduranga, Director, Engineering Geology Division, Op: Karnataka and Goa for his technical guidance and scrutiny of the report. He is thankful to Dr. K. Rajaram, Director (CT), Op: Karnataka and Goa, Geological Survey of India, Bangalore for his guidance and support. He is also thankful to the Dy. Director, DMG, Karwar and his team of geologists for cooperation and combined filed trip to the site. He is also thankful to the members of the Western Ghat Task Force Committee who provided information about the various fields they represent. Thanks are also due for the Additional Dy. Commissioner of Uttar Kannada district, Karwar for providing necessary logistic support for smooth conduct of the field work. Besides the local residents of Kadvad village who provided vital information for interpretation of the data.

Annexure III: Report by Dr. V S Hegde, SDM College of Engineering, Dharwad

Report of the site investigations of the land slides at Karwar

Dr. V.S.Hegde
SDM College of Engg and Tech., Dharwad

28-10-2009

Sri Ananth Hegde Ashisar
Chairman
Western Ghat Task force, Vidhansoudha, Bangalore

Report of the site investigations of the land slides at Karwar
Date of visit 14-10-2009

Land slided area around Karwar was visited on 10-11-2009. During the visit, 21 locations have been visited. Location of the sites have been recorded using Garmin make GPS. Materials involved in sliding; topography, post slide slope have been investigated and pre-slide slope have been inferred based on the observations of the adjacent areas. Nature of slide has been studied and inferred based on the discussion with the local people. Man made structures have been investigated.

In the laboratory contour map is generated based on the Google earth 2008; Drainage frequency map for the slided and surrounding area, vegetation change over the last 10 year; bifurcation analysis; lineaments patterns have been studied using PAN, Google earth, and LISS III images; based on the recent earth quakes records and previous works by other experts earth quake intensity distribution map has been prepared.

Observations: Land slide at Kadwad and Karwar fishery port is classified as soil slide; road side near Karwar port it is rock fall; along the highway side it is soil and debris slide.

Area is dominated by granites/granite gneisses that are moderately jointed. Only locally laterite capping is seen. Soil cover in the high way section is less where as near Kadwad it is very thick. Drainage frequency is low (Fig.1), bifurcation index is high for the lower orders (Table 1); first order show valley lengthening (Fig 2), hence erosion. West –East cross profiles show sudden rise in the landform gradient in the coastal belt (Fig 3) which is unusual in the coastal plains; Profiles across the river indicate terraces and entrenching; rivers tributaries show anomalous bends in the lower course; pebble beds (Fig 4) and raised terraces are observed near Belikaeri. All these points to neotectonic activities in the area.

Area is affected by intensive quarrying; Rocks are quarried for road aggregate, for construction, etc; blasting appears to be the dominant mode involved in quarrying the rocks. This not only shatters the rocks, increases the intensity of the joints, widens the joints and sets up minor vibration in the rocks. To prevent drainage entry into sea bird project area compound walls constructed along the high way side are not provided with drainage. Natural drainages have been closed, leading to water logged in highway during high rain fall times; slope areas under/toe cutting is increased, resulted in land sliding and debris slides along hill side highway sections. There are many lineaments crossing the railway tracks (Fig 5). For railway line and other domestic works, hill slopes have been cut at higher angle than the angle of rest. During passage of train vibration sets, get converted into complex chains of vibration when the waves of vibrations reach the planes of non continuity defined by the joints/lineaments/ faults.

Seismically the area comes under the high seismic risk zone. It is supported by the data of recent earth quakes (Fig 6). At many places, especially in landslide affected area, original forest has been degraded and in place shrubs are replacing the original vegetation (Fig 7). Owing to high rain fall; low porosity of the granites, and moderate jointing percolated water flow laterally as subsurface flow. Sine laterite is missing at many places, there is no continuity between rocks and soil, and hence water lubricates the contact between rocks and soil/weathered debris.

Conclusions:

The above details suggest that landslide in the area is due to the combined effect of the natural and anthropogenic activities. If without understanding the natural geological and geomorphologic and hydrological condition, anthropogenic activities, landslides could be more severe in the forthcoming days and hence proper measures is suggested.

A scientific technical article based on the detail study of the landslide is underway.

Fig.1.Drainagemap of the Karwar around area (Based on satellite data)

Fig.2.Log of drainage number v/s drainage order for the drainage patterns around Karwar area.

Fig.3.Google earth generated contour map for the area around Karwar

Fig.4.Laterite like rock at Belikeri showing pebbles.

Fig.5.Lineament maps for Karwar area Based on LISS III, and PAN data).

Fig.6.Seismic zonation map of South India

Fig.7.Vegetation change pattern in landslide areas of Karwar between 1990 and 2000 (based on TM-ETM).

Table.1.Drainage statistics of Karwar area.

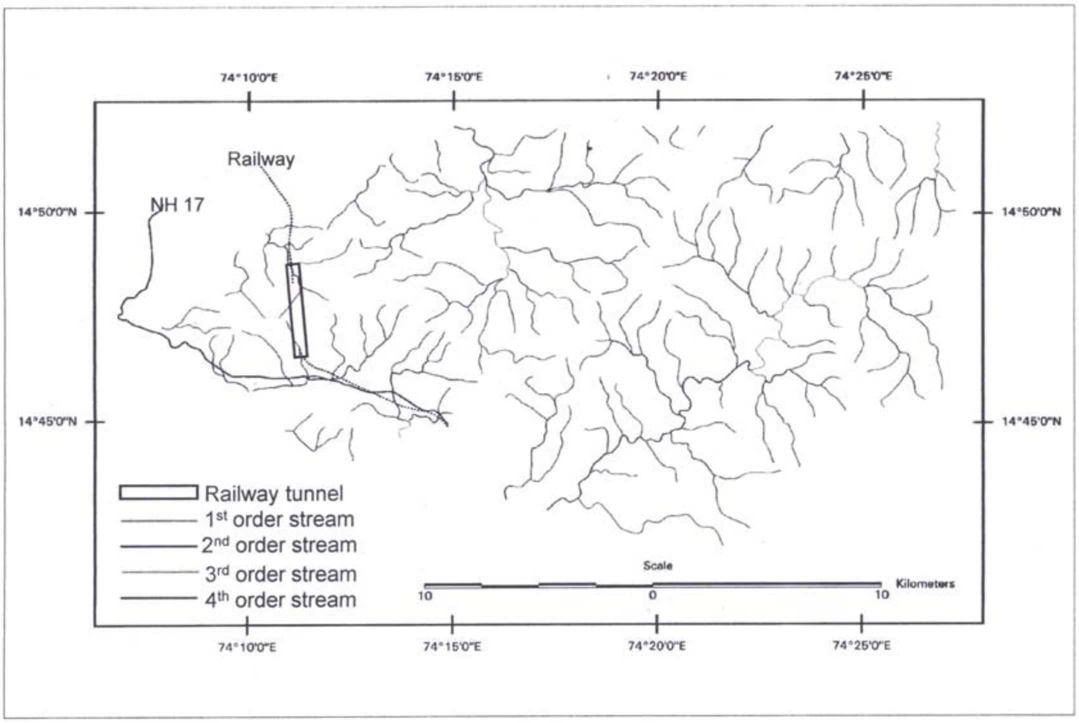


Fig.1.Drainage map of the Karwar around area (Based on satellite data)

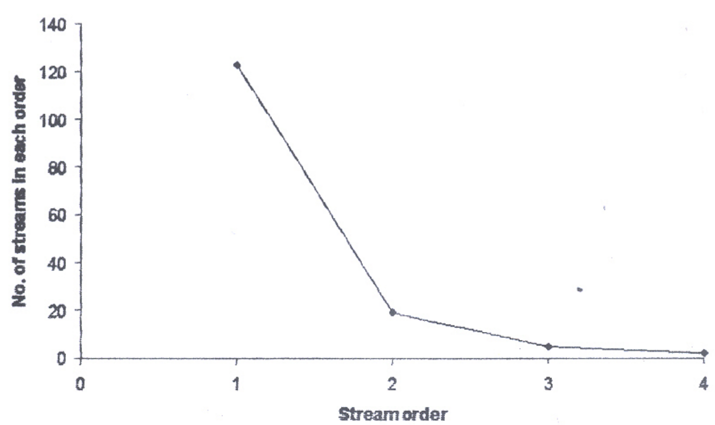


Fig.2. Log of drainage number v/s drainage order for the drainage patterns around Karwar area.

Table 1. Drainage statistics of Karwar area

Steams order	No. of steams	Bifurcation Ratio
1	124	
2	29	4.28
3	6	4.83
4	2	3.00

Drainage Frequency

0-1	76.71
1-3	21.88
>3	1.41

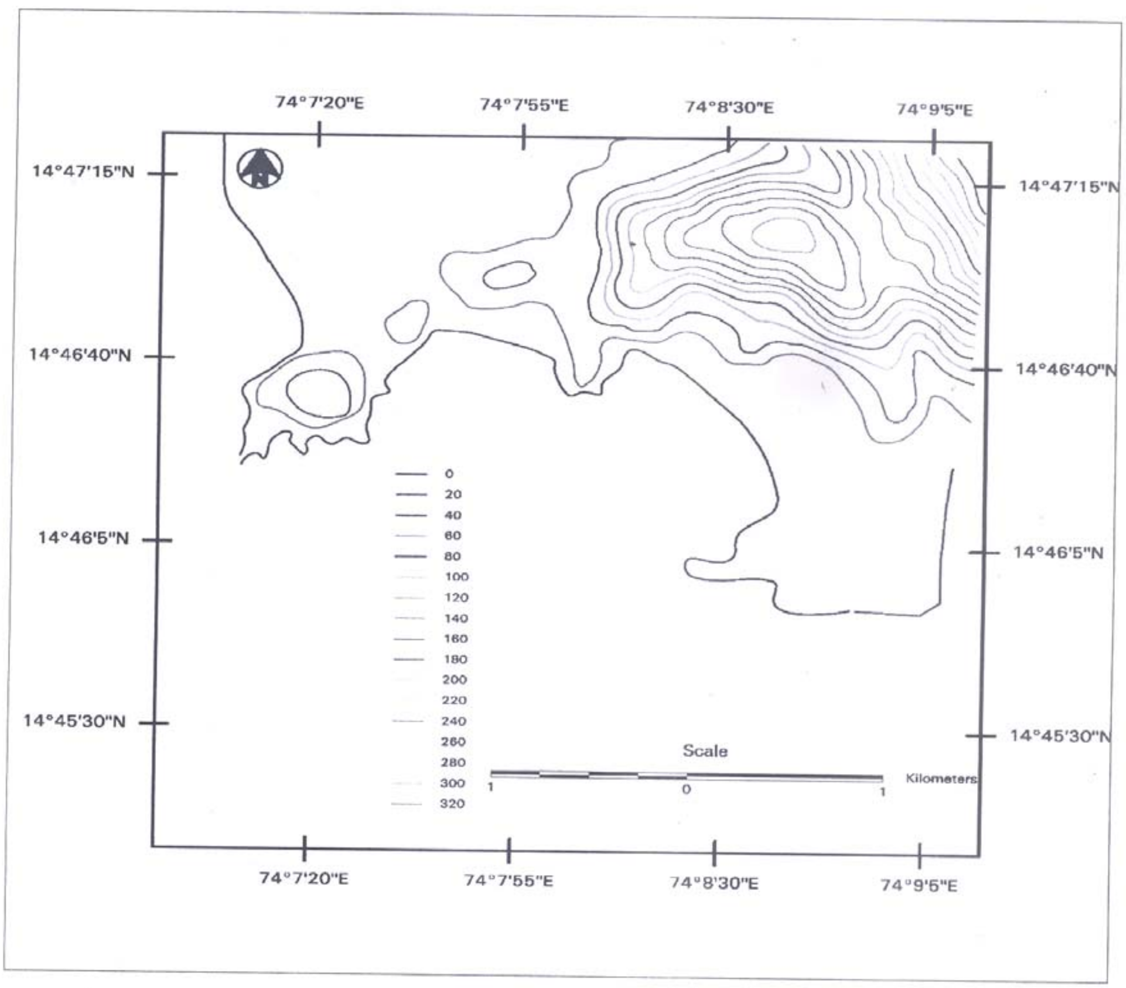


Fig.3. Google earth generated contour map for the area around Karwar.

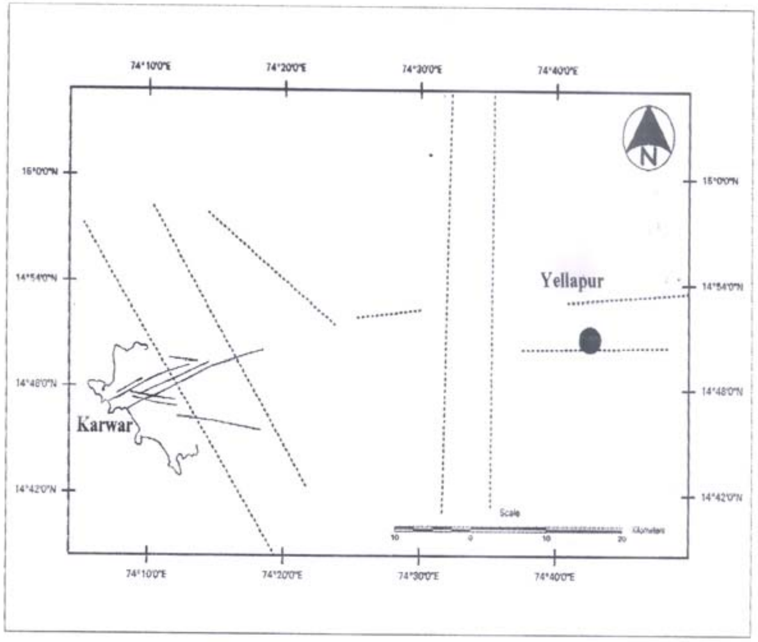


Fig.5.Lineament maps for Karwar area (Based on LISS III, and PAN data).

.... Earlier works

______ our works

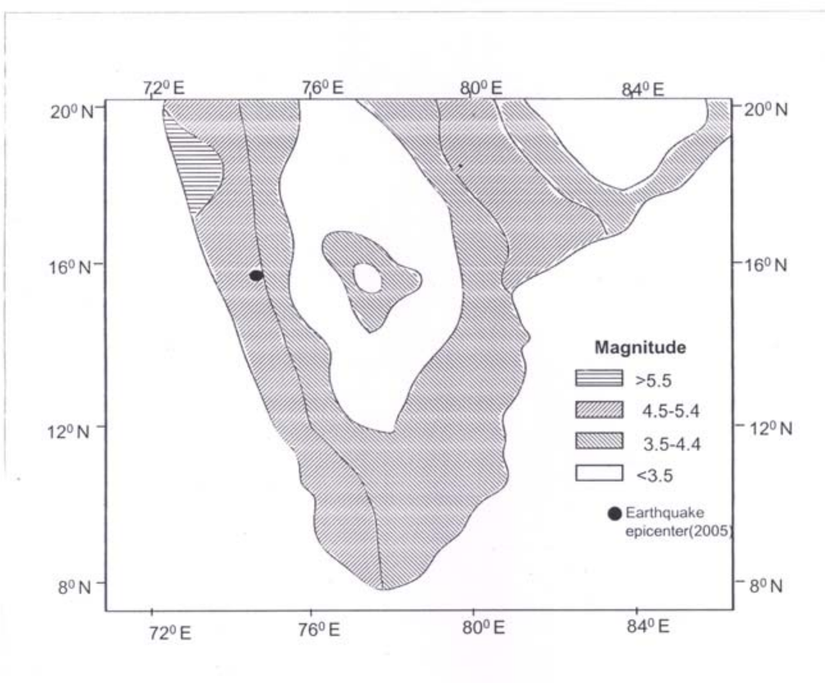
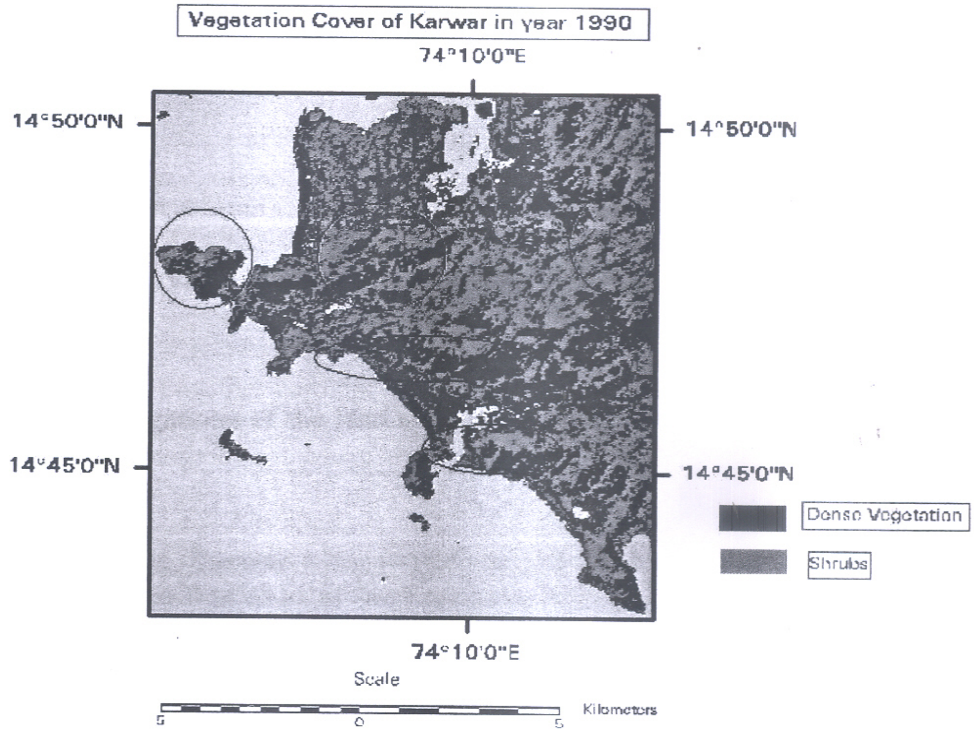


Fig.6. Seismic zonation map of South India.



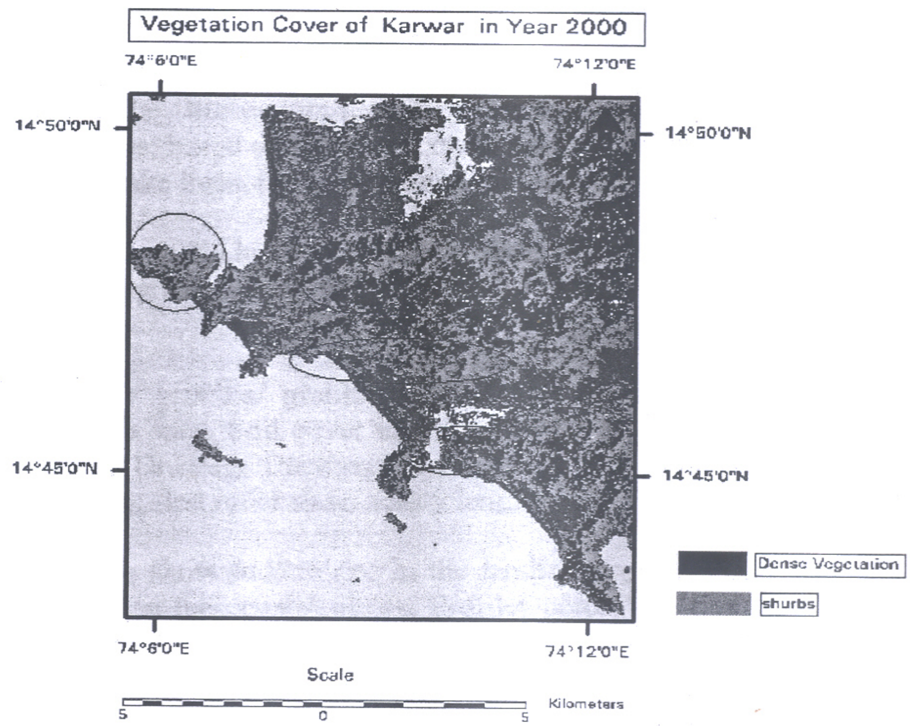


Fig.7. Vegetation change pattern in landslide areas of Karwar between 1990 and 2000. (based on TM-ETM).

Annexure IV: Report by Dr. V N Nayak, DOS Marine Biology, Karwar

Land slide scenario in Karwar

Dr. V. N. Nayak,
Chairman, Dept of Studies in Marine Biology, Kodibag, Karwar

Opinion

In following lines I forward my preliminary observations as seen on 14.10.09:

The primary cause has been unprecedented heavy downpour in a very short period preventing immediate drain leading to creation of pressure on loose soil component. In addition anthropogenic activities also have contributed largely in each of the places visited.

I. Sankrubag-Binga hillock

1. There has been large scale quarrying activity wherein frequent powerful blasts are made to break the rocks. This has caused large scale vibration loosening the boulders, and also root system of the plants that binds the soil. As most of the slides are around the quarry this could be one of the major causes.
2. While constructing the high way the hillock is cut vertically and therefore the water pressure on the rocks and soil must have made the hillock part to slide downwards.
3. Heavy traffic of loaded Lorries also adds to the vibration and might have contributed to the impact.

II. Baithkol hillock

1. Soil quarrying for construction of road along the southern border to transport boulders to break water has made an impact on the slope.
2. A road constructed to approach the drying place and vertical cut to expand the area of fish drying places loosened the soil

III. Kadwad Region:

1. The entire top portion of hillock is devoid of any large trees.
2. The major component of the hillock is loose soil with hardly any granite beds.
3. When there is high tide there is increase in the water level at the base of the hillock preventing the easy seepage of water
4. It is said that the dam water was released during the same time thus increasing the water-reverse pressure.
5. There has been large scale soil quarrying along the first slide making vertical cuts.

6. Water flow from the hillock in the form of seepage and rain drain was prevented by long term encroachments.
7. Houses were constructed on the slope of hillock by leveling the soft soil and without any protective measures for possible land slide
8. Railway track running by the side of the hillock not only creates vibration, it echoes in view of other hills around.
9. The track platform prevented easy drain of water during floods.

Immediate action suggested in Kadwad

1. Western portion of the hillock between two slide points is still intact mainly due to little forest created by protected trees. This portion is highly vulnerable in the near future in view of the open hillock. There is a need to survey and rehabilitate them.
2. Making proper rain drain and slopes to prevent further slide.

REPORT OF FOREST DEPARTMENT IN THE MATTER OF MUD SLIDE INCIDENCE IN MADIBAGH JARIVADI VILLAGE ON 01 OCTOBER 2009

INTRODUCTION:

"Mudslides", defined as rapid movement (upto 80 kmph) of soil mixed with stones, small vegetation and debris due to the shearing force of high intensity rainfall is a phenomena that is not uncommon in coastal regions. They attract our attention when they cause some damage to property or obstruct traffic, but when they result in human casualties they are viewed very seriously. In coastal areas, the presence of lateritic soils which are notorious to lead to mudslides along with long hot summers and high intensity prolonged period of rainfall, is a perpetual and potential hazard.

HISTORY: The mudslide that caused severe damage in the village of Kadwad was on 01st October 2009. It was a day on which 443 mm of rain was received in 24 hours. But is that the highest intensity and hence the mudslide?

Data shows that on 12 June 1999 there was 469.3 mm. of rain and on 29 May 2006 there was 439.8mm of rain received in 24 hours in Karwar. These are greater than the figures of 01st October 2009. There are no mudslides reported on these days. This does not mean that mudslides did not take place on those days. Probably they happened in areas away from human inhabitation and were thus not spotted and reported.

Another possibility to be borne in mind is that ainfall figures for 24 hours is not a veryreliable measure of peak intensity. Had all the rain fallen in a period of just 2 hours within the 24 hour period we are looking through, the peak intensity which is actually responsible for mudslides, was more than that reported will be 12 times more than what will be computed. My inquiries with the local people reveals that almost 75% of the rain reported on the day of mudslide had fallen in just 4 hours. Thus the actual intensity of rain on the day of mudslide was much more than that reported on 12 June 1999 and 29 May 2006 .Had the national highway not been breached by the district administration the town would have remained under water for days together.

There is also a definite pattern in mudslides. They will frequently occur in high gradient bare slopes but will not occur in low gradient forested slopes. This can be seen if one walks along

Haider ghat (nearly 14 kms of jungle path made by Hyder Ali from Todur to Shirwar). I have done so along with Mr. Pankaj Kumar Pandey, IAS., (he was an IAS Probationer attached to Karwar and is now Deputy Commissioner, Shimoga), Dr Bhandari of Government Arts and Science College, Karwar, and my staff. From Todur side upto about 8 kms the country is fairly well covered with multi storeyed forest. No mudslides and its indications are seen there. But as one crosses a ridge near Nagahalla, the land gets denuded od big trees. In this stretch many incidences of mudslides are seen. The soil and slope in the entire stretch is almost the same, the absence of good tree cover can be thus be taken as a cause of mudslides.

GEOLOGY: My experience of working in Karwar from 2000 to 2003 has provided me some insight into the geology of the area. The underlying rock is almost everywhere granite which is nonporous to water. Though granite hills look monolithic, one of the inspections of the railway tunnel that I was required to do along with Konkan railway authorities (the first tunnel towards Ankola after Shirwad railway station) in 2000-01, revealed that there were many deep cracks in the granite rocks that were draining rainwater that fell on the hill surfaces.

Over this granite is the soil, rich in oxides and hydroxides of iron and aluminum, of varying thickness bound and staying in place primarily due to cohesive and adhesive binding forces. It is plastic but rock like hard in dry summers, but becomes a viscid mass capable of moving under sufficient shearing force in the form of a semi solid mass having great momentum along slopes, and thus capable of causing great damage. And rainwater that falls on the lateritic soil hills, when draining through the natural cracks in the granite, accumulate huge quantity of water that provides the shearing force which tends to move the soil. The four facts that cause mudslides are –

1) High intensity rainfall,
2) Non porous nature of underlying rock,
3) High slope gradient of hills, and,
4) Porous nature and shallow depth of soils.

The first two factors are beyond human control, the third one can be modified to some extent by engineering measures (having contour terracing done or by building retaining walls of small height etc.,) and the fourth one can be improved by introducing vegetation, only shrubs and deep rooted trees.

CAUSE OF THE PRESENT MUDSLIDE: My inspection of the mudslide on 14-10-2009 reveals the following :-

1) The hill abutting the village was quite steep,
2) The soil is deep (more than 5 metres),
3) The tree cover is not good, the deep rooted huge trees that bind soils at depths and retard

the speed of rainwater flowing along the slope giving shearing force for mudslides absent,

4) The houses that were affected were precariously close to the base of the hill,
5) and the **most important fact is that the hill in the forest portion was vertically cut to a height of upto 20 mts and the soil sold by the malkidar for monetery gain or to enable him to encroach forest land (a very very common thing in the entire district) thare by craeting an unstable land mass standing against gravity.**

The cause of the mudslide, in my judgement is purely natural. But had the hill been covered with good vegetation and the hill not cut as detailed above, the tragedy could have been averted or the damage would have been less. Regarding mudslides along the national highway, the main cause is quarrying including the use of explosives.

RECOMMENDATIONS

Based upon the above, I would make the following recommendations:-

1. No one should be allowed to cut any hill for any purpose nor any activity that vibrates the soil continously be allowed in the area.
2. All the hills that fall close to inhabitations may be planted with trees along contours.
3. Since fire becomes the first cause of denudation of hills, all the hills close of inhabitation should be rigidly protected against fires.
4. No activity that can cause or alter cracks in the underlying rocks (using explosives, working with heavy machinery etc.,) and/or those which increase the slope of hills (examples: quarrying, mining on the curved surfaces of hills between the base and the top) are to be allowed.

Land cover Assessment-Uttara Kannada District

T. V. Ramachandra, *Senior Member, IEEE*, Uttam Kumar, *Student Member, IEEE*
P. G. Diwakar and N. V. Joshi

***Abstract*—Landslide is induced by a wide range of ground movements, such as rock falls, deep failure of slopes, shallow debris flows, etc. These ground movements are caused when the stability of a slope changes from a stable to an unstable condition. A change in the stability of a slope can be caused by a number of factors acting together such as loss or absence of vegetation (changes in land cover), soil structure, etc. Loss of vegetation happens when the forest patch is fragmented that can be either anthropogenic or natural. Hence land cover mapping with forest fragmentation can provide an opportunity for visualising the areas that require immediate attention from slope stability aspects. In this paper, À Trous algorithm based wavelet transform is used to merge IRS 1D LISS-III MSS (23.5 m) and PAN (5.8 m) images. The fused images are classified using K-nearest neighbour for land cover categories . A fragmentation model is developed to analyse the extent of forest fragmentation in Uttara Kannada district, Karnataka, India. This helped in visualising the effect of land use changes in five west flowing river basins in the district. Field investigation of land slide region confirm that land cover plays a very vital role in landslides. Change in land cover in the catchment area of these rivers has triggered landslide.**

***Index Terms*—Landslide, à trous, multiresolution**

I. Introduction

A LANDSLIDE is a geological phenomenon involving small to medium to large ground movements caused due to change in stability of a slope to an unstable condition. Change in the stability of a slope can be induced by a number of factors, acting together or alone such as rock falls, deep failure of slopes, shallow debris flows, ground water pressure, loss or absence of vegetative cover, erosion, soil nutrients, soil structure, etc. Although the action of gravity is the primary driving force for a landslide to occur, there are other contributing factors affecting the original slope stability. The pre-conditional factors build up specific sub-surface conditions that make the area/slope prone to failure, whereas the actual landslide often requires a trigger before being released. A change in land cover due to the loss of vegetation is a primary factor that builds up specific sub-surface conditions for landslide to occur. The losses in vegetation cover results in fragmenting large, continuous area of forest into two or more fragments. Forest fragmentation apart from affecting the biodiversity and ecology of the region has a significant influence in the movement of soil (silt) and debris in an undulating terrains with high intensity rainfall. Forest fragmentation analysis spatially aids in visualizing the regions that require immediate attention to minimize landslides. Spatial fragmentation map depicts the type and extent of fragmentation. These are derived from land use (LU) data which are obtained from multi-source, multi-sensor, multi-temporal, multi-frequency or multi-polarization remote sensing (RS) data. The objectives of this paper are

i.) Pixel based image fusion of LISS (Linear Imaging Self Scanner)-III MSS (Multispectral) images of 23.5 m spatial resolution with PAN (Panchromatic) image of 5.8 m spatial resolution using À Trous algorithm based wavelet transform (ATW).
ii.) Classification of fused image using K-nearest neighbour to obtain LU map.
iii.) Forest fragmentation analysis to characterise the type and extent of fragmentation or loss of vegetation cover.

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II. Methods

A. Pixel based image fusion: Earth observation satellites provide data at different spatial, spectral and temporal resolutions. Satellites, such as IRS bundle a 4:1 ratio of a high resolution PAN band and low resolution MSS bands in order to support both colour and best spatial resolution while minimizing on-board data handling needs [1]. For many applications, the fusion of spatial and spectral data from multiple sensors aids in delineating objects with comprehensive information due to the integration of spatial information present in the PAN image and spectral information present in the low resolution MSS data. Pixel based image fusion refers to the merging of measured physical parameters or fusion at the lowest processing level of co-registered or geocoded data. Many fusion techniques are developed to integrate both PAN and MSS data considering, application of the user. In this communication we use the À Trous algorithm based wavelet transform (ATW).

Multiresolution analysis based on the wavelet theory (WT) is based on the decomposition of the image into multiple channels depending on their local frequency content. While the Fourier transform gives an idea of the frequency content in image, the wavelet representation is an intermediate representation and provides a good localisation in both frequency and space domain [2]. The WT of a distribution *f(t)* is expressed as

$$W(\mathrm{f})\ (a,b) = |a|^{-\frac{1}{2}} \int_{-\infty}^{+\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt \qquad (1)$$

where a and b are scaling and transitional parameters, respectively. Each base function $\psi\left(\frac{t-b}{a}\right)dt$ is a scaled and translated version of a function ψ called *Mother Wavelet*. These base functions are $\int \psi\left(\frac{t-b}{a}\right) = 0$. Most of the WT algorithms produce results that are not shift invariant. An algorithm proposed by Starck and Murtagh [3] uses a WT known as à trous to decompose the image into wavelet planes that overcomes this problem. Given an image **p** we construct the sequence of approximations: $F_1(\mathbf{p}) = \mathbf{p}_1,\ F_2(\mathbf{p}_1) = \mathbf{p}_2,\ F_3(\mathbf{p}_2) = \mathbf{p}_3,\ \ldots$. by performing successive convolutions with a filter obtained from an auxiliary function named scaling function which has a $\mathbf{B_3}$ cubic spline profile. The use of a $\mathbf{B_3}$ cubic spline leads to a convolution with a mask of 5 x 5:

$$\frac{1}{256}\begin{pmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{pmatrix}. \quad (2)$$

The wavelet planes are computed as the differences between two consecutive approximations $\mathbf{p}_{l-1}$ and $\mathbf{p}_l$. Letting $w_l = \mathbf{p}_{l-1} - \mathbf{p}_l$ (l = *1*, …, *n*), in which $\mathbf{p}_0 = \mathbf{p}$, the reconstruction formula can be written as

$$\mathrm{p} = \sum_{l=1}^{n} w_l + \mathrm{p_r}. \quad (3)$$

The image $\mathbf{p}_l$ (l = 0, …, n) are versions of original image **p**, $\mathbf{w}_l$ (l = 1, …, n) are the multiresolution wavelet planes, and $\mathbf{p}_r$ is a residual image. The wavelet merger method is based on the fact that, in the wavelet decomposition, the images $\mathbf{p}_l$ (l = 0, …, n) are the successive versions of the original image. Thus the first wavelet planes of the high resolution PAN image have spatial information that is not present in the MSS image. In this paper, we follow the Additive method [2] where the high resolution PAN image is decomposed to n wavelet planes. For 1:4 fusion (as in IRS 1D) n is set to 2.

$$\mathbf{PAN} = \sum_{l=1}^{n} w_{\mathrm{P}l} + \mathbf{PAN}_r \quad (4)$$

The wavelet planes of the PAN decomposition are added to the low resolution MSS images individually to get high resolution MSS images.

B. K-nearest neighbour classification: Two of the main challenges in RS data interpretation with using parametric techniques are high dimensional class data modeling and the associated parameter estimates. While the Gaussian normal distribution model has been adopted widely, the need to estimate a large number of covariance terms leads to a high demand on the number of training samples required for each class of interest. In addition, multimode class data cannot be handled properly with a unimodal Gaussian description. Nonparametric methods, such as K-nearest neighbour (KNN) have the advantage of not needing class density function estimation thereby obviating the training set size problem and the need to resolve multimodality [4]. The KNN algorithm [5] assumes that pixels close to each other in feature space are likely to belong to the same class. It bypasses density function estimation and goes directly to a decision rule. Several decision rules have been developed, including a direct majority vote from the nearest k neighbours in the feature space among the training samples, a distance-weighted result and a Bayesian version [6].

Let **x** be an unknown pixel vector and suppose there are k_i neighbours labelled as class ω_i out of k nearest neighbours. $\sum_{i=1}^{M} k_i = k$ (M is the number of class defined). The basic KNN rule is $x \in \omega_i,\ \ if\ \ m_i(x) > m_j(x)$ for all $j \neq i$

where

$$m_i(x) = k_i \quad (5)$$

If the training data of each class is not in proportion to its respective population, $p(\omega_i)$, in the image, a Bayesian Nearest-Neighbour rule is suggested based on Bayes' theorem

$$m_i(x) = \frac{p(x \mid \omega_i)p(\omega_i)}{\sum_{j=1}^{M} p(x \mid \omega_i)p(\omega_j)} = \frac{k_j p(\omega_i)}{\sum_{j=1}^{M} k_j p(\omega_j)} \quad (6)$$

The basic rule does not take the distance of each neighbour to the current pixel vector into account and may lead to tied results every now and then. Weighted-distance rule is used to improve upon this as

$$m_i(x) = \frac{\sum_{j=1}^{k_i} 1/d_{ij}}{\sum_{i=1}^{M}\sum_{j=1}^{k_i} 1/d_{ij}} \quad (7)$$

where d_{ij} is Euclidean distance. Assuming there are S training samples, one needs to find the *k* nearest neighbours from S training samples for every pixel in a large image. This means S spectral distances must be evaluated for each pixel. The above algorithm is summarised as follows:

The variable unknown denotes the number of pixels whose class is unknown and the variable wrong denotes the number of pixels which have been wrongly classified.

set No: of pixels = 0.
set unknown = 0.
set wrong = 0.
For all the pixels in the test image
do
{
1. Get the feature vector of the pixel and increment no. of pixels by 1.

2. Among all the feature vectors in the training set, find the sample feature vector which is nearest (nearest neighbor) to the feature vector of the pixel.

3. If the no. of nearest neighbors is more than 1, then

Check whether the corresponding class labels of all the nearest sample feature vectors are the same.

If the corresponding class labels are not the same, then increment unknown by 1 and go to Step 1 to process
the next pixel else go to Step 4.

4. Class label of the image pixel=class label of the nearest sample vector. Go to Step 1 to process the next pixel.
}

C. Forest fragmentation: Forest fragmentation is the process whereby a large, continuous area of forest is both reduced in area and divided into two or more fragments. The decline in the size of the forest and the increasing isolation between the two remnant patches of the forest has been the major cause of declining biodiversity [7, 8, 9, 10 and 11]. The primary concern is direct loss of forest area, and all disturbed forests are subject to "edge effects" of one kind or another. Forest fragmentation is of additional concern, insofar as the edge effect is mitigated by the residual spatial pattern [12, 13 and 14].

LU map indicate only the location and type of forest, and further analysis is needed to quantify the forest fragmentation. Total extent of forest and its occurrence as adjacent pixels, fixed-area windows surrounding each forest pixel is used for calculating type of fragmentation. The result is stored at the location of the centre pixel. Thus, a pixel value in the derived map refers to between-pixel fragmentation around the corresponding forest location. As an example [15] if *Pf* is the proportion of pixels in the window that are forested and *Pff* is the proportion of all adjacent (cardinal directions only) pixel pairs that include at least one forest pixel, for which both pixels are forested. Pff estimates the conditional probability that, given a pixel of forest, its neighbour is also forest. The six fragmentation model that identifies six fragmentation categories are: (1) interior, for which Pf = 1.0; (2), patch, Pf < 0.4; (3) transtitional, 0.4 < Pf < 0.6; (4) edge, Pf > 0.6 and Pf-Pff > 0; (5) perforated, Pf > 0.6 and Pf-Pff < 0, and (6) undetermined, Pf > 0.6 and Pf = Pff. When Pff is larger than Pf, the implication is that forest is clumped; the probability that an immediate neighbour is also forest is greater than the average probability of forest within the window. Conversely, when Pff is smaller than Pf, the implication is that whatever is nonforest is clumped. The difference (Pf-Pff) characterises a gradient from forest clumping (edge) to nonforest clumping (perforated). When Pff = Pf, the model cannot distinguish forest or nonforest clumping. The case of Pf = 1 (interior) represents a completely forested window for which Pff must be 1.

III. Study Area and Data

The Uttara Kannada district lies 74°9' to 75°10' east longitude and 13°55' to 15°31' north latitude, extending over an area of 10,291 km^2 in the mid-western part of Karnataka state (Fig. 1). It accounts for 5.37 % of the total area of the state with a population above 1.2 million [16]. This region has gentle undulating hills, rising steeply from a narrow coastal strip bordering the Arabian sea to a plateau at an altitude of 500 m with occasional hills rising above 600–860 m. This district, with 11 taluks, can be broadly categorised into three distinct regions — coastal lands (Karwar, Ankola, Kumta, Honnavar and Bhatkal taluks), mostly forested Sahyadrian interior (Supa, Yellapur, Sirsi and Siddapur taluks) and the eastern margin where the table land begins (Haliyal, Yellapur and Mundgod taluks). Climatic conditions range from arid to humid due to physiographic conditions ranging from plains, mountains to coast.

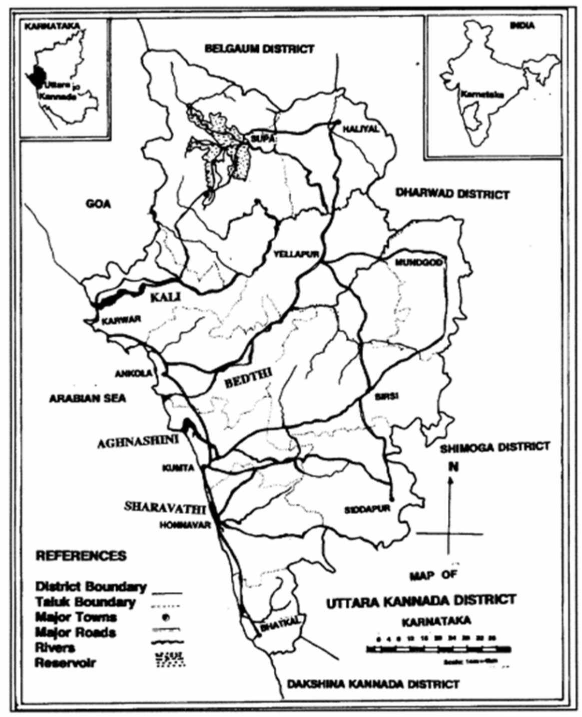

Fig. 1. Uttara Kannada district, Karnataka, India

Survey of India (SOI) toposheets of 1:50000 and 1:250000 scales were used to generate base layers – district and taluk boundaries, water bodies, drainage network, etc. Field data were collected with a handheld GPS. RS data used in the study were LISS-III MSS (in Blue, Green and Red bands) and PAN band, procured from NRSA, Hyderabad, India. Google Earth data (http://earth.google.com) served in pre and post classification process and validation of the results.

IV. Results and Discussion

RS data were geometrically corrected on a pixel by pixel basis. The low resolution MSS images (7562 x 4790) were upsampled to the size of high resolution PAN image (30284 x 19160). MSS and PAN data were fused using ATW method and the decomposition level (*n*) was set to 2. Land cover (LC) mapping (Fig. 2) was done using normalised difference vegetation index (NDVI) given as

$$\frac{\text{NIR-Red}}{\text{NIR+Red}} \qquad (8)$$

NDVI values range from -1 to +1; increasing values from

0 indicate presence of vegetation and negative values indicate absence of greenery. LC analysis showed 94 % green (agriculture, forest and plantation) and remaining 6 % other categories (builtup, sand, fallow, water).

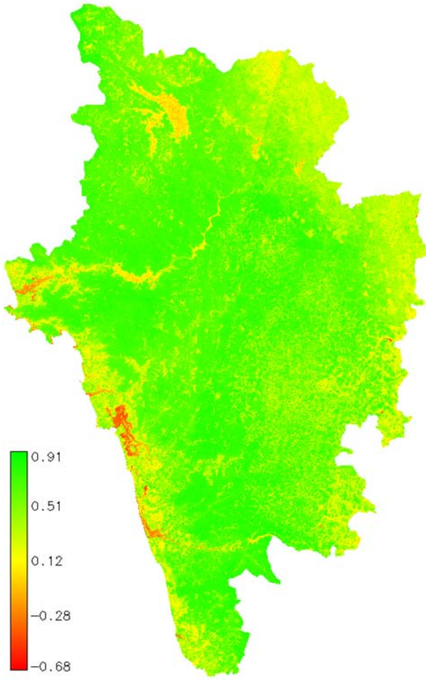

Fig. 2. LC of Uttara Kannada district.

Mapping of water bodies (Fig. 3) was done using normalised difference water index (NDWI) [17] given as

$$\frac{\text{Green-NIR}}{\text{Green+NIR}} \tag{9}$$

NDWI values above 0 indicate presence of water bodies and values below 0 indicate other classes. The major rivers in Uttara Kannada are showed in blue in Fig. 3 that constitute approximately 2.5 % (25000 ha) of the entire district.

The class spectral characteristics for six LU categories (agriculture, builtup, forest, plantation, waste land / fallow / sand, and water bodies) using LISS-III MSS bands 2, 3 and 4 were obtained from the training pixels spectra to assess their inter-class separability and the images were classified using KNN with training data uniformly distributed over the study area collected with pre calibrated GPS (Fig. 4). This was validated with the representative field data (training sets collected covering the entire city and validation covering ~ 10% of the study area) and also using Google Earth image.

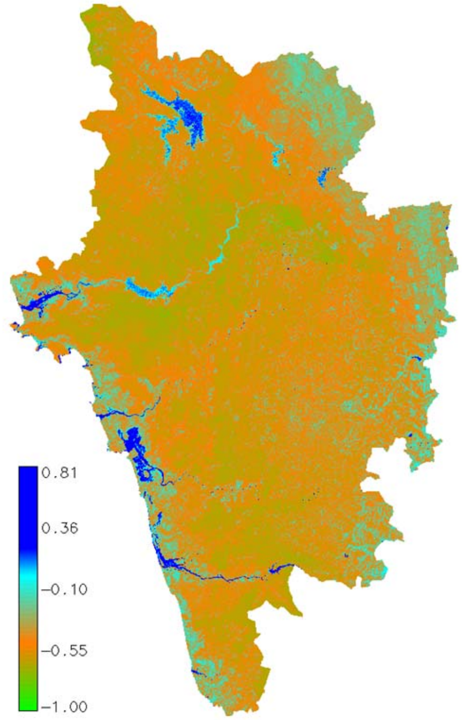

Fig. 3. Water Index of Uttara Kannada district.

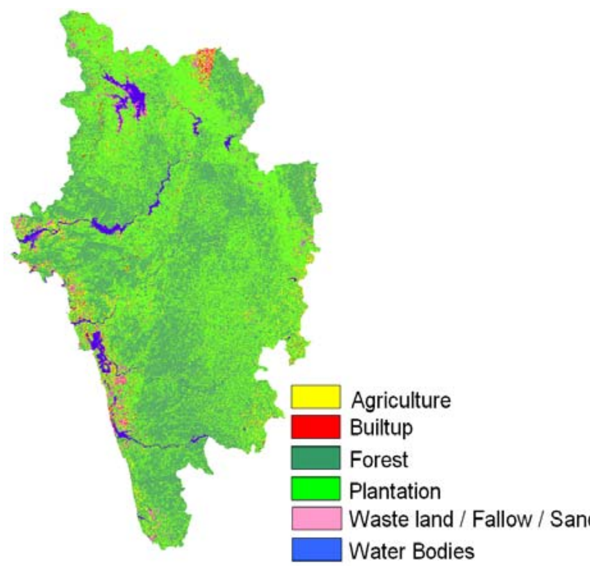

Fig. 4. LU in Uttara Kannada district.

LU statistics, producer's accuracy, user's accuracy and overall accuracy computed are listed in table 1. Using the results from classification, forest fragmentation model was used to obtain fragmentation indices as shown in Fig. 5 and the statistics are presented in table 2. Forest and plantation were considered as a single class - forest and all other classes were considered as non-forest as the extent of land cover is a decisive factor in landslides. It is seen that majority of the area (97 %) is interior forest.

TABLE I: LU DETAILS OF UTTARA KANNADA DISTRICT

CLASS	AREA (HA)	AREA (%)	P* (%)	U* (%)	O* (%)
AGRICULTURE	38023	3.71	85.21	84.54	89.63
BUILTUP	6638	0.65	86.47	83.11	
FOREST	448815	43.79	94.73	96.20	
PLANTATION	484389	47.26	92.27	91.73	
WASTE LAND / FALLOW / SAND	22311	2.18	88.49	87.88	
WATER BODIES	24663	2.41	93.13	94.33	
TOTAL	1024839	100	-	-	-

TABLE II: FOREST FRAGMENTAION DETAILS

CLASS	AREA (HA)	AREA (%)
PATCH	917	0.10
TRANSITIONAL	2838	0.33
EDGE	11529	1.24
PERFORATED	9115	0.98
INTERIOR	906946	97.38
TOTAL	931345	100.00

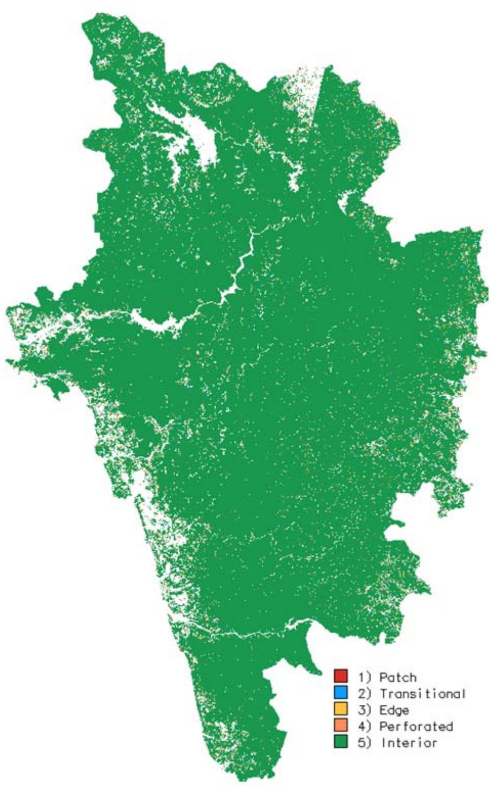

Fig. 5. Fragmentation of forests in Uttara Kannada district.

While the forest fragmentation map produced valuable information, it also helped to visualise the state of forest for tracking the trends and to identify the areas where forest restoration might prove appropriate to reduce the impact of forest fragmentation. Forest fragmentation also depends on the scale of analysis (window size) and various consequences of increasing the window size are reported in [15]. The measurements are also sensitive to pixel size. Nepstad et al., (1999a, 1999b) [18, 19] reported higher fragmentation when using finer grain maps over a fixed extent (window size) of tropical rain forest. Finer grain maps identify more nonforest area where forest cover is dominant but not exclusive. The strict criterion for interior forest is more difficult to satisfy over larger areas. Although knowledge of the feasible parameter space is not critical, there are geometric constraints [20]. For example, it is not possible to obtain a low value of Pff when Pf is large. Percolation theory applies strictly to maps resulting from random processes; hence, the critical values of Pf (0.4 and 0.6) are only approximate and may vary with actual pattern. As a practical matter, when Pf > 0.6, nonforest types generally appeared as “islands” on a forest background, and when Pf < 0.4, forests appeared as “islands” on a nonforest background.

There are five major west flowing rivers – Kali, Bedthi, Aginashini, Sharavathi and Venkatpura. Since LU in the catchment area of a river plays an important role in defining the course of the river, water quality and water retaining properties of the soil grains due to the presence of vegetation, the analysis was done for each watershed separately. LU map and forest fragmentation map of the five river basins are shown in Fig. 6 and statistics are given in table III. All the rivers are perennial since the catchment areas are mainly composed of interior forest. However, people have started converting forest patches for agricultural purposes. In addition, the dams present in the major rivers of the district have inundated large vegetation areas. These areas have silt deposit at the river beds and have been classified as sand / waste land. If the vegetative areas have been cleared, the water retaining capacity of the soil has decreased, triggering landslides in those areas. There is a immediate need to restore those vegetative by forestation to ensure that the soil is retained on the hill slopes and do not activate any downward movement of the hill tops.

V. CONCLUSION

The analysis showed that although the proportion of vegetation (natural forest and plantation which include – Acacea, Araca, Euclyptus, etc.) constitute major part of the LU in the district, recent field survey indicate many forest patches being used for agricultural activities. Conversions of land from forests to agriculture in undulating terrains have contributed to land slides, evident from the field data of landslides in the region. Hence, forest restoration is required to avoid erosion and prevent landslides.

VI. ACKNOWLEDGMENT

This research was carried out with the financial assistance from ISRO-IISc Space Technology Cell. We thank NRSA, Hyderabad for providing IRS 1D data.

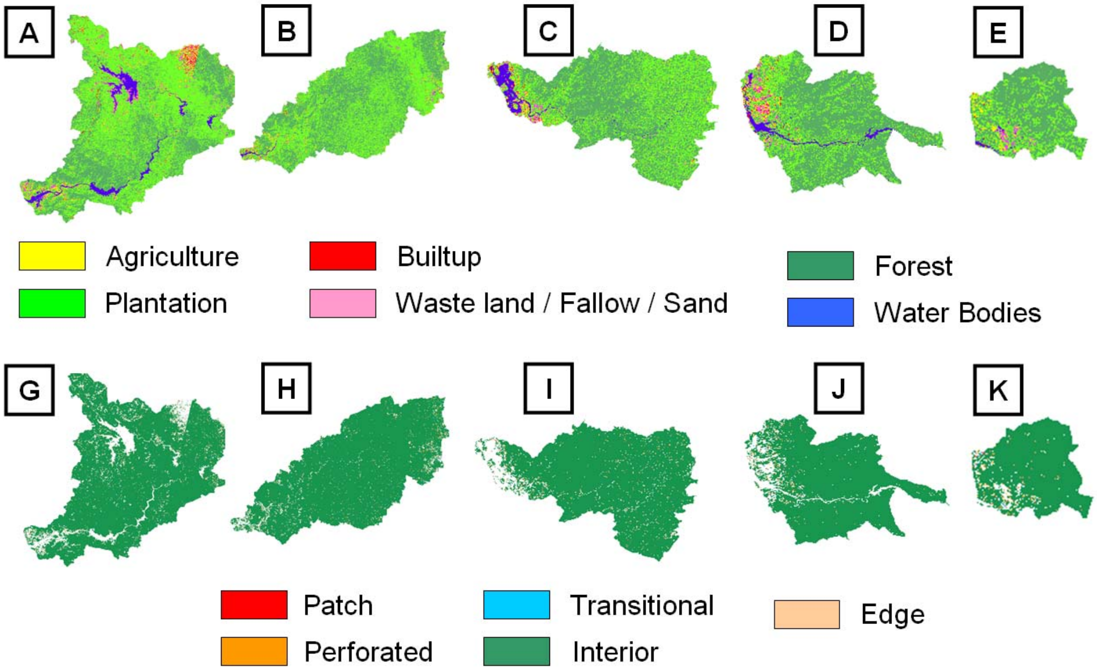

Fig. 6. LU in the catchments of five major river basins in Uttara Kannada district – (A) Kali, (B) Bedthi, (C) Aginashini, (D) Sharavathi, (E) Venkatpura.
Forest fragmentation in five river basins in Uttara Kannada district – (G) Kali, (H) Bedthi, (I) Aginashini, (J) Sharavathi, (K) Venkatpura.

TABLE III: LU DETAILS OF THE FIVE RIVER BASINS

CLASSES →	AGRICULTURE		BUILTUP		FOREST		PLANTATION		WASTE LAND / FALLOW / SAND		WATER BODIES	
AREA →	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
KALI	13305	3.56	3176	0.85	127311	34	203491	54.4	11240	3	15023	4
BEDTHI	5671	2	652.4	0.24	126532	46.3	136746	50	2616	0.96	1242	0.45
AGINASHINI	3654	2.68	673	0.49	72356	53	53604	39.3	1929	1.41	4323	3.17
SHARAVATHI	2537	3.13	607.7	0.75	49367	61	23794	29.4	2093	2.58	2627	3.24
VENKATPURA	778	3.45	73	0.32	14491	64.3	6507	28.8	509	2.26	197.8	0.88

TABLE IV: FOREST FRAGMENTATION DETAILS OF THE FIVE RIVER BASINS

CLASSES →	PATCH		TRANSITIONAL		EDGE		PERFORATED		INTERIOR	
AREA →	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
KALI	359	0.11	1085	0.33	4119	1.25	3027	0.92	321589	97.4
BEDTHI	159	0.06	501	0.19	2462	0.94	1655	0.63	258209	98.18
AGINASHINI	70.8	0.06	234.6	0.19	1191	0.95	961	0.76	123265	98.05
SHARAVATHI	53	0.07	163.3	0.22	632.2	0.87	571.1	0.78	71465.8	98.05
VENKATPURA	23.49	0.11	67.08	0.32	246.3	1.18	225	1.07	20379	97.32

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