GOVERNMENT OF INDIA
GEOLOGICAL SURVEY OF INDIA

A NOTE ON THE PRELIMINARY POST DISASTER INVESTIGATION OF LANDSLIDES OCCURRED AROUND MADIKERI, COORG DISTRICT, KARNATAKA

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BANGALORE

2013

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Introduction: The monsoon showers of July 2013 caused many landslides in Coorg district. There were media reports of cracks in the ground near Mannangeri village in Madikeri taluk. The Preliminary investigation of the landslides was taken up on priority as per the instruction received from the Dy. Director General, SU: Karnataka and Goa, Geological Survey of India, Bangalore. The investigation aimed at the assessment of the nature, causes, the future risk and vulnerability at the Landslide sites as well as suggesting remedial measures both immediate and long term.

The preliminary investigation was carried out at the following sites in two phases from 25.07.2013 to 28.07.2013 and from 12.8.2013 to 13.8.2013.

First phase

i. Ground cracks near Mannageri Village
ii. Ground cracks near Makandur village
iii. Landslide on SH-88 between Madikeri-Sampaje
iv. Landslide on Makandur- Mukkodlu tantipal road
v. Landslide on Hattihole- Avandi road
vi. Landslide near Makandur Village, Sinchona estate road.
vii. Subsidence on SH-88 near Sinchona estate between Madikeri-Suntikoppa
viii. Landslide near Kattalekadu on SH-89 between Madikeri-Chettali
ix. Landslide near Abbiyala on SH-89 between Madikeri-Chettali
x. Landslide near Jodpal on SH-88 between Madikeri-Sampaje

Second Phase

xi. Subsidence near Koynad on SH-88 between Madikeri and Sampaje

Rainfall data: The area of investigation receives very high rainfall during the monsoons, data was collected from the rain gauge station in Madikeri and antecedent distribution pattern was worked out (Table 1& 2; Figure 2). Though the rainfall data is not from the actual site the general trend of rainfall may be brought out from the data. The average rainfall trend of the region is seen from the rainfall data for Madikeri (ARS) rainguage station for last 11 years and till July 30 of this year (Table 3; Fig 3).

Table: 1. Rain fall data for the month of June2013 at Madikeri Rain gauge Station

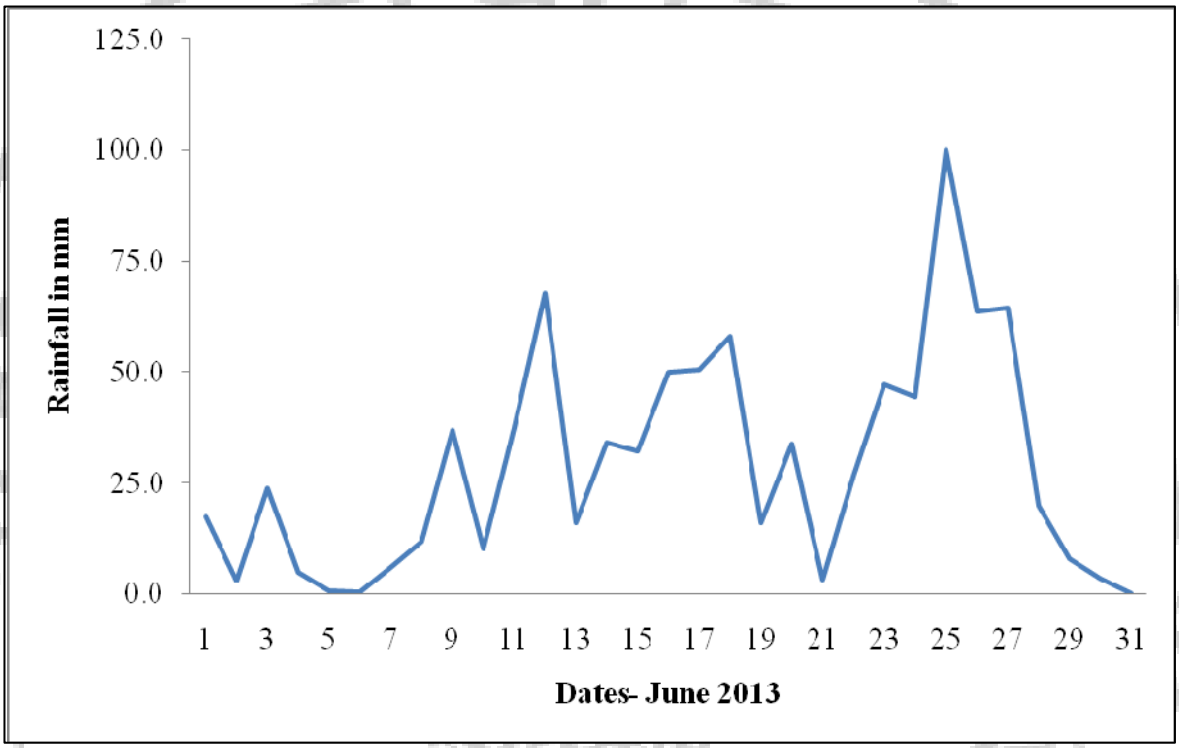
Date	Rain fall (in mm)	Date	Rain fall (in mm)
01.06.2013	17.2	17.06.2013	50.4
02.06.2013	2.8	18.06.2013	57.8
03.06.2013	23.8	19.06.2013	16.0
04.06.2013	4.8	20.06.2013	33.8
05.06.2013	0.6	21.06.2013	3.2
06.06.2013	0.4	22.06.2013	26.4
07.06.2013	5.8	23.06.2013	47.2
08.06.2013	11.6	24.06.2013	44.4
10.06.2013	36.8	25.06.2013	100.0
10.06.2013	10.0	26.06.2013	63.6
11.06.2013	37.2	27.06.2013	64.4
12.06.2013	67.8	28.06.2013	19.8
13.06.2013	16.0	29.06.2013	7.8
14.06.2013	34.0	30.06.2013	3.4
15.06.2013	32.0		
16.06.2013	50.0	**Total**	**889.0**

Source: Taluk office, Madikeri, Coorg dist., Karnataka

Table: 2. Rain fall data for the month of July 2013 at Madikeri Rain gauge Station

Date	Rain fall (in mm)	Date	Rain fall (in mm)
01.07.2013	2.0	17.07.2013	49.2
02.07.2013	30.8	18.07.2013	43.2
03.07.2013	66.6	19.07.2013	150.2
04.07.2013	134.6	20.07.2013	107.8
05.07.2013	117.0	21.07.2013	101.4
06.07.2013	46.4	22.07.2013	98.8
07.07.2013	123.0	23.07.2013	53.0
08.07.2013	26.2	24.07.2013	60.6
10.07.2013	27.8	25.07.2013	107.0
10.07.2013	30.2	26.07.2013	61.0
11.07.2013	4.6	27.07.2013	51.2
12.07.2013	68.0	28.07.2013	60.0
13.07.2013	35.4	29.07.2013	59.2
14.07.2013	40.4	30.07.2013	10.2
15.07.2013	22.6	31.07.2013	
16.07.2013	40.6	**Total**	**1829.0**

Source: Taluk office, Madikeri, Coorg dist., Karnataka



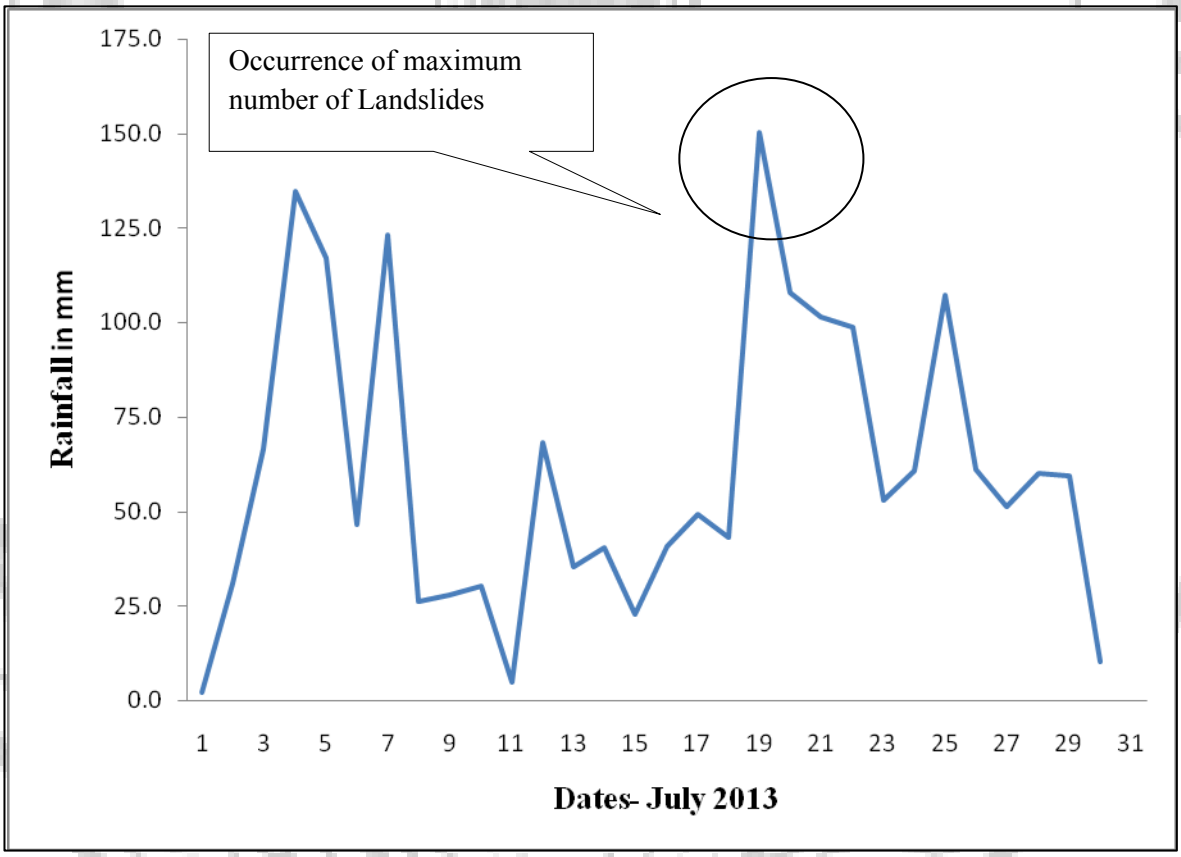


Fig 2: Antecedent rainfall distribution pattern and the sliding event

Table 1: Annual Rainfall at Madikeri (ARS) rain gauge station over years

Year	Annual rain fall(in mm) at Madikeri (ARS) rainguage station
2002	2849.3
2003	2754.2
2004	3380.9
2005	3504.5
2006	3429.8
2007	4110.2
2008	2923.8
2009	3334.8
2010	2837.8
2011	3441.8
2012	2477.9
Average for 11 years	3185.9

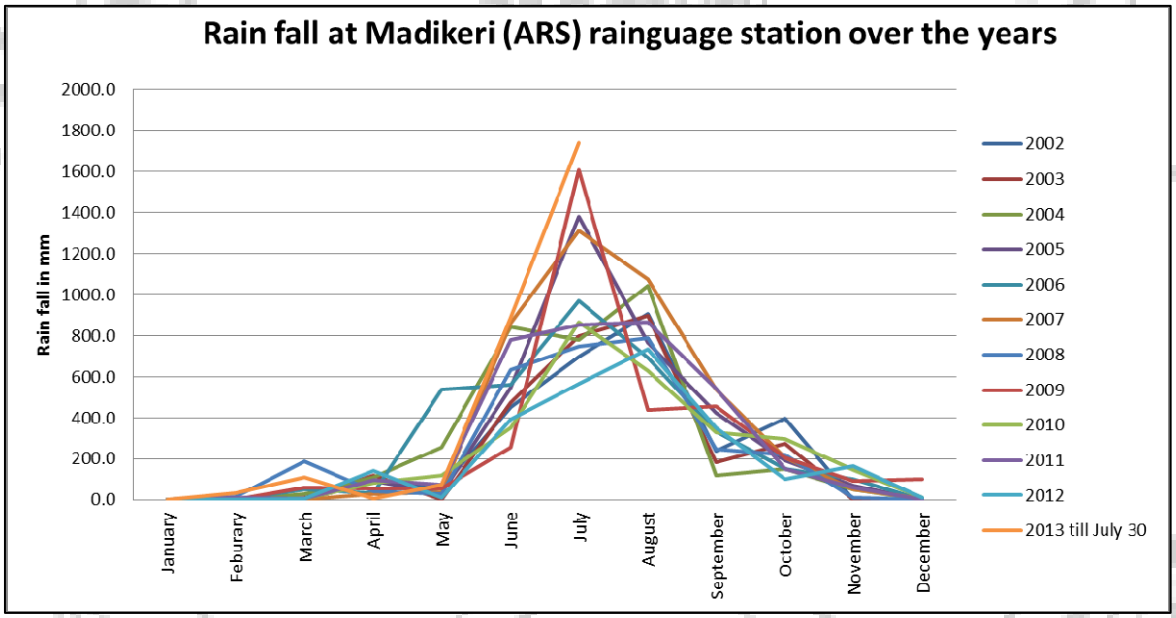


Fig 3: Annual rainfall at Madikeri (ARS) rainfall station.

The study of rainfall data reveals that the average annual rainfall at Madikeri and surrounding areas where landslide/ subsidence have occurred is around 3180 mm and the monthly average rainfall of July is around 900 mm. This year the rainfall is heavy with cumulative annual rainfall already reaching about 2848.7 by the end of July, and in July month alone the rainfall is around 1829.0 mm i.e. almost double the average rainfall. It may be stated here that the rainfall is the main trigger for causing all the landslide/ subsidence.

ASSESMENT OF INDIVIDUAL LANDSLIDE/ GROUND CRACKS/ SUBSIDENCE

1. Ground cracks near Mannageri Village:

Ground cracks were first appeared and seen at the house of one Shri. Jayaprakash in Mannageri village on 21.07.2013 and subsequently seen at the house of Babu Pujari down the valley.

Location: the area of ground cracks is located in toposheet no 48P/11 at latitude 12º 26′ 19.5″N and longitude 75º 40′ 40.0″E (Shri. Jayapraksh house); latitude 12º 26′ 15.9″N and longitude 75º 40′ 35.7″E(Shri. Babu Pujari house). The cracks are seen on the south west slope of the NW-SE trending mound.

Landuse and landcover: The slope has been modified for habitation and plantation since last two decades. the slope is modified by cutting the original trees and making way for cash crops like coffee, pepper and other spices.

Geology at site: Highly weathered granite gnessis is the only lithounit exposed in the area.

Crack geometry: The geometry of the cracks was difficult to delineate due to constant rainfall and ground covered with plantation and vegetation. The cracks at the house of Jayaprakash at the back wall are 10-15 cm wide. On the pavement of the house it is radial in nature with 12-15 cm wide (Photo 1). The cracks are extending down the valley for about 600-700 m (Photo 4) including the road leading to school of the village. There was no evidence of subsidence at the time of study.

Causes for the cracks: The causes for the ground cracks as observed during investigation are as follows:

i. The cracks are mainly caused due to increase in pore water pressure due to heavy infiltration of rainwater. The increase in ground water level has reduced the cohesion and the shear strength of the slope material. The weathered gneissic material at places is converted to clay causing lower permeability of slope(slope material includes highly weathered granite gneiss rock particles of different size ranging from boulders to pebbles, soil, and clay derived from weathering) and increase in pore water pressure.

ii. The slope has been modified for construction of house and plantations. In fact the house of Jayaprakash is constructed right on the *nala* course (Photo 2 & 3). The modification of slope geometry for plantations and settlements in long term has reduced the slope stability.

iii. The rain fall is the triggering factor as the antecedent rainfall in July 2013 shows a sharp rise.

iv. The cracks have appeared in the houses which are not constructed on best practiced structural construction methods. The houses are rather mud houses without any proper basement and structural design.

Recommendations: As per site condition at the time of preliminary studies following measures are recommended.

i. The house of Shri. Jayaprakash is in grave danger and to be evacuated permanently (as of now it is temporarily evacuated) as it is not safe for habitation.

ii. The cracks on the pavement of house, in front of house and road should be monitored regularly to see any new developments including widening, deepening, any subsidence or movement of slope material.

iii. The drainage conditions in the study area have to be improved with channelizing the excess run off of rain water during the rain. Also horizontal perforated pipes may be inserted at suitable intervals and at different levels to drain excess water from the slope to reduce pore water pressure.

The long term remedial measures can only be given after studying the area as whole with proper delineation of crack geometry and crack propagation.

2. Ground cracks near Makandur village:

Ground cracks were first appeared and seen at the house of Smt. M.D.Janaki & Smt. Sittamma in Makandur village on 21.07.2013.

Location: the study area of ground cracks is located in toposheet no 48P/15 at latitude 12º 27′ 28.7″N and longitude 75º 45′ 41.4″E(M.D.Janaki house).The cracks are seen on the northwest slope of the NW-SW trending mound which is on a nala course draining in to Kalur Nala.

Landuse and landcover: The slope has been modified for habitation and plantation since last two decades. the slope is modified by cutting the original trees and making way for cash crops like coffee, pepper and other spices.

Geology at site: The highly weathered granite gnessis is the only lithounit exposed in the area.

Crack geometry: The geometry of the cracks was difficult to delineate due to constant rainfall and ground covered with plantation and vegetation. The cracks on the back wall of house of Janaki are 7-13 cm wide. On the pavement of the house it is radial in nature with 12-15 cm width (Photo 5 & 7). There was a small evidence of subsidence of 40-50 cm seen 150.0 m upstream of the Janaki house (Photo 6). Longitudinal cracks are observed at the side of Sitamma house as well (Photo 8).

Causes for the cracks: The causes for the ground cracks as observed during investigation are as follows:

i. The cracks are mainly caused due to increase in pore water pressure due to heavy infiltration of rainwater. The increase in ground water level has reduced the cohesion and the shear strength of the slope material. The weathered gneissic material at places is converted to clay causing lowering of the permeability of slope material and increase in pore water pressure.

ii. The slope has been modified for construction of house and plantations .The modification of slope geometry for plantations and settlements in long term has reduced the slope stability.

iii. The rain fall is the triggering factor as the antecedent rainfall in July 2013 shows a sharp rise.

iv. The cracks have appeared in the houses which are not constructed on best practiced structural construction methods. The houses are rather mud houses without any proper basement and structural design.

Recommendations: As per site condition at the time of preliminary studies following measures are recommended.

i. The house of Smt. M.D.Janki is in grave danger and to be evacuated immediately as it is not safe for habitation.

ii. The cracks at the house of Janaki and side of the house of Sitamma(ground cracks) should be monitored regularly to see any new developments including widening, deepening, any new subsidence or movement of slope material.

iii. The drainage conditions in the study area have to be improved with channelizing the excess run off of rain water during the rain. Also horizontal perforated pipes may be inserted at suitable intervals and at different levels to drain excess water from the slope to reduce pore water pressure.

The long term remedial measures can only be given after studying the area as whole with proper delineation of crack geometry and crack propagation.

3. Landslide on SH-88 between Madikeri-Sampaje

The landslide along SH-88 between Madikeri-Sampaje occurred on 21.07.2013. The State highway was blocked by the fallen debris (Photo 9&10).

Location **:** The slide is located in toposheet no 48P/11 at latitude 12º 25′ 58.7″N and longitude 75º 40′ 17.8″E**,** nearly 6 Km northwest of Madikeri town.

Land use and land cover: The slope of the study area is modified for coffee plantations and for making of the road.

Geology at site: Lithologically the area exposes weathered gneiss. Two sets of prominent joints are noticed in the gneiss J1-S22^{0}E/80^0 E dipping, 10-20 cm spacing and is tight and J2-S80^0 W/82^0 W dipping 10-20 cm spacing and is tight. The two joints are making a wedge failure also.

Slide morphometry: The slide is a new debris slide (>380.0 m^2 area). The different morphometric parameters of the slide are as follows:

a) Length of slide: 36.0-39.0m
b) Width of slide: 19.6m
c) Depth of slide: ~ 1.0m

d) Base Length: 21.9 m
e) Scarp radius: ~8.0m
f) Scarp height: ~7.0m
g) Scarp angle: ~vertical to 85^0
h) Run out distance :~50.0m
i) Cut slope angle near the toe: 90º
j) Cut slope height near the toe: 10-12 m
k) Slide direction: N25ºE
l) Slope prior to failure: 70º
m) Slope after failure: 65º
n) Overburden thickness: soil of 0.5m
o) Crown condition: Unstable
p) Head condition: Unstable
q) Toe condition: Unstable

Slide material: The slide material in the zone of accumulation and depletion is debris comprising of different fractions of gneisses/weathered gneissic material. The gneisses are highly weathered and patches of limonitic clay are seen on the debris material .The size fraction of debris varies from huge gneissic boulders to small cobbles and pebbles and soil/clay material.

Causes: The causes of this slide are as follows:

i. Slope cut for road formation is vertical and cut slope height is very high (about 12.0 m). The slope is modified for coffee plantation.
ii. The failure is a wedge failure. The wedge failure occurred along two major joint planes J1-S22^0E/80^0 E and J2-S80^0 W/82^0 W. High rainfall removed the material along these planes by infiltrating and acted as lubricant reducing the resisting force.
iii. No proper drainage at toe and crown portions. The drainage at the toe is clogged.
iv. The high rainfall during July 2013 acted as triggering factor.

Recommendations: The corrective measures recommended for stabilisation of slope are as follows:

i. The slided debris is to be removed from the slope. The heaped up debris on the other side of the road has to be removed.
ii. Remove all the loose boulders and hanging boulders.
iii. Reduction in the height of the cut slope by slope grading.
iv. Arrest infiltration of water at the top. Make a proper drainage at the base with concrete lining.
v. A retaining wall of 2m height is to be constructed at the toe. Backfilling the slope with stone pitching at 1:1 slope angle.

4. Landslide on Makandur- Mukkodlu tantipal road:

The landslide along Makandur- Mukkodlu tantipal road occurred on 20.07.2013. The road was blocked by the fallen debris (Photo 11&12). Electric poles by the side of the road were uprooted.

Location **:** The slide is located in toposheet no 48P/15 at latitude 12º 28′ 45.7″N and longitude 75º 40′ 28.3″E**,** nearly 9 Km northeast of Madikeri town .

Land use and land cover: The slope of the study area is modified for coffee plantations, banana other species and also for making of the road.

Geology at site: Lithologically the area exposes weathered granite gneiss.

Slide morphometry: The slide is a new debris slide (>1950.0 m^2 area). It is a multiple slide zone as three slides nearby have occurred during the same time. The slide has occurred on cut slope and slide debris flown over the road in to the nala, (Kalur nala- Photo 13& 14). The zone is still unstable as the crown cracks are seen .The different morphometric parameters of the main slide are as follows:

a) Length of slide: 120.0-130.0 m
b) Width of slide: 30.0 m
c) Depth of slide: ~ 1.0m
d) Run out distance :~50.0m
e) Cut slope angle near the head: 70º
f) Cut slope height near the head: 10-12 m
g) Original slope angle: 17º
h) Slide direction: N30ºW
i) Slope prior to failure: 70º
j) Slope after failure: 65º
k) Overburden thickness: soil of 0.5m
l) Crown condition: Unstable
m) Head condition: Unstable
n) Toe condition: Unstable

Slide material: The slide material in the zone of accumulation and depletion is debris comprising of different fraction of gneisses/weathered gneissic material. The size fraction of debris varies from huge gneissic boulders to small cobbles and pebbles and soil/clay material.

Causes: The causes of this slide are as follows:

i. The slope modification for making road and for plantations.
ii. The Kalur nala is flowing at toe and has undercut/ eroded the toe of the slope.
iii. High rainfall removed the slope material which is highly weathered gneiss. No proper drainage at toe and crown portions. The high rainfall during July 2013 acted as triggering factor.

Recommendations: The corrective measures recommended for stabilization of slope are as follows:

i. As whole road has been washed away the road for a stretch of 500 m is to be realigned.
ii. Retaining wall has to be constructed with back filling and stone pitching for the down slope at 1:1 slope angle.
iii. The slide debris is to be removed from the slope and down slope.
iv. Arrest infiltration of water at the top with proper concrete lined drainage.
v. Erect proper sign boards indicating slide zone on either end of the distressed stretch.

5. Landslide on Hattihole- Avandi road

The landslide along Hattihole-Avandi road near Mukkodlu village occurred on 20.07.2013. The road was blocked by the fallen debris (Photo 15).

Location **:** The slide is located in toposheet no 48P/15 at latitude 12º 29′ 45.8″N and longitude 75º 45′ 53.5″E**,** nearly 10 Km northeast of Madikeri town .

Land use and land cover: The slope of the study area is modified for coffee plantations and for making of the road.

Geology at site: Lithologically the area exposes weathered gneiss. Two sets of prominent joints are noticed in the gneiss J1-S40^{0}E/59^0 W dipping, 10-20 cm spacing and is tight and J2-N40^0 E/60^0 E dipping 10-20 cm spacing and is tight. The failure occurred along J1 joint plane and it is a planar failure (Photo 16).

Slide morphometry: The slide is a new debris slide (>1500.0 m^2 area). The different morphometric parameters of slide are as follows:

a) Length of slide: 90.0-100.0 m
b) Width of slide: 30.0 m
c) Depth of slide: ~ 1.0m
d) Run out distance :~100.0.0m
e) Cut slope angle near the head: 90º
f) Cut slope height near the head: 13-15 m
g) Original slope angle: 20º
h) Slide direction: S70ºW
i) Slope prior to failure: 90º
j) Slope after failure: 65º
k) Overburden thickness: soil of 0.5m
l) Crown condition: Unstable
m) Head condition: Unstable
n) Toe condition: Unstable

Slide material: The slide material in the zone of accumulation and depletion is debris comprising of different fraction of gneisses/weathered gneissic material. The size fraction of debris varies from huge gneissic boulders to small cobbles and pebbles and soil/clay material.

Causes: The causes of this slide are as follows:

i. The slide is a overburden slide with weight of the overburden coupled with saturation of water increasing the pore water pressure.
ii. Highly weathered gneissic rock on surface has failed on J1 joint plane but as the base rock has exposed no further sliding has taken place. Danger still persists as Overburden material is still there on the exposed bed rock.
iii. The slope modification for making road and for plantations.
iv. The nala is flowing at toe and has undercut/ eroded the toe of slope
v. High rainfall removed the slope material which is highly weathered gneiss. No proper drainage at toe and crown portions. The high rainfall during July 2013 acted as triggering factor.

Recommendations: The corrective measures recommended for stabilization of slope are as follows:

i. The remaining about 10.0 m overburden material may cause reactivation of the slide. Management of this overburden in the form of slope gradation, benching is recommended.
ii. The slide debris is to be removed from the slope and down slope.
iii. Arrest infiltration of water at the top with proper concrete lined drainage.
iv. Precariously hanging tree from the slope should be removed. An abandoned house located at crown portion to be removed as this gives dead weight and may fall if slide is reactivated.
v. Erect proper sign boards indicating slide zone on either end of the distressed stretch.

6. Landslide near Makandur Village, Sinchona estate road.

The landslide near Makandur village occurred on 20.07.2013. It is a reactivated slide and shows clear evidences of failure due to unscientific implementation of remedial measures. The retaining structure constructed at toe has been washed away.

Location **:** The slide is located in toposheet no 48P/11 at latitude 12º 27′ 28.7″N and longitude 75º 45′ 58.8″E**,** nearly 6 Km northeast of Madikeri town .

Land use and land cover: The slope of the study area is modified for making of the road. The area has been modified for settlements and paddy cultivation in low lands.

Geology at site: Lithologically the area comprises weathered granite gneiss.

Slide morphometry: The slide is a reactivated debris slide (>45.0 m^2 area). The different morphometric parameters of the slide are as follows:

a) Length of slide: 15.0 m
b) Width of slide: 12.0 m
c) Depth of slide: ~ 0.5 m
d) Run out distance :~16.0 m
e) Cut slope angle near the head: 90º
f) Cut slope height near the head: 10.0 m
g) Original slope angle: 9º
h) Slide direction: S50ºW
i) Slope prior to failure: 90º
j) Slope after failure: 70º
k) Overburden thickness: soil of 0.5m
l) Crown condition: Unstable
m) Head condition: Unstable
n) Toe condition: Unstable

Slide material: The slide material in the zone of accumulation and depletion is debris comprising of different fraction gneisses/weathered gneissic material. The size fraction of debris varies from huge gneissic boulders to small cobbles and pebbles and soil/clay material.

Causes: The causes of this slide are as follows:

i. The slide is a filled slope failure as the road is constructed by filling the slope. The retaining wall constructed at toe without backfilling has added dead weight on toe portion.
ii. No proper drainage to drain out excess water from the slope and weep holes is absent.
iii. The slope modification for making road and for plantations.
iv. The nala/ paddy field at toe have increased the water content of the slope material and in turn pore water pressure.
v. The high rainfall during July 2013 acted as triggering factor.

Recommendations: The corrective measures recommended for stabilization of slope are as follows:

i. The retaining structure at toe has to be rebuilt with proper backfilling and provision for water leak out in the form of weep holes.
ii. The slide debris is to be removed from the slope and down slope.
iii. Arrest infiltration of water at the top with proper concrete lined drainage.

7. Subsidence on SH-88 near Sinchona estate (Boyikere) between Madikeri-Suntikoppa

The cracks on SH-88 near Sinchona estate (Boyikere) between Madikeri-Suntikoppa appeared on 26.07.2013 and followed by subsidence and flow of the debris material on the toe part (Photo 19, 20 & 21). Due to grave dangerous condition of the road the district administration has stopped the vehicular movement immediately.

Location **:** The slide is located in toposheet no 48P/15 at latitude 12º 25′ 43.4″N and longitude 75º 46′ 22.2″E**,** nearly 6 Km northeast of Madikeri town.

Land use and land cover: The slope of the study area is modified for coffee plantations and for the construction of the road. The road is built on a depression / lake (Anjapparvanda family lake) by slope filling.

Geology at site: Lithologically the area comprises weathered gneiss.

Slide morphometry: It is a new subsidence followed by some debris flow at the toe. The toe wall constructed to prevent lake water from entering the filled slope has been moved 10-12 m from its original position (Photo 22). The crown cracks above the zone of subsidence are longitudinal in nature with 60-70 m length wise some are 25-40 cm width with opening of 1-2 m. The subsidence depth at the crown varies from 1.0 to 1.5 m. The different morphometric parameters of the subsidence are as follows:

a) Length of flow after the subsidence: 12.0-18.0 m
b) Width of subsidence at crown portion: 90.0 m
c) Depth of flow after the subsidence: ~ 0.5 m
d) Direction of flow after the subsidence: N10ºE

Causes: The causes of this subsidence are as follows

i. It is a filled slope failure. The road is constructed on a depression/lake by filling. The filled up material consisted of different fraction of gneissic material which are locally available.
ii. There was a very little provision for drainage and to prevent water infiltration in to the filled up slope. The filled up slope material was saturated from both by infiltration from lake and from rain water runoff.
iii. Heavy vehicular movements may to a certain extent have added weight to destabilize the filled slope.
iv. The high rainfall during July 2013 acted as triggering factor which has made the slope material to be oversaturated and decreased the resisting force.

Recommendations: The corrective measures recommended for stabilization of slope are as follows:

i. Reconstruction of road with grade separator is needed. Unstable material may be removed and refilled properly and road may be reconstructed. The slopes on either side of the road may be constructed with gabion walls or Backfilling the slope with stone pitching at 1:1 slope angle.
ii. The drainage maintenance is of paramount, arrange proper drainage facilities at top of the road and toe portion so that no water infiltrates in to the filled slope. Also arrangements may be made to block infiltration of water from lake.
iii. Proper handling of the vehicular traffic till slope stabilizes viz., one vehicle at time
iv. Proper sigh boards on either side of the road.

8. Landslide near Kattalekadu on SH-89 between Madikeri-Chettali

The landslide near Kattalekadu on SH-89 road between Madikeri-Chettali occurred on 22.07.2013. The road was partly damaged as the part of road towards valley side has fallen and district administration has stopped vehicular movement on this stretch (Photo 23&24).

Location **:** The slide is located in toposheet no 48P/15 at latitude 12º 23′ 27.0″N and longitude 75º 47′ 54.9″E**,** above coffee estate of Mr. K.Thomas Kurrien nearly 5 Km southeast of Madikeri town .

Land use and land cover: The slope of the study area is modified for coffee plantations and for the construction of the road.

Geology at site: Lithologically the area comprises weathered granite gneiss.

Slide morphometry: The slide is a new debris slide (>840.0 m^2 area). The different morphometric parameters of the slide are as follows:

a) Length of slide: 22.0-24.0 m
b) Width of slide at crown: 70.0 m
c) Depth of slide: ~ 1.0m
d) Run out distance :~25.0.0m
e) Cut slope angle near the head: 90º
f) Cut slope height near the head: 13-15 m
g) Original slope angle: 20º
h) Slide direction: S70ºW
i) Slope prior to failure: 70º
j) Slope after failure: 65º
k) Overburden thickness: soil of 0.5m
l) Crown condition: Unstable
m) Head condition: Unstable
n) Toe condition: Unstable

Slide material: The slide material in the zone of accumulation and depletion is debris comprising of different fraction of gneisses/weathered gneissic material. The size fraction of debris varies from huge gneissic boulders to small cobbles and pebbles and soil/clay material.

Causes: The causes of this slide are as follows

i. The slide happened due to toe removal in the form of construction of road below the SH-89, the toe removal of the slope has made the slope unstable and opening of the slope face has increased the infiltration and increase in pore water pressure.
ii. The hill side slope of the road is intact with massive gneiss .While constructing the road the slope was not fully cut rather it was filled slope construction.
iii. High rainfall removed the slope material which is highly weathered gneiss. No proper drainage at toe and crown portions. The high rainfall during July 2013 acted as triggering factor.

Recommendations: The corrective measures recommended for stabilization of slope are as follows

i. Construction of retaining wall with back filling and stone pitching for the down slope at 1:1 slope angle.
ii. The slide debris is to be removed from the slope and down slope.
iii. Arrest infiltration of water at the top with proper concrete lined drainage.
iv. Erect proper sign boards indicating slide zone on either end of the distressed stretch.

9. Landslide near Abbiyala on SH-89 between Madikeri-Chettali

The landslide near Abbiyala on SH-89 road between Madikeri-Chettali occurred on 18.07.2013. The road was partly damaged and district administration has stopped vehicular movement on this stretch. The resort building at the crown portion is in grave danger (Photo 25 &26).

Location : The slide is located in toposheet no 48P/15 at latitude 12º 23′ 14.9″N and longitude 75º 48′ 6.8″E, below a private resort 8 Km southeast of Madikeri town .

Land use and land cover: The slope of the study area is modified for coffee and other plantations and for construction of road.

Geology at site: Lithologically the area comprises weathered granite gneiss.

Slide morphometry: The slide is a reactivated debris slide (>900.0 m^2 area). The different morphometric parameters of the slide are as follows:

a) Length of slide: 85.0-90.0 m
b) Width of slide: 20.0 m
c) Depth of slide: ~ 1.0m
d) Run out distance :~95.0 m
e) Cut slope angle: 80º
f) Cut slope height: 13-15 m
g) Original slope angle: 20º
h) Slide direction: S70ºW
i) Slope prior to failure: 70º
j) Slope after failure: 65º
k) Overburden thickness: soil of 0.5m
l) Crown condition: Unstable
m) Head condition: Unstable
n) Toe condition: Unstable

Slide material: The slide material in the zone of accumulation and depletion is debris comprising of different fraction of gneisses/weathered gneissic material. The size fraction of debris varies from huge gneissic boulders to small cobbles and pebbles and soil/clay material. Even the protective wall constructed by resort people has come hurling down with the slide debris.

Causes: The causes of this slide are as follows:

i. The slide happened due to Crown/ head loading in the form of construction of a resort above the SH-89. The crown loading has made the slope unstable and opening of the slope face has increased the infiltration of water and increase in pore water pressure.
ii. The wall constructed by resort people has added to the dead weight on the top.
iii. The slope height is added to the destabilization and the slide has been reactivated by increase in pore water pressure by prolonged rainfall. High rainfall removed the slope material which is highly weathered gneiss. No proper drainage at toe and crown portions. The high rainfall during July 2013 acted as triggering factor.

Recommendations: The corrective measures recommended for stabilization of slope are as follows:

i. Construction of retaining wall with back filling and stone pitching for the down slope at 1:1 slope angle.
ii. The slide debris is to be removed from the slope and down slope.
iii. Arrest infiltration of water at the top with proper concrete lined drainage. Give perforated contour drains at different levels to push away the excess seepage water.
iv. Erect proper sign boards indicating slide zone on either end of the distressed stretch

10. Landslide near Jodpal on SH-88 between Madikeri-Sampaje

The landslide near Jodpal on SH-88 road between Madikeri-Sampaje occurred on 17.07.2013. The road was partly damaged and plantations mainly coffee, banana and areca nut belonging to one Shri. Abdulla was completely destroyed (Photo 27 &28).

Location **:** The slide is located in toposheet no 48P/11 at latitude 12º 26′ 11.4″N and longitude 75º 40.0′ 9.4″E**,** 6 Km northwest of Madikeri town .

Land use and land cover: The slope of the study area is modified for coffee and other plantations, other crops and for construction of road.

Geology at site: Lithologically the area comprises weathered gneiss.

Slide morphometry: The slide is a fresh debris slide (>270.0 m^2 area). The different morphometric parameters of the slide are as follows:

a) Length of slide: 18.0 m
b) Width of slide: 30.0 m
c) Depth of slide: ~ 1.0m
d) Run out distance :~19.0 m
e) Scarp radius: ~3.0 m
f) Scarp height: ~2.5m
g) Scarp angle: ~vertical to 85^0
h) Cut slope angle: 80º

i) Cut slope height: 13-15 m
j) Original slope angle: 20º
k) Slide direction: S70ºW
l) Slope prior to failure: 80º
m) Slope after failure: 70º
n) Overburden thickness: soil of 0.5m
o) Crown condition: Unstable
p) Head condition: Unstable
q) Toe condition: Unstable

Slide material: The slide material in the zone of accumulation and depletion is debris comprising of different fraction of gneisses/weathered gneissic material. The size fraction of debris varies from huge gneissic boulders to small cobbles and pebbles and soil/clay material.

Causes: The causes of this slide are as follows:

i. Slope cut for road construction is vertical and cut slope height is very high (about 12.0 m). The slope is modified for coffee plantation.
ii. Highly weathered gneissic rock is seen in debris. Water due to high rainfall removed the material along weak planes by infiltrating and acted as lubricant reducing the resisting force.
iii. No proper drainage at toe and crown portions. The drainage at the toe is clogged.
iv. The high rainfall during July 2013 acted as triggering factor.

Recommendations: The corrective measures recommended for stabilization of slope are as follows:

i. The slide debris is to be removed from the slope. The heaped up debris on the other side of the road has to be removed. The House at the top should be vacated permanently as it adds dead weight (temporarily the house is vacated)
ii. Remove all the loose boulders and hanging boulders.
iii. Reduction in the height of the cut slope by slope grading.
iv. Arrest infiltration of water at the top. Make a proper drainage at the base with concrete lining.
v. A retaining wall of 2m height is to be constructed at the toe.
vi. Backfilling the slope with stone pitching at 1:1 slope angle.

11. Subsidence near Koynad on SH-88 between Madikeri and Sampaje

The cracks on SH-88 near Koynad between Madikeri-Sampaje appeared on 02.08.2013 and followed by subsidence and little flow of the debris material at the toe part (Photo 29, 30, 31, 32 & 34). Due to grave dangerous condition of the road the district administration stopped the vehicular movement immediately.

Location and Physiography **:** The slide is located in toposheet no 48P/11 at latitude 12º 28′ 10.5″N and longitude 75º 36′ 36.1″E**,** nearly 13 Km northwest of Madikeri town. Sampaje hole is flowing at the toe part of the subsidence.

Land use and land cover: The slope of the study area is having a fairly mixed jungle.

Geology at site: Lithologically the area comprises weathered granite gneiss.

Slide morphometry: It is a new subsidence followed by some debris flow at the toe. The road has been built about 2-3 years back when the road was widened (Old road still exists and presently repaired and reopened for light vehicular traffic). The new road is built on edge of the hill slope very near to the river flowing down. The crown cracks above the zone of subsidence are longitudinal in nature with 40 to 50 m length, 25 to 40 cm width with opening of 1to 2 m (Photo 33). The subsidence depth at the crown varies from 1.0 to 2.5 m. The different morphometric parameters of the subsidence are as follows:

a) Length of flow after the subsidence: 16.0-18.0 m
b) Width of subsidence at crown portion: 30.0 m
c) Depth of flow after the subsidence: ~ 0.5 m
d) flow after the subsidence direction: N15ºE

Causes: The causes of this slide are as follows:

i. It is a partly filled slope failure and caused mainly due to saturation and toe infiltration and toe cutting by the river. The new road was on the edge of hill slope and the material involved was highly weathered gneiss which at places was converted to clay particles.
ii. There was a very little provision for drainage and prevention of water infiltration in to the filled up slope. The filled up slope was saturated from both by infiltration from river and from rain water runoff.
iii. Heavy vehicular movements may to a certain extent have added weight to destabilize the filled slope.
iv. The high rainfall during July 2013 acted as triggering factor which has made the slope material to be oversaturated and decreased the resisting force.

Recommendations: The corrective measures recommended for stabilization of slope are as follows:

i. Reconstruction of road with proper filling of the slope. Remove the unstable material refill properly and reconstruct the road. Backfilling the slope with stone pitching at 1:1 slope

angle. If possible push the valley slope further inwards and extend the road as the valley side slope is stable with the fresh gneissic rock. Construct toe wall near the river to arrest toe cutting by the river.

ii. The drainage maintenance is very important; arrange proper drainage facilities at top of the road and toe portion may be made so that no water infiltrates in to the filled slope.

iii. Proper handling of the vehicular traffic till slope stabilizes viz., one vehicle at time

iv. Proper sigh boards on either side of the distressed stretch of the road.

Long term strategies and general recommendations to be adopted for Landslide mitigation in this area:

a. 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. For all future cuttings in slopes of this kind, proper guidance of a geologist/ structural engineer may be sought.

b. Vertical cut slopes should be avoided in future as it unstabilises the slope. Due care should be given to the cut slopes made for road construction and plantations during cutting of the slope by following proper slope stability practices. The cut slopes may be provided with suitable retaining structures.

c. Plantations like vetriver grass may be planted which is best means to improve the slope stability conditions.

d. The implementation of the proposed remedial measure do not entail stability of the slope in the vicinity if due care has not been taken to adopt systematic excavation techniques in future.

e. The design of the retaining structure should be made as per standards keeping in view the strength parameter of the rocks (granite gneiss) in the area.

f. Drainage management is of paramount. It is observed that in most of the cases proper drainage facilities are absent or poorly maintained. Weep holes are to be provided to retaining structures with suitable graded filters.

g. Sign boards on roads, proper evacuation facilities in case of any emergency and proper guidance and information regarding landslide hazard to locals may be made.

h. 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.

i. Municipal authorities/ district authorities/ town planners must formulate strict guidelines in giving permission to any kind of construction in unstable slopes.

ACKNOWLEDGEMENT: The authors are thankful to Shri. M. Ravikumar, Dy.DG, SU: K&G for providing logistic support, guidance and encouragement. They thank Shri. M.K.Rao, Superintending Geologist, Engineering Geology Division, SU: Karnataka and Goa, GSI Bangalore for his technical guidance and scrutiny of the report. They also thank Deputy Commissioner Coorg district, and other district and taluk revenue officials for providing necessary logistic support to smoothly carry out the field work. The taluk office officials are thanked for providing rainfall data. They are also thankful to the local residents who provided many of the information for interpretations of the data.

PHOTOGRAPS OF POST DISASTER STUDIES OF LANDLSIDE AROUND MADIKERI

Photo 1: Cracks seen in house of Shri. Jayaprakash in Mannangeri village.

Photo 2: Nala flowing just behind the house of Shri. Jayaprakash in Mannangeri village

Photo 3: House of Shri. Jayaprakash in Mannangeri village constructed on nala course by slope cutting

Photo 4: Cracks seen road leading to School in Mannangeri village.

Photo 5: Cracks seen in house of Smt. Janaki in Makandur village.

Photo 6: Subsidence observed Upstream of Smt. Janaki house.

Photo 7: Cracks seen in house of Smt. Janaki in Makandur village.

Photo 8: Cracks seen besides house of Smt. Sitamma in Makandur village.

Photo 9: View of Landslide on SH-88 between Madikeri-Samapje

Photo 10: View of slide Landslide on SH-88 between Madikeri-Samapje

Photo 11: View of Landslide on Makandur-Mukkodlu tantipal road.

Photo 12: View of Landslide on Makandur-Mukkodlu tantipal road.

Photo 13: Runout of Landslide on Makandur-Mukkodlu tantipal road in to Kalur Nala.

Photo 14: View of first Landslide on Makandur-Mukkodlu tantipal road.

Photo 15: Birds eye view of the Landslide on Hattihole-avandi road.

Photo 16: View of the Hattihole-Avandi road landslide with fresh gneissic bed rock exposed.

Photo 17: View of landslide near Makandur village, Sinchona estate road.

Photo 18: View of landslide near Makandur village, Sinchona estate road.

Photo 19: Cracks on SH-88 near Sinchona estate (Boyikere) between Madikeri – Suntikoppa with subsidence.

Photo 20: Cracks on SH-88 near Sinchona estate (Boyikere) between Madikeri – Suntikoppa.

Photo 21: Subsidence on SH-88 near Sinchona estate (Boyikere) between Madikeri – Suntikoppa.

Photo 22: Movement of toe wall after subsidence on SH-88 near Sinchona estate (Boyikere) between Madikeri – Suntikoppa.

Photo 23: View of landslide near Kattalekadu on SH-89 between Madikeri-Chettali.

Photo 24: View of landslide near Kattalekadu on SH-89 between Madikeri-Chettali.

Photo 25: View of landslide near Abbiyala on SH-89 between Madikeri-Chettali.

Photo 26: View of landslide near Abbiyala on SH-89 between Madikeri-Chettali.

Photo 27: View of landslide near Jodpal on SH-88 between Madikeri-Sampaje.

Photo 28: View of landslide near Jodpal on SH-88 between Madikeri-Sampaje.

Photo 29: View of subsidence on SH-88 near Koynad between Madikeri –Sampaje.

Photo 30: View of subsidence on SH-88 near Koynad between Madikeri –Sampaje.

Photo 31: View of subsidence on SH-88 near Koynad between Madikeri –Sampaje.

Photo 32: Run out after subsidence in to Sampaje hole.

Photo 33: Ground cracks on SH-88 Near Koynad.

Photo 34: View of subsidence on SH-88 near Koynad between Madikeri –Sampaje.