Landslides and associated mass movements events in the eastern part of Madagascar: risk assessment, land use planning, mitigation measures and further strategies

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Abstract - The eastern region of Madagascar is frequently subject to landslides. The slides of lateritic soil occur during periods of heavy rainfall, and these events cause damage and destruction to infrastructure. A comprehensive documentation of historical and recent landslides occurring along two national roads and surroundings has been completed for Madagascar. The record of damaging landslide events in historical time as well as recent occurrences was compiled from archival data, existing case history accounts, information supplied by government agencies and actual site visits.
A few reported occurrences of mass movements including gullies, crumbling, lavaka, slumps and rockfalls were also investigated and described in the inventory.
Field investigations, interpretation of aerial photography, interpretation of satellite imagery, analyses of geological data and laboratory tests suggest that some factors have acted together on the slopes to cause the sliding.
The implications of the hazard rating in terms of roads, farmlands, buildings and other development applications are explained.
Landslides and mass movements in Madagascar cause a few fatalities per year, mainly during cyclonic period. They pose threats to settlements and structures, and often result in catastrophic damage to roads, pipelines, buildings and agricultural lands.
This paper provides a framework for a regional hazard assessment and for evaluating risk assessment, land management, risk prevention planning, mitigation measures, emergency preparedness and further strategies in response to landslide and mass movement disaster.

Keywords: Rainfall, lateritic soil, mass movements, mitigation measures, Madagascar.

Résumé – La région orientale de Madagascar est fréquemment soumise à des glissements de terrain. Les glissements de terrain dans les sols latéritiques se produisent pendant les périodes de fortes pluies, et ces événements causent le dégât et la destruction des infrastructures.
Une documentation complète des glissements de terrain anciens et récents se produisant le long de deux routes nationales et leurs alentours a été effectuée à Madagascar.
L'inventaire des événements catastrophiques anciens et récents ont été compilés à partir des données provenant des archives, des histoires et récits existants, des informations fournies par les agences gouvernementales et des actuelles visites de sites.
Quelques formes de mouvements de masse comprenant ravinement, écroulement, lavaka, effondrement et éboulement sont aussi investigués et décrits dans l'inventaire.
Les investigations de terrain, l'interprétation de photographies aériennes, l'interprétation d'images satellites, les analyses des données géologiques et les essais en laboratoire suggèrent que divers facteurs ont agi ensemble sur les pentes pour causer le glissement.
Les implications sur l'estimation du danger quant aux routes, les terrains agricoles, les bâtiments et les autres applications du développement sont expliquées.
Les glissements de terrain et les mouvements de masse à Madagascar causent beaucoup de fatalités chaque année, principalement pendant la période cyclonique.

Ils posent des menaces aux infrastructures, et souvent peuvent entraîner des dégâts catastrophiques aux routes, canalisations, maisons et terrains agricoles.
Cet article fournit un document de base sur l'estimation du danger régional et sur l'évaluation du risque, la gestion des terres, la planification de la prévention du risque, les mesures d'atténuation, le mode de préparation des urgences et les stratégies supplémentaires en réponse au désastre des glissements de terrain et des mouvements de masse.

Mots clés: Chute de pluie, sol latéritique, mouvements de masse, mesures d'atténuation, Madagascar.

1. INTRODUCTION

Madagascar is an island nation in the south-west Indian Ocean that lies across the Mozambique Chanel from continental Africa. The country was originally covered completely by wet or dry evergreen forest and palm savanna. Almost 75% of the 20 million populations in Madagascar practices subsistence agriculture and unfortunately, the rainforest of the eastern side of the island is already considerably fragmented and will be further destroyed by slash and burn agriculture and deforestation (Green and Sussman, 1990). Much of the indigenous forest has been dramatically reduced by burning and logging for pastoral farming. Consequently, landslide erosion, associated with large rainstorms, has increased.

Mass movements including landslides, gullies, crumbling, slumps, rockfalls, large hillslope gully ("lavaka" in Malagasy) and disperse erosion are frequent mainly in the eastern part of Madagascar. These phenomena are also a subset of the more general landslide phenomena, which can include falls, slumps, and slides in all kind of ground material from stiff rock mass to unconsolidated or poorly cemented materials forces (Varnes, 1978).

Problem statement

- Despite their spectacular nature, these landslides, gullies and associated mass movements have not yet been studied in detail.
- No systematic information on the distribution of landslides and other mass wasting processes in Madagascar is available in the literature.
- Increasing number of landslide occurrences in the eastern part of Madagascar cause damage to infrastructure and farmlands.
- Repeated landsliding is gradually decreasing the pastoral productivity of the hill country and increasing sedimentation and its detrimental environmental effects in streams and rivers.

These are the main reasons why we are developing this project in which the objectives are to:

- Prioritise soil conservation work
- Prepare inventory of landslides and other mass wasting features for Madagascar;
- Undertake risk assessments of mass wasting events;
- Prepare hazard map showing distribution and hazard rating for landslides and associated processes, for land use planning purposes;
- Advise on mitigation measures.

2. STUDY AREA

Landslides are particularly visible in and occur along national roads in east Madagascar.

Our chosen traverses have the advantage of easy access and it links with previous studies. The first northern traverse followed the Route National 2 (RN2), the main road between Antananarivo and the port of Toamasina. It extends across the regional strike of the Malagasy basement, passing through the eastern part of the Antananarivo block and the overlaying Beforona belt (Figure **1**) of Tsaratanana sheet (Collins et al, 2000). The RN2 descends eastwards from the central plateau around Antananarivo to the Indian Ocean. This descent is marked by a number of steep escarpments (Figure **2**), but basement exposure is limited by a combination of dense forest, the alluvial plain of Mangoro intracontinental rift, a locally high degree of lateritisation and a cover of sedimentary rocks at the coast.

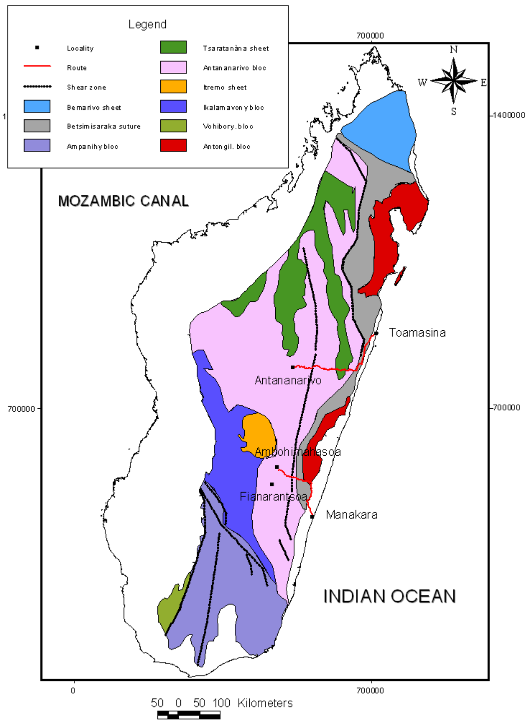

Figure 1: Location map and geological sketch of the study area

We also present data from a second southern traverse along the national road RN25 between Ambohimahasoa (Fianarantsoa) and Mananjary for comparison with our more detailed traverse to the north (Figure **3**).

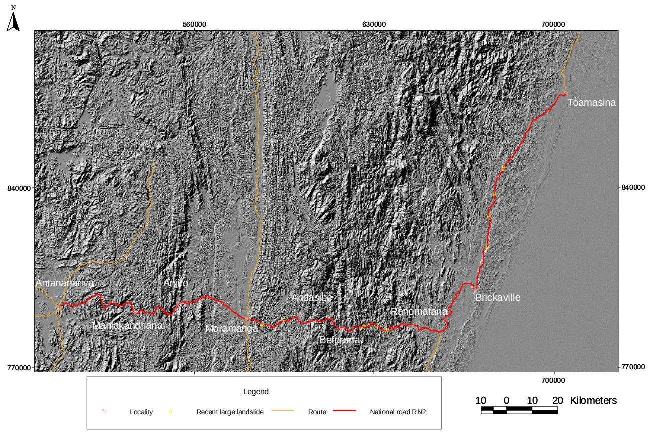

Figure 2: Location of large landslides along national route 2 and the surroundings

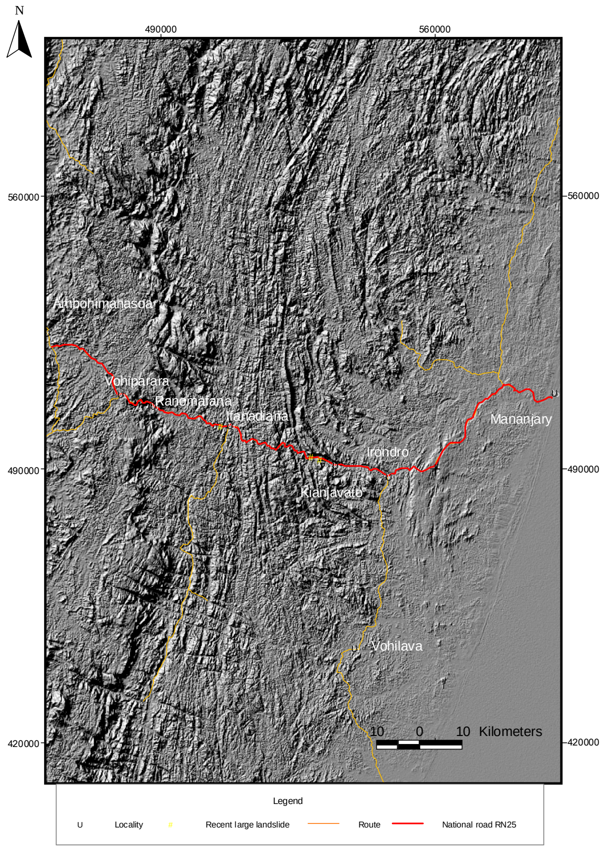

Figure 3: Location of large landslides along national route 25 and the surroundings

The geology of the study area consists of two main tectono-metamorphic blocks. The first one, called Antananarivo block, has been recognized along much of Madagascar's eastern margin: a basement mainly composed of late Archaean granitoids and migmatitic gneisses containing a significant Neoproterozoic juvenile component (Collins et al, 2000) which is structurally overlain by a late Archaean mafic sequence. The second unit, called Tsaratanana sheet and including Beforona belt (Figure **1**) composed of hornblende-bearing mafic gneiss and metasedimentary rock (Collins et al, 2000), overlie the granitoids of the Antananarivo block (Mangoro migmatites, Manampotsy group, Brickaville migmatites). Cretaceous sedimentary rocks occur along the near-whole east coastline.

As Madagascar rifted from Gondwana, starting its separation from Africa some 160 million years ago, and following up with a break from India and the Seychelles between 90–66 million years ago (De Wit, 2003), the country has been tectonically isolated as an island in the Indian Ocean since the end of the Cretaceous.

Thus, the east coast of Madagascar exhibits a juvenile, stepped topography (Figures **2** and **3**) that follows a staircase up from the coast to an elevation of more than 1400 in the central high plateau. Flowing across this deformed and elevated plain are rivers that have carved valleys and through orogenic uplift and downcutting have left dissected hills and terraces.

Indigenous forest formerly covered the hills and lowlands, but has now been cleared for pastoral agriculture on the less steep slopes. This deforestation accelerated the existing erosion, leaving much evidence of slope failure and aggraded river beds. In addition, the thick tropical soils have in many places passed a critical threshold and are collapsing into large hillslope gully called “lavaka”.

The climate is tropical and maritime with prevailing east to south-easterly winds (Alizée regime). Annual rainfall varies from 1400 mm at the coast to more than 2865 mm at the top of the ranges mainly in the Ranomafana County. Landslide-triggering rainstorms occur about once per year, particularly during cyclonic period or during the famous “Zone de Convergence Inter-Tropicale” (ZCIT) passage in the western part of the Indian Ocean.

2. METHODOLOGY

The action plan is based on a desk review of available documents regarding emergency needs assessment and preparedness. Desktop study and documentation review (data available, aerial photographs) of historical and recent mass movements have been undertaken.

In addition, in order to obtain more information concerning the distribution, the frequency and the negative effects of mass movements in the study area, check lists, questionnaires and interviews of public, inhabitants and local instances, stakeholders and local authorities have been undertaken. Several reported occurrences of landslides were investigated and described in the inventory.

A preliminary study was carried out, including site visits, based on field observations and a diachronic comparison of aerial photographs and satellite images dating from 2000s (panchromatic LANDSAT image and Shuttle Radar Topography Mission – SRTM image).

Conventional techniques (such as photo interpretation, satellite imagery, topographic surveys), allowed quantification of scar and deposit volumes, indicating the rate of decompaction associated with the landslide process.

This paper deals with landslide phenomena, mainly discusses the relationships between the landslide and the hydrogeology.

Various sources of information and data are used in this analysis, such as aerial photographs, detailed topographic surveys, analyses of grain-size distribution, meteorological information, data on rainfall and hydrology, and other characteristics of soils, alluvial sediments, indications about land management and land-use mapping information. This naturalistic approach already brings contribution to risk prevention planning.

A qualitative evaluation of mass movement hazards, based on the hydro-geomorphological method, brings useful contribution to hazard mitigation in this field.

The compiled record of damaging mass movements has been assembled in a relational database, with accompanying hazard maps showing their distribution.

Hazard mitigation strategies are also proposed in this study. Finally, the authors propose some useful recommendations related to soil conservation, site selection, land uses, building, construction and further research.

2. RESULTS AND DISCUSSION

4.1. Landslide inventory map based on aerial photo interpretation

Different mapping techniques can be used to create landslide inventory maps. At present, aerial photo interpretation is the most commonly used technique for the production of regional landslide inventories in sparsely vegetated areas. But in a densely forested region such as in the eastern part of Madagascar up to 85% of the landslides mapped in the field were not visible on aerial photographs.

We could not delineate an old landslide on aerial photographs because the main characteristics had been partly erased by water erosion on the landslide site.

Because most of these landslides are not visible because of vegetation cover, aerial photo interpretation commonly used for the inventory is not a suitable tool to map the landslides.

An attempt to detect landslides from aerial photographs failed as only very few often recently reactivated landslides under pasture were visible.

A detailed investigation in the field was needed to identify the feature as a landslide.

4.2. Landslide inventory map based on remote sensing techniques

Other mapping techniques are based on remote sensing techniques using satellite images. The inventory based on the Landsat ETM+ (30-m spatial resolution) mosaic contained only 40% of the landslides on the aerial photograph-based inventory map. About 70% of the indicated area on the Landsat -based landslide inventory was classified incorrectly as landslides. The errors mainly originated from the omission of large landslides, the incorrect indication of shadows and artificial features.

Only less than 20% of the landslides mapped in the field were also visible on the satellite imagery Landsat ETM+.

4.3. Landslide inventory map based on field survey

Therefore, an intensive field survey was carried out. The survey resulted in a detailed landslide inventory map. But its creation needed more time (ca. 3 months) and therefore expensive.

During the last field survey, the whole national roads RN2 and RN25 and surroundings were checked for the occurrence of new landslides. Figures **2** and **3** show the location of the 12 field survey based large landslides or true landslides on the satellite imagery. More than recent 100 shallow slides have been recognized after the passage of the recent two cyclones in the country.

All landslides were classified directly in the field. Each landslide is classified as rotational or translational one based on the characteristics of the depletion zone.

The dimensions of the depletion zone of the landslides vary widely throughout the study area. Tests and measurements during field survey reveal that the great variety in volumetric dimensions of the depletion zone is generally controlled by the depth of the shear plane and to a lesser extend by its length and width.

An example of shallow or less deep-seated landslide map (Figure **4**) with an average affected area of less than 10 square meter and a shear surface less than 1 meter depth was indicated on a topographical map (Figure **5**) and then stored in a Geological Information System (GIS).

Figure 4: Field view of shallow landslide due to loss of suction (PK 270 of RN2)

Despite our serious effort to carry out cautiously this field survey, the landslide inventory map is incomplete and contains errors in the delineation of the landslide borders or may be because the edges of the old landslides are rather vague.

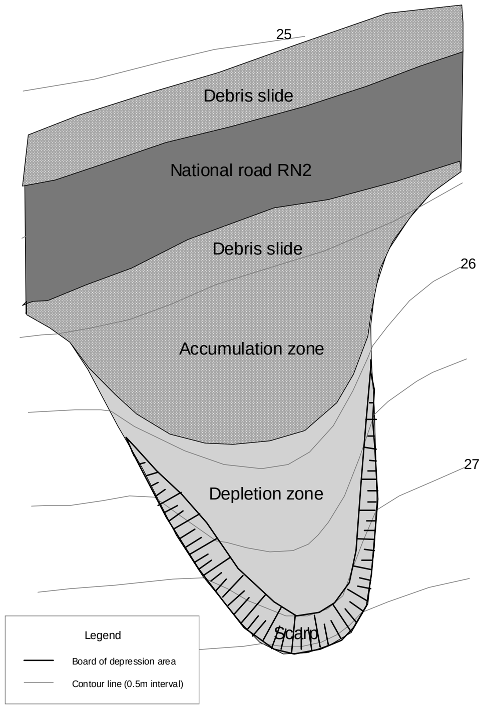

Figure 5: Topographical map of the landslide

4.4. Landslide causal factors

The search for possible recommendations or solutions concerning the landslide problem in Madagascar is possible when the local causes are more or less understood.

In order to characterize the geological setting of the landslide, we need to identify the forces acting on this system. Such forces may be the long-term tectonic forces due to plate tectonic dynamics (slope, active tectonic). Short-term forces that act on the landslides are mainly climatic forcing (i.e., fluvial incision, rainstorm or heavy rainfall, cyclone passage) and earthquake waves.

The geographically distributed parameters that can influence the potential for landslides are referred to in this study as "Landslide causal factors". These have been selected based on consideration of the mechanisms that cause landslides and other mass wasting features, and correlating with existing landslides. Some of the more important landslide dependent variables that have been used to develop the landslide hazard map are: relief, geology, soil characteristics, rainfall, land cover (vegetation), land use, hydrography and population pressure.

Within each parameter class, we gave weightings to different groupings depending on their correlation with the incidence of landslides and associated features.

4.4.1. Topographic factors

The relief include slope aspect and modifications to slopes, such as cut, fill and retaining walls.

Steep, plan concave slope segments are the most favorable preconditions for mass movement, especially on relatively large distances from the water divide (Thomas, 1994).

A typical shallow rotational landslide on a concave slope segment is shown in Figure **6**. Rotational landslides are more likely to occur on concave slopes where runoff and subsurface water can easily concentrate (Thomas, 1994).

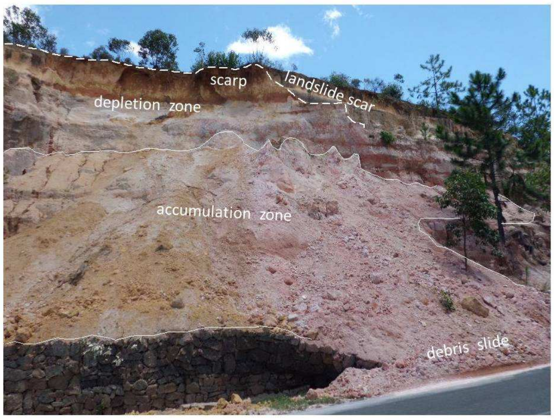

Figure 6: Landslide of complex-type with a predominance of rotational-type movement

Figure **4** shows the scarp of a surficial translational landslide, triggered on the steep slopes during the 13-14 February 2012 rains (passage of Giovanna cyclone).

A lesser increase in pore water pressure is needed (Westerberg and Christiansson, 1998) for the occurrence of translational slides. Thus, this can be found at a smaller distance from the water divide (e.g. Figure **4**).

Furthermore, the rectilinear slopes with shallow soils and a sharp contrast between saprolite and solum, where translational landslides generally occur, are inherently more unstable.

4.4.2. Lithology

Although the shear planes of most landslides are located within the soil and on the sharp contact between the shallow soil (0.2–2 m) and the parent rock, the strong weathering and fracturing of the gneiss, migmatite and granite parent material definitely plays a role in the origin of the few landslides occurring in rock material.

4.4.3. Lateritic soils

All landslide scarps show a similar profile of at least two buried soils, created by an alternation of stable pedogenesis phases and unstable phases of regressive erosion (Figure **7**). In this example of slump, the superposition of a soil horizon with a silty clay texture (52-57% clay, Ap category according to the Laboratoire des Ponts et Chaussées - LPC classification) on a coarser, sandy silt loam horizon (45-48% clay, SL or SA category) of an older soil (Ramasiarinoro, 2008) creates a pore discontinuity that hinders drainage.

The Ap horizon has a nutty structure and corresponds to the nitric horizon of a buried soil profile and thus rapidly expands upon wetting. As a result large forces are exerted on the soil, creating the possibility to overcome the sliding inertia (Thomas, 1994).

Figure 7: Alternation of stable pedogenesis phases and unstable phases of regressive erosion

Some of the soils have a distinct boundary between the soil and the underlying rock in common. During heavy rainfalls, water stagnates on this discontinuity, creating positive pore water pressures on this shear plane on which the soil may easily slide down.

It is also shown that the slope-infiltrated waters are trapped in a perched aquifer in the upper slope. Therefore, from there, water migrates inside the landslide itself, inducing landslide slip acceleration.

4.4.4. Annual heavy rainfall

Heavy rainstorms during the recent passage of Giovanna cyclone (13-14 February 2012) and Irina cyclone (25 February – 02 mars 2012) combined with ZCIT passage are responsible for landslides occurrences and cause damage to roads, buildings (Figure **8**) and farmlands.

The high average annual rainfall rate (2700 mm in Ranomafana-Ifanadiana) and the concentration of rain in two wet seasons cause high moisture contents and/or saturation of a large portion of the soil column over a great time span. This process should therefore be seen as predisposing factors creating a low margin of instability for the region.

Figure 8: Destruction of house due to translational landslide (PK 189 of the RN2)

The landslide history of this eastern region, with repeated landslides, highlights the presence of one triggering phenomena: the presence of infiltrated waters related to rainfalls.

Concerning the role of water in slope stability, it causes a decrease in shear strength either by reducing the apparent soil cohesion or through the potential slip surfaces, a fact directly related to intense or long-lasting rainfall events (Gostelow, 1991).

4.4.5. Population pressure

Human activities can also play an important role in affecting the susceptibility of a slope to failure, especially in the eastern region, where slopes are extensively farmed for agriculture (and road).

Human presence may decrease the margin of hillslope stability drastically in more or less densely populated.

Besides the valleys and the major road tracks, several gentle slopes (example of the Beforona zone) may have the highest population density, implying the highest human impact on hillslope stability. The main malefactors are the excavation of slopes and the concentration of runoff water through linear landscape elements (e.g. footpaths parcel boundaries).

Deforestation

The influence of vegetation on landsliding is of special interest because vegetation cover is usually controlled by human activities.

The human role in landsliding in this eastern region is restricted to the effects of deforestation in recent history.

Deforestation is considered as one of the main preparatory causal factors in most east African highlands (e.g. Inganga et al., 2001, Nyssen et al., 2002; Davies, 1996) and in Madagascar (this study).

The east region of the island has been deforested since the 18th century but spatial and temporal information is lacking.

An indication for the importance of a forest cover in prohibiting mass movements in the area, is the absence or rarely of landslides under forest on slopes with similar topographic and soil properties as in the Andasibe and Ranomafana Parks (own observations, observations by the local population and by game rangers of the National Parks).

Excavations

Another remarkable example of human interference in Madagascar is the removal of lateral slope support.

Excavation is particularly destabilizing (Figure **9**) when the bedding planes of the substrata are parallel to the slope. In addition, farmers often dig away parts of the slope in order to level their plots. The formation of step-like slopes by agricultural practices and intensified by natural processes removes the lateral support. Then, it causes water stagnation and increased infiltration, leading to an increased pore water pressure and landslide risk.

Figure 9: Dip of the bedding planes parallel to the slope enhances slope failure (PK94 of RN25)

A few examples of a slope excavated for house building, footpaths or for agricultural purposes can be seen along these 2 national roads. The excavation for house building (Figure **10**) was the direct triggering cause for slope failure and creep phenomena during the passage of recent cyclones (February 2012).

Strict regulations, such as Madagascar National Environment Regulations for Mountainous and Hilly Areas Management, that for example prohibit cultivation of slopes steeper than 30%, are not known by the local population and certainly not followed in any of the regions.

Figure 10: Slope excavated for house building and the consequent small slides above (left) the excavated zone (PK 189 of the RN2)

4.5. Important factors in shallow landsliding, process and mechanisms of instabilization

Most of the landslides in Madagascar hill country are more or less shallow (about 0.2-2 m deep) involving the soil horizon only, in which we could classify them as shallow rapid earthflows according to the terminology of Varnes (Vames, 1978).

The main mechanisms of instabilization of lateritic soils and rock slopes can be summarized as follows:

- Rupture by cyclic pore pressure in lateritic soils
- Loss of suction
- Mobilization of debris flows

When the gravitational force per unit area down the hillside exceeds the shear strength of the soil mass in any plane, the soil slips and flows rapidly (~3 m s^{-1}) downhill, leaving a debris-tail about 0.2 m thick (Johnson and Rodine, 1984). The gravitational force per unit area down the slope on a soil mass is given by

$$\sigma_v = \rho g z \sin\theta \qquad (1)$$

where ρ is the density of the soil mass, g is acceleration due to gravity, z is the thickness of the soil mass, and θ is the slope angle.

Hence, as slopes get steeper, the sheer force required to maintain stability also increases by $\sin\theta$. The strength of soil may be described by Terzaghi's modification of Coulomb's law (Terzaghi, 1950):

$$\tau = c + (\sigma_n - u) * \tan\varphi \qquad (2)$$

where τ is shear stress (N m^{-2}), c is cohesive strength, σ_n is normal stress on the shear surface, u is pore water pressure, and φ is the angle of internal friction. For a given soil type, C and φ are constants.

During storms, rainfall infiltrates the soil mass, hence creating and then increasing pore water pressure as infiltration continues, until a maximum of $gz / \cos\theta$, is reached at saturation. As pore water pressure increases, soil strength reduces and there is a risk of soil strength being exceeded by the shear force required for stability (Ekanayake and Phillips, 1999b).

Where there is woody vegetation on the slope, their roots, which are usually stronger than soil, increase the effective strength of the soil mass (Ekanayake and Phillips, 1999b). Thus, slope angle, storm rainfall, soil strength, and vegetation cover are all important factors in shallow landsliding.

These four physical factors have been recognized in field-based studies of storm-triggered landslides occurring along the two national roads (RN2 and RN25) in the eastern part of Madagascar.

When the rain intensity is higher than 70 mm/h, and it happens after a period of extended rain (typically 200 mm of accumulated rain in the last 7 days) there is the danger of tens or thousands of shallow landslides initiating almost at the same time. Recent events included the passage of Giovanna cyclone (13-14 February 2012) and Irina cyclone (25 February - 02 Mars 2012) in Madagascar (e.g. Figure **4**). Locally, rainstorms can affect just a small region, and isolated landslides initiate debris flows.

4.6. Improvements and recommendations for future use

4.6.1. Mitigation measures

A preliminary survey has shown that the majority of these events can be linked to road construction.

These landslides cause several fatalities per year. They pose threats to settlements and structures, and often result in catastrophic damage to roads, waterways, pipelines and farmlands.

The land shortage in the study area prevents people from abandoning the most landslide prone areas. As population pressure increases, not only the stability of the slopes will be reduced, but people will also be forced to cultivate even more unstable slopes. As a consequence of both, the risk on damage by slope failure will increase.

However, the instability can be partly reduced by tempering the human impact.
Excavation or terracing of slopes and the construction of structures concentrating water to vulnerable zones should be avoided.

In addition, total or partial reforestation with deep-rooted trees (e.g. Acacia, Grevilia, Vetiver) would reduce the landslide risk.

Tools for vegetation management could include reforestation, farm forestry, space-planted trees (Figure **11**), riparian planting or retirement, gully wall planting, or channel planting. These soil conservation techniques in risk zones could locally enhance stability.

Figure 11: Technical measurements of stabilization (PK 95.200 of the RN25)

However, these measures can never completely impede the occurrence of landslides and it seems that the search for solutions will only come to results when the fast population growth takes a turn.

Authorities at government level have been trying various methods depending on the nature of the slide and its geological and environmental setting. Mitigation measures include:

- Water control measures : control and remove;
- Excavation methods : removal of slide, unloading head of the slide, hillside benching (construction of man-made terraces and beams), grading (adjusting the gradients to take care of slope irregularities) and slope reduction;
- Restraining structures (Figure **11**): buttresses (placing of rock or earth fill material on or into the toe of the slide to provide additional weight to increase the shear strength of materials in the slide), shear keys, retaining walls, rock bolts, and pipes;
- Miscellaneous methods : grouting (emplacement of new materials on or into the regolith to cement, harden and stiffen materials or release water) ;
- Reforestation of steep slopes: will need to be combined with improved vegetation management for soil

conservation on moderate slopes to significantly reduce future landsliding.

4.6.2. Further strategies

Our proposals for additional strategies to reduce the number of injuries, and economic costs caused by landslides and associated events include:

- Research : by developing a predictive understanding of landslide and other mass wasting processes and triggering mechanisms;
- Real-time Monitoring : by monitoring active landslides and associated events that pose substantial risk;
- Loss assessment : by compiling and evaluating information on the economic impacts of landslide hazards;
- Information collection, interpretation and dissemination : by establishing an effective system for information transfer;
- Implementation of loss reduction measures by encouraging mitigation actions;
- Guidelines and training : by developing guidelines and training for scientists, engineers and other professionals, and decision-makers;
- Emergency preparedness, response, and recovery: by building resilient communities;
- Public awareness and education : by developing information and education for the user community

5. CONCLUDING REMARKS

The amount of water entering a slope, which is a function of the vegetation cover, drainage, soil type and rock structure, will be a very important factor indicating the significant linkages between geomorphological hazards and the processes and conditions in the atmosphere and hydrosphere.

Most of the landslides are probably related to heavy rainfall and can be linked to road construction.

For a better evaluation of natural risks, the naturalistic analyses (based on observations) and the quantitative ones (based on measurements) should be used and combined as tightly as possible. The knowledge of natural disasters has obvious implications for emergency response, public administration and land management concerns, and also, for the long-term, for architecture, urbanism and even sociology.

This paper provided a framework for a regional hazard assessment and for evaluating risk assessment, mitigation measures, emergency preparedness and further strategies in response to landslide disaster.

Amongst the different outcomes expected for this project we emphasized the following:

(1) An inventory (including occurrence and distribution) of recent large landslides and associated hazards along two national roads (RN2 and RN25) and surroundings in the eastern part of Madagascar is being constructed;

(2) An evaluation of hazard posed by these phenomena is being made, using an adopted classification system;

(3) A production of a landslide hazard map delimiting most prone areas, and the other types of mass wasting processes, at a scale useful for land use planning and decision making is being undertaken;

(4) Based on the above analyses an action plan for landslide abatement is proposed.

This action plan is a result of (i) a situation analysis of the landslide situation along the two national roads in this eastern part of Madagascar; (ii) and a review of the existing information systems and processes for responding to an emergency.

The conditions for ensuring the successful implementation of the proposed plan include a sustained high-level political commitment, sufficient financial resources and resource mobilization. The high-level political commitment is necessary both at the central as well as the decentralized level.

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