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The El Nino triggered landslides and their socio-economic impacts on Kenya

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Kenya experienced extraordinarily heavy rainfall between May 1997 and February 1998 due to the El Nino weather phenomenon. This period of about 10 months of heavy rainfall caused widespread landslides and floods in various parts of the country. Normally mid-December to late March is the driest and hottest season in Kenya. However, during this period, the season turned out to be the wettest, with one of the heaviest precipitation recorded in the country in the past several decades. Research has revealed that the landslides were a result of four major factors—the geology and soils of the landslide-prone areas, high relief, steep slopes with poor anchorage for slope stability, and continuous heavy rainfall precipitation which resulted in over-saturation of rocks and soils. The effects of the El Nino-triggered landslides in Kenya were enormous. Although statistical data about landslide destruction have not yet been quantified, human and animal fatalities and plant destruction were enormous. Fertile farmlands, roads, railway lines, bridges, and telephone and power lines were shifted and destroyed. Soil erosion which resulted from heavy rainfall filled rivers with sediments. The sediments were transported to the hydroelectricity-producing dams, which eventually became clogged, and power generation stopped. The national economic loss to the country is estimated at about one billion US dollars and the country will take a long time to recover.

Introduction

The Republic of Kenya is located on the eastern side of Africa and is divided by the Equator into almost two equal parts (Figure 1). The country extends between latitudes 5°30'N and 4°30'S and longitudes 34°00'E and 42°00'E. Kenya has a total area of about 582,000 km².

During the period between May 1997 and February 1998, most parts of Kenya experienced the El Nino weather phenomenon, characterized by an all-season continuous heavy rainfall. This heavy rainfall coupled with the relief, drainage patterns and varied geology of the country triggered major landslides in many parts of the country.

On 10th November 1997, a landslide occurred along the Thika-Murang'a highway at Karugia, which swept away a one-kilometer section of the highway downslope. The landslide rendered about 356 km² of arable land useless in addition to cutting off road and other communications between Thika and Murang'a towns, which are

major administrative and commercial centres with very rich agricultural hinterlands.

On 26th December 1997, another landslide occurred at Gatara village located in Murangia, which swept away an estimated 50,000 tea bushes in addition to killing three people who were buried while asleep in their house.

On 3rd January 1998 a major landslide also occurred along the Embu-Meru highway and washed away a 3-kilometer section of the highway. The landslide washed away a moving bus which was carrying about 70 passengers into a deep ravine on the slopes of Mount Kenya, and 36 passengers were killed. The rest were critically injured.

Later, on the 15th January 1998, another landslide occurred, along the Thika-Garissa highway at Makutano and swept away a bridge, cutting off the eastern part of Kenya from the rest of the country.

As if that was not enough, yet another landslide occurred, near Kibwezi market on the main Nairobi-Mombasa highway on 17th January 1998 and destroyed a major bridge. Although there were no fatalities, the landslide cut off Mombasa which is not only the main port of Kenya but also the main port for East and Central Africa. This city is also a major tourist destination in the country.

The list of landslides which occurred during the period is therefore enormous, and it is only appropriate to state that the damage caused to the national infrastructure will take a long time to rectify. This paper hence describes some of the landslides and the factors which caused them. The paper also points out some of the socio-economic impacts of the landslides.

Relief and drainage distribution

Most of the El Nino-associated landslides in Kenya occurred in areas of high relief. The relief of Kenya is divided into four major zones: the Coastal and Eastern Plains, the Central and Western Highlands, the Rift Valley Basin and the Lake Victoria Basin (Figure 1).

The Coastal and Eastern plains, which approximately cover one third of the country, have an elevation which varies from 0 m at sea level to about 500 m at the hinterland coastal hills. The Rift Valley Basin runs approximately north-south along 36°E longitude and separates both the Eastern and Western Highlands. The basin is broadest in its northern part around Lake Turkana, where it is about 300 km wide. It is narrowest around Lake Naivasha, where it is only about 30 km wide. The highest elevation of the basin (500 m above sea level) occurs at its narrowest and middle zone which is enclosed by the Mau Hills in the west and the Aberdares Ranges in the east.

The Eastern and Western Highlands are separated by the Rift Valley Basin. The highlands have an altitude which varies from 1,500 to 5,200 m. The Western Highlands are marked by the Mau Hills (about 3,100 m) which occur in the central part of the area. Further north, the area is marked by the Cherangani Hills (about 3,400 m) and Mount Elgon (about 4,300 m). The Eastern Highlands are marked by the Ndoto Mountains in the north, while the Aberdare Ranges (about 4,000 m) and Mount Kenya (about 5,200 m) mark the highest peaks in the central area of the eastern highlands.

Figure 1 Map of Kenya showing the relief, drainage and distribution of El-Nino related landslides.

The Lake Victoria Basin is semicircular in shape and encloses Lake Victoria. The basin is bounded on the eastern side by 35°E longitude and by latitudes 1°N and 1°S, respectively. The general elevation of the basin is between 500 m and 1000 m above sea level.

Most of the rivers in Kenya, which have been the main recipients of the sediment load brought by landslides, originate in the Central Highlands, and they form a radial drainage pattern (Figure 1). The water levels of the rivers vary from season to season. During the dry season, most of the rivers contract to narrow channels, while some of them dry up altogether (Mathu and Davies, 1996). During the rainy season when most of the landslides occur, the rivers swell enormously and carry large amounts of sediment.

Rainfall and temperatures

Rainfall patterns in Kenya are governed by its equatorial location on its position on the east coast of Africa as well as on the eastern side of Lake Victoria, which is one of the largest fresh water lakes in Africa. The rainfall distribution can similarly be divided into four major zones based on the amount of precipitation. They are the Lake Basin, around Lake Victoria, the Highlands, and the Coastal and Interior Plains (Figure 2).

The Lake basin region receives an average annual rainfall of over 1,800 mm with the driest month receiving an average minimum of only 200 mm. Temperatures rarely fall below 20°C, while the maximum temperatures are about 30°C.

The Highlands receive an average annual rainfall of over 1,000mm. The months of January and February and July to September are the driest, with an average rainfall of less than 30 mm each. The wettest months are April and May and October to November, with average rainfall of over 200 mm each month. During the hot

months the temperature in the Highlands is about 25°C, while the temperature during the cool months is about 17°C.

The Coastal Zone receives an annual rainfall of about 1,500 mm. The months of January and February, which are usually the driest, receive less than 10 mm of rainfall each. The months of April and May, which are the wettest, receive over 200 mm of rainfall each. The rest of the months in the year receive an average of 50 to 100 mm of rainfall each. During the hot months, the temperature in the Coastal Zone rises to over 30°C while during the warm months, the temperature is about 24°C.

Figure 2 Generalised annual rainfall map of Kenya showing the precipitation of the landslide prone areas. (Modified from EAEP Limited 1991).

Regional geology

Rock types are an important factor in the triggering of landslides because in the landslide-prone areas such rocks are associated with deep weathering, which leads into a reduction in their strength. The main rock types which constitute the geology of Kenya include the Archaean rocks of the Nyanzian and Kavirondian Groups, which are found in western Kenya; the Proterozoic rocks of the Kisii Group and the Mozambique Belt; the Upper Palaeozoic rocks of the Taru Formation; the Mesozoic rocks of the Mjai ya Chumvi Formation, Mazeras Formation and Maheran Formation; the Cenozoic of the East African Rift System including lava and pyroclastic flows, the Faratumu Formation, the Magari Formation and the Oloronga Formation (Figure 3).

The Nyanzian and Kavirondian Groups form the Archaean greenstone belt of western Kenya. The Nyanzian Group is composed of metavolcanic rocks which range from tholeiitic basalts to calc-alkaline andesites, dacites and rhyolites (Opiyo-Akech, 1988; Ichang'i and MacLean, 1991). The group is unconformably overlain by the Kavirondian Group, which consists of greywackes, mudstone and conglomerates (Huddleston, 1954; Ngecu, 1993; Ngecu and Gaciri, 1993).

The granite batholiths of western Kenya, which include the Mumias and Maragoli granites, have heterogeneous lithologies which vary from granodiorites, through adamellites to tonalites (Shiozaki, 1983; Opiyo-Akech, 1988; Mathu and Nyambok, 1993).

Figure 3 Geological map of Kenya showing the distribution of the major lithological units.

The Kisii Group is represented by a volcano sedimentary sequence that occurs in the Kisii district (Figure 3). This group represents marginal marine sediments and volcanic rocks of the original Mozambique geosynclinal basin (Mathu and Davies, 1996). The rocks of the group were dated at 1.30 Ga to 1.00 Ga (Cahen et al., 1984).

The Mozambique Belt is a complex chrono-tectono-lithostratigraphic unit which stretches from the south to the north across the eastern African countries. The rocks of this geological unit have been dated at 1.00 Ga–0.50 Ga (Stern, 1994). The Belt is characterized by medium- to high-grade metamorphic rocks which include schists, migmatites, granitoid gneisses, amphibolites, granulites, quartzites and marbles (Saggerson et al., 1960; Sanders, 1965).

The Palaeozoic-Mesozoic sedimentary rocks occur in the coastal and northeastern regions of the country, where they are unconformably overlain by the Raroro Series which include both Jurassic and Cretaceous sediments.

The Cenozoic volcanic rocks, largely of the Rift System, include basalts, phonolites, nephelinites, trachytes and rhyolites. The pyroclastic rocks such as tuffs, agglomerates and ashes are associated with both the large central-type volcanoes (Mounts Kenya, Elgon and Kilimanjaro, and the Aberdare Ranges) as well as the numerous central volcanic cones of the Rift System floor (Shackleton, 1945; Dixey, 1946; McCall, 1967; Williams, 1970; Baker and Wohlenberg, 1971; Baker, et al., 1988). During the Cenozoic, most of Kenya was above sea level, and the limited marine transgressions that occurred were confined to the coastal region (Saggerson, 1972). The Tertiary period was therefore dominated by continental deposition.

Causes and distribution of landslides

The distribution of landslides (Figure 1) which occurred during the El Nino assault, were governed by physical and structural imbalance of soils and geological formations caused by increased precipitation, oversaturation, and the high slope gradient of the affected areas. On the eastern slopes of the Aberdare Ranges, where the Gataru and Maringa landslides occurred, the highly permeable Miocene pyroclastic rocks which rest conformably over the impervious Tertiary basalts became oversaturated after a continuous heavy rainfall. At the contact between the two formations, the pyroclastic rocks became detached and slid down the slope.

The Gataru landslide (Figure 4) caused the deaths of three people, and shifted and destroyed thousands of tea bushes. The landslide occurred on andosols whose plasticity index value is PI-20-22. The soil lost its shear strength and because detached from the underlying formation.

The Maringa landslide (Figure 5) caused the deaths of 11 people, who were buried while they slept. This landslide occurred when deeply weathered pyroclastic rocks became oversaturated and slid along their contact with the underlying impervious basalts.

The landslides which occurred around Mount Kenya were caused by oversaturation of steep-sided man-made cuts between hills and on hillsides during road constructions. The slope cuts reduced the confining pressure and the unconfined compression strength of the over-steepened slopes which supported the soil materials, and consequently landslides occurred.

The landslides which occurred along the Embu-Meru highway (Figure 6) on the slopes of Mount Kenya, took place when oversaturated andosols, which formed the lower embankment of the highway, gave way as a result of intensive erosion at its foot, which was caused by the flooding of the Tula River. The erosion of the embankment had been going on for some time before the landslide occurred. The increased rainfall caused by the El Nino assault accelerated the removal of soil and facilitated the occurrence of the landslide. During the landslide, soil and rock material broke off and destroyed tunnels which had been used to construct a bridge on the highway, rendering the road completely impassable.

The Makutano landslide, which occurred along the Thika-Garissa highway, was caused by removal of the frontal support of the road embankment when the water level increased in a river flow below the embankment after a heavy rainfall. Increased water levels caused a decrease in the internal strength of the materials which had been used for construction of the road embankments, making the shear strength of the material insufficient to resist the shear forces, and the landslide subsequently occurred.

Another landslide occurred on 16th March 1998 and destroyed a 2-kilometer section of the Masii-Makueni highway (Figure 7) in

Figure 4 A photograph showing a section of Gataru landslide where thousands of tea bushes and houses were relocated and destroyed.

Figure 5 A photograph showing the head of Maringa landslide where 11 people were killed when their houses were covered by rock and soil debris.

Figure 6 A photograph showing destroyed road and bridge on Embu-Meru highway where a moving bus was washed away into a deep ravine killing 36 passengers.

eastern Kenya. The landslide also destroyed a major bridge on the highway, thereby cutting off communication between the two towns. The landslide occurred when the River Tana became swollen after a heavy rainfall and its flood water oversaturated the ferralsols which formed its banks and the surrounding region. The oversaturated ferralsols lost their shear strength, and the landslide occurred.

The most devastating landslide, however, occurred near the Kibwezi market along the Nairobi-Mombasa highway (Figure 8). The landslide damaged about three kilometers of the highway, in addition to destroying a major water pipeline which was constructed parallel to the highway. The Nairobi-Mombasa highway connects Mombasa town, which is a major port for the East Africa region and a famous tourist destination. The landslide occurred on strongly deformed and fractured Precambrian metamorphic Mozambique belt rocks. The slope instability was caused by oversaturation of embankments which had been constructed to support the road on the surfaces of cleavage and schistosity.

Summary and conclusions

This paper has documented some of the landslides which were triggered by the El Nino weather phenomenon which occurred in Kenya between May 1997 and February 1998. The number of landslides discussed here is only a small fraction of the total number which actually occurred, although it is by no means a small representation of the national landslide phenomenon during this period.

Figure 7 A photograph showing a section of Massii-Makueni highway where a major bridge was destroyed by a landslide.

Figure 8 A photograph showing a destroyed section of a road and a broken water pipe on Nairobi-Mombasa highway. They were destroyed by a major landslide which was triggered by El-Nino related rainfall.

Most of the landslides occurred due to failure occasioned by the existence of steep slopes, heavy rainfall, response of high clay volcanic soils with high absorption capacity and well-jointed fractured metamorphic rocks.

On the slopes of the Aberdare Ranges and in the Mount Kenya region, most of the landslides occurred as a result of the interplay of several factors, including heavy rainfall, steep slopes and high-clay moisture-absorbing andosols. The landslides which occurred in the Coastal and Rift Valley basins, which are geologically constituted by Mozambique belt rocks, were induced by heavy rainfall, steep slopes, and a network of well jointed and fractured metamorphic rocks.

Despite these natural factors, the majority of the landslides were triggered by human activities, including slope cutting, vegetation degradation on hill slopes, earth-fill operations and alteration of natural drainage regimes.

The overall socio-economic implications of the El Nino-triggered landslides in Kenya are enormous and cannot be adequately quantified at this stage. However, the landslides caused several hundreds of fatalities and injuries, in addition to destroying farmland and settlements. In most parts of the country, the infrastructure ground to a halt. Several roads were impassable because they were partially destroyed and their bridges washed away, while telephone and electricity lines were shifted and destroyed. Finally, considering the quick disbursement loan of 800 million US dollars which Kenya Government borrowed from the World Bank to restore the destroyed

infrastructure, it becomes clear that El Nino weather took a heavy toll on Kenya's economy.

References

- Baker, B. H., Mitchell, J. G. and Williams, L. A. J., 1988, Stratigraphy, geochronology, volcanotectonic evolution of the Kedong-Naivasha-Kinangop region, Gregory Rift Valley. *Journal Geological Society*, London 145, pp. 107-117.
- Baker, B. H., and Wohlenberg, J., 1971, Structure and evolution of the Rift Valley. *Nature* 229, 538-541.
- Cahen, L., Snelling, N. J., Delha, J. R., Bonhomme, M. and Lendent, D., 1984, *The Geochronology and Evolution of Africa*. 512p. Clarendon press, Oxford.
- Dixey, F., 1946, Erosion and tectonics in the East African System. *Quarterly Journal Geological Society*, London 102, 339-388.
- EAEP, Limited, 1991, *Phillips EAEP Atlas*. 136p. EAEP, Nairobi.
- Huddleston, A., 1954, *Geology of Kakamega District*. Report number 28, 59p. Geological Survey of Kenya, Nairobi, Kenya.
- Ichang'i, D. W. and MacLean, W. H., 1991, The Archaean volcanic facies in the Migori segment, Nyanz greenstone belt, Kenya: Stratigraphy, geochemistry and mineralization. *Journ. African Earth Sci.*, 13, pp. 277-290.
- McCall, G. J. H., 1967, *Geology of the Nakuru-Thompson's Fall-Lake Hannington area*. Report 78. Department of Mines and Geology, Kenya.
- Mathu, E. M. and Davies, T. C., 1996, Geology and the environment in Kenya. *Journ. of African Earth Sci.*, vol. 23, No. 4, pp. 511-539.
- Mathu, E. M. and Nyambok I., 1993, A re-evaluation of the geology and tectonics of the granitoid plutons around Kakamega town, western Kenya.

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- In: Proceedings of the 5th Conference on the Geology of Kenya* (Edited by Opiyo-Akech, N.) pp 63-68, UNEP/UNESCO, Nairobi.
- Ngecu, W.M. and Gaciri, S. J., 1995, Lithostratigraphy, provenance and facies distribution of Archaean Cratonic successions in western Kenya. *Journ. African Earth Sci.*, vol.21, No.3, pp. 359-372.
- Ngecu, W. M., 1993, Stratigraphy and sedimentology of the Archaean Greenstone Belt of western Kenya. *In: Proceedings of the 5th Conference on the Geology of Kenya* (Edited by Opiyo-Akech, N) pp. 57-62. UNEP/UNESCO, Nairobi.
- Opiyo-Akech, N., 1988, *Geology and geochemistry of the late Archaean greenstone belt association, Maseno area, Kenya*. Ph. D. dissertation 188p. University of Leicester. U. K.
- Saggerson, E. P., Joubert, P., MacCall, G. J. H. and Williams, L. A. A., 1960, Cross-folding and refolding in the basement system of Kenya Colony. *In: proceedings of the International Geological Congress, 21st Session: Part 18*, pp. 335-364. Copenhagen, Denmark.
- Sanders, L. D., 1965, *Geology of the contact between the Nyanzian Shield and the Mozambique belt in Western Kenya*. Bulletin No.7. 45p. Geological Survey of Kenya, Nairobi.
- Shackleton, R. M., 1945, *Geology of Nyeri area*. Geological Survey of Kenya, Report No.12, 26p.
- Shiozaki, H., 1983, Magnetic susceptibility of the granitic bodies in the Tanzania craton of west Kenya. 8th Preliminary Report on African Studies. Nagoya University (Earth Sciences 5). Edited by Suswa, K pp. 165-180. Nagoya, Japan.
- Stern R. J., 1994, Arc assembly and continental collision in the Neoproterozoic East African Orogen: Implications for the consolidation of Gondwanaland. *Annual Reviews Earth Planetary Science* 22, pp 319-351.
- Williams, L. A. J., 1970, The volcanics of the Gregory Rift Valley. *East Africa Bulletin volcanology* 34, 436-465.

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