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Kaben Location Lagam Landslides and Preparedness Measures, Kenya

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Abstract:- The Kaben Location Lagam escarpment landslides of Elgeyo-Marakwet County, Marakwet East in Kenya, are not only recurrent but are highly cataclysmic and destructive. They cause mayhem whenever they occur. The first known landslides on the Lagam escarpment of the Kaben location, occurred during the 1961 El-Nino, when a major rainstorm hit the area (Kiptungu). The landslides denudated Embosumer River and left huge boulders scattered over many farmlands. Four decades later, on the night of 12th April 2010, a catastrophic landslide once again hit Kaben location. Embosumer River was again the perpetrator, having broken its banks due to excessive water inflow from Lagam escarpment. Fourteen (14) people lost their lives, others were badly injured and lots of property was destroyed. A decade later, on Sunday, 19th April 2020, in the afternoon, heavy rains pounded the area, once more, causing massive mudslides that involved many rivers and streams. Thus, twenty six (26) people lost their lives and homes, schools and farmlands were washed away and several bodies trapped in the mudslide material. This preliminary study was undertaken to understand the causes of Lagam recurrent landslides and identify possible mitigation and preparedness measures. Data was collected using secondary data analysis and presented in the form of ground photographs, satellite images and discussions made thereon. Since then, it is still expected that recommendations made and mitigation measures envisaged in this research-related work will draw positive action from the area residents and all concerned parties in Kaben Location.

Keywords:- *Landslides, Recurrent, Lagam Escarpment, Kaben Location, Marakwet.*

I. INTRODUCTION

The Lagam escarpment is a section of the Elgeyo-Marakwet escarpment (Kerio Valley escarpment), that traverses Keiyo, Marakwet and West Pokot regions. The steep palisade is the western scarp of the Kerio Valley depression. It is highly rugged, being dissected in many sections, by parallel escarpment rivers and streams. This gives it an appearance of wedged hills that are separated by sharp V-shaped valleys. It is also high, reaching an altitude of about 3520m Above Sea Level (ASL) at Chemnirot and 3500m ASL at Kamalogon hill. The rivers originate from Embobut forest and mostly flow eastwards, joining River Kerio, which drains into Lake Turkana.

The Lagam Escarpment is sparsely vegetated, except for the deteriorating Embobut forest that still has a semblance of a continuous canopy. The vegetation cover on the escarpment and the Embobut forest, is thoroughly degraded by escalating human settlement and agriculture in the unfavourably steep and rugged area. Consequently, a large section of the Lagam escarpment is deplorably 'bare'.

The escarpment soils are lateritic in nature, except for the isolated grooved sections and river valleys where alluvium soil is found. The soil is also highly erodible, owing to the steep nature of the terrain.

The Kaben Location section of the escarpment continues to be hit by landslides more than any other section of the Lagam escarpment and this may have everything to do with the area's geology. The area, right from Embosumer River in Marakwet East to Chemisto and Sonokor areas of West Pokot County (Cheptulel Location), appears to be rocky and the rocks seem to be one continuous dark formation. This makes the Kerio Valley escarpment of Kaben Location unique. In fact, it appears to be pushed backwards, comparing it to the other sections of the Lagam escarpment, such as Wewo and Katilit sections, which are equally steep but semi stable. According to Mason and Gibson [1], the Kerio valley floor (Kew) was alluvium deposits and the escarpment has its base in gneissic rocks with an irregular capping of porphyritic phonolite lava. Some phonolite is often found exposed beneath the gneiss rocks, suggesting uneven lava outpourings during the formation of the Kerio Valley [2, 3, 4].

The gneiss on the escarpment is of the Basement System. There are dark hornblende rocks in several areas of the escarpment. The gneiss rock appears to be un-weathered across the Lagam escarpment of Kaben location, making it easy for the thin overlying escarpment soils to slide downhill during heavy precipitation. This is evidenced by the bare rock scars that were left behind by the mudflows of 2020 which covered the entire location, all the way to Cheptulel Location.

On 19th April 2020, in the afternoon, heavy rains on the Lagam escarpment of Marakwet East, caused rapid flash floods and mudslides to erupt, both on the Marakwet and Pokot sections of the escarpment. Two rivers: Embosumer and Emboreberwo, joined forces to wreak havoc. The two rivers are in Marakwet East but Emboreberwo taps runoff from both the Pokot and Marakwet sections of the Kerio Valley

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escarpment, to the west. Downstream, they become River Chesegon.

The mudslides left massive scars on the escarpment and rock trails, on the river valleys and farmlands from which local residents draw their livelihood. As a result, twenty six (26) people lost their lives, when the Liter and Chesegon areas of Marakwet East and West Pokot and on the Kerio Valley floor were washed away (Plate 1).

Plate 1: Embosumer and Emboreberwo Rivers on their upper sections and at source, as well as mudslides (M) paths of the Lagam escarpment (April, 2020). of a figure caption.

There were some mudslides at Kipchumwa location as well. Cracks have been reported on parts of Katilit and Kipchumwa, indicating that the landslide problem in the Lagam escarpment may not be over but could be spreading to other areas, outside Kaben location. Furthermore, step faulting may have affected the landslide area, as shown by the pictures presented, especially in Plates 2, 3 and 4.

Plate 2: Emboreberwo and its post-landslide flow (April 2020).

The Rock that makes up the escarpment can be clearly seen from Plate 2.

Plate 3: Farmlands washed away by the Lagam escarpment mudslides and Emb

osumer River on its lower section (April 2020).

Plate 4: A rocky river Chesegon, at the border of Marakwet East and West Pokot-on the Kerio Valley floor (April 2020)

A. Statement of the Problem

Although the Lagam escarpment landslides have taken place recurrently and are extremely deadly, no formal study was conducted on them and consequently, very sparse literature exists on their occurrence, causes, and effects. This preliminary study was, thus, conducted to determine the geomorphological and geotechnical factors that continue to influence the recurrent landslides.

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B. Objectives

The main objective of the present study is to understand the geoenvironmental causes of the recurrent landslides on the Lagam escarpment of Kaben Location, Elgeyo-Marakwet County. The study also proposes possible mitigation and preparedness measures to arrest the landslides problems in the escarpment.

C. Present Study Area

The present study area covered a small section of the Lagam escarpment, in Kaben location, Tot division, Elgeyo-Marakwet County (Fig. 1 and Plate 5). It covers a section of Katilit, Kakisoo, Mung'wo and Kobil, on the upland section, to the West and North West of the Kerio Valley. To the East (towards Kerio Valley) is Bororwo, Kitony, Ng'achar, Cheptokou, Sambalat, Liter and Chesegon areas.

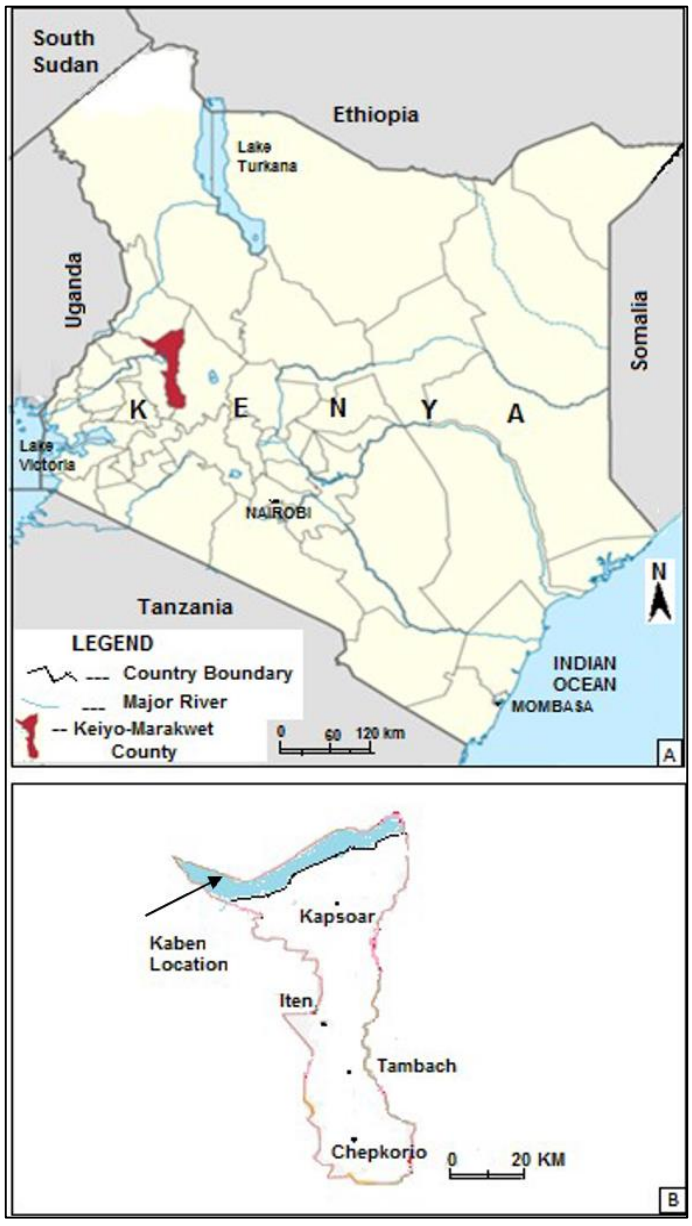

Fig. 1: Location of Elgeyo-Marakwet County, Kenya (A) and Kaben location as main study area (B) in Elgeyo-Marakwet County.

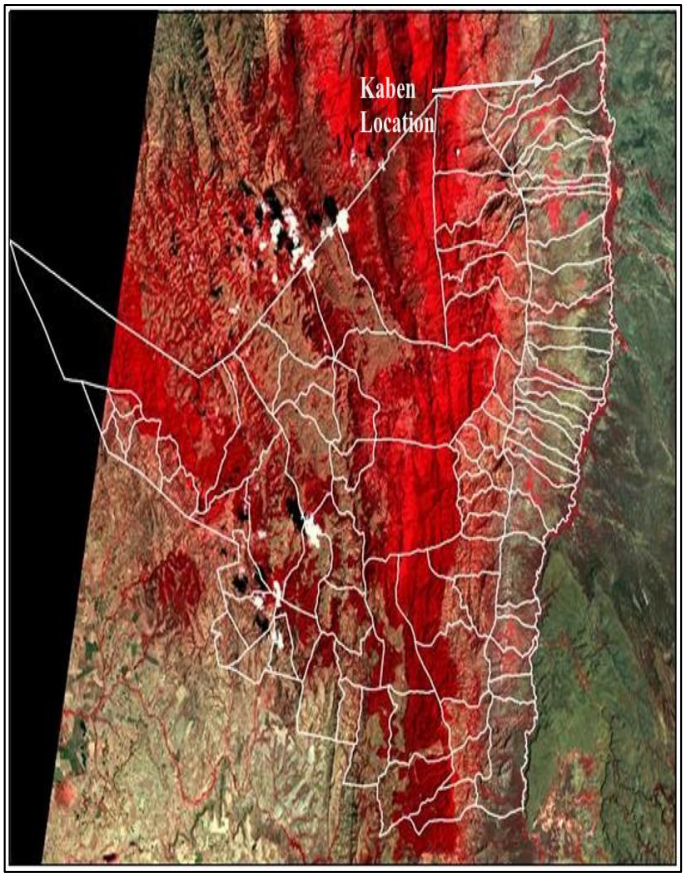

Plate 5: Landsat Enhanced Thematic Mapper (ETM), False Colour composite, showing Kaben location- pointed by a white arrow. The image also shows the ruggedness of the Lagam escarpment [2]

The landslides prone areas are watered by two rivers and their tributaries. The rivers are Embosumer and Emboreberwo. These two rivers originate from the lower edge of the Embobut forest, on the upland plateau, above the escarpment, to the west. Emboreberwo originates from the forest, while Embosumer oozes out of the escarpment, from a cliff face. It is believed that Embosumer is the product of an aquifer that disconnected when the Lagam escarpment and the Kerio Valley were formed through faulting. The river is also called Barelach (White water), owing to its brightness when it reflects the midday sun. Unfortunately, like all the escarpment rivers, Embosumer is on its deathbed, because of deforestation in Embobut forest, right above it, as the pictures show.

The landslide area is almost two thirds of the whole Kaben location, and that makes this study crucial.

II. MATERIALS AND METHODOLOGY

Data was collected through secondary data analysis. Past studies and reports on the area of study and on the landslides, were perused for relevant data. Satellite images of the area of study were also analysed besides online data sources. Ground photography supplemented data collection.

Information was then presented in the form of analysed satellite images, pictures and discussion of the study results.

D. Causes of the Recurrent Landslides in Lagam Escarpments

The following factors were found to be the collective causes of the recurrent Lagam landslides in Kaben Location, Elgeyo-Marakwet County:

1) The steep terrain of the escarpment,
2) The nature of the escarpment soils,
3) Faulting of the escarpment rock masses,
4) Destructive human activities,
5) Heavy rainfall during the wet season.

1 The Steep Terrain of the Escarpment

From the presented satellite images and pictures, it is succinct that the Lagam escarpment is acutely steep. This encourages water runoff/ surface flow after heavy downpours. The steep terrain also enhances the force of gravity on the escarpment overload material, making it vulnerable to sliding, especially when the soil mass is wet.

The relief of the Lagam escarpment also comprises bare rock areas, rock outcrops, step faults, valleys-including river valleys, interlocking spurs, hills, landslide lumps, fault scarps, slopes and landslide scars [4]. The hills are mainly products of faulting, weathering, and erosion. They may have formed when the Kerio Valley was formed and with time, denudation forces shaped them, coupled with vertical river/stream erosion. They form divides of the major escarpment rivers, though themselves possessing dry river valleys, which are basically the pathways of water runoff. Agricultural activities, on these hills, have heightened soil erosion, besides instigating landslides. The image and pictures represented by Plates 6 to 12 depict geomorphological characteristics of the Lagam escarpment, together with human activities particularly; human settlement, communication lines, agricultural activities and the general environment of the study area.

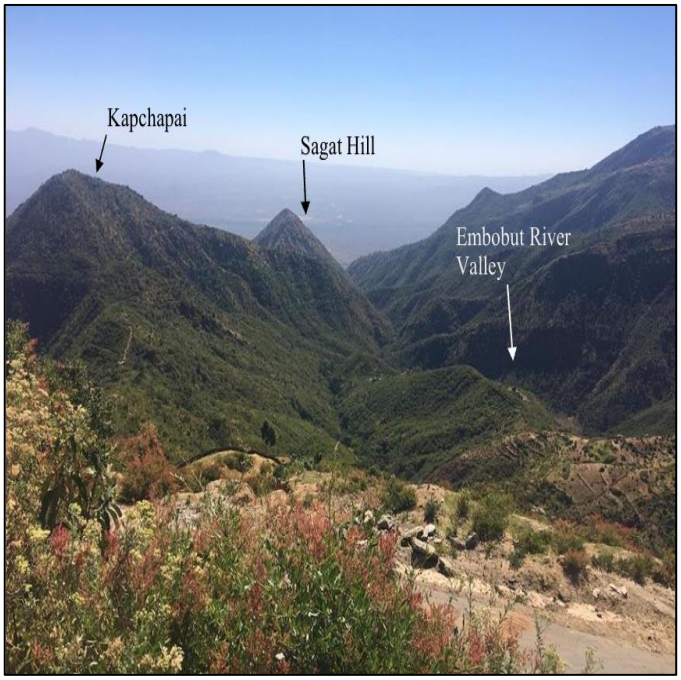

Plate 6: The Lagam escarpment viewed from a section of the road between Maron and Sambalat

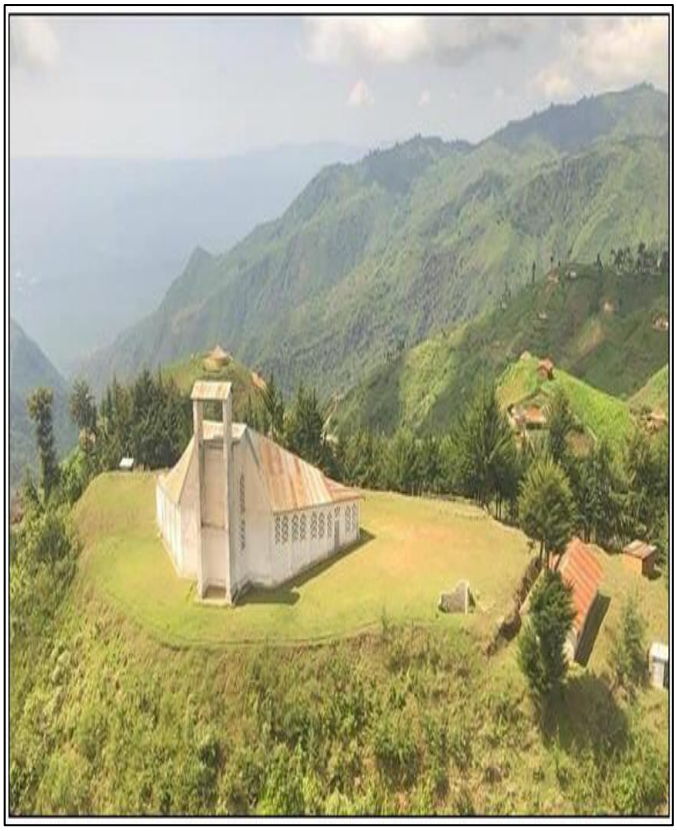

Plate 7: Wewo Catholic church, on Wewo Hill. Source: Unknown

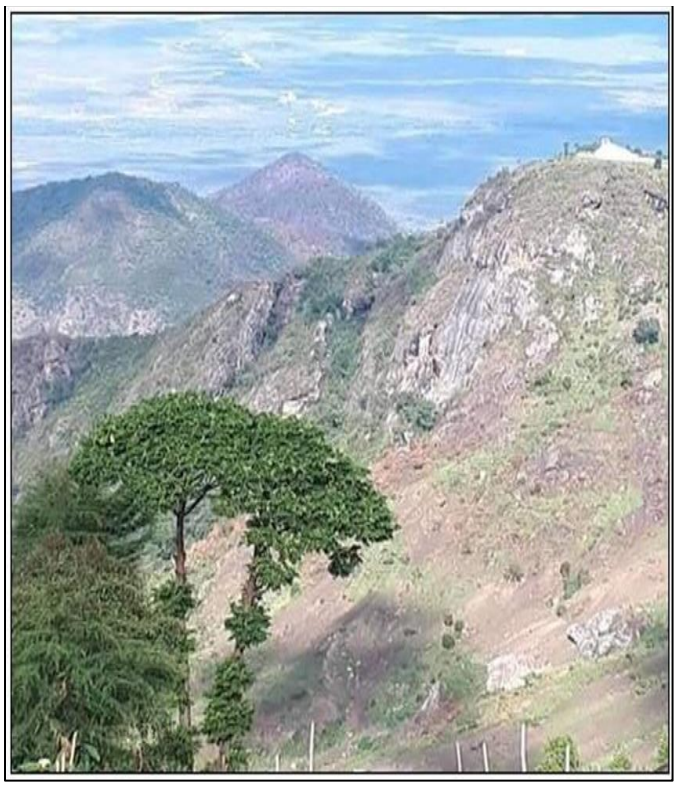

Plate 8: Wewo Hill (Wewo Catholic Church in the background), Kapchapai Hill and Sagat Hill in the horizon. Source: Unknown

Plate 9: The landslide areas, Wewo Hill and Katilit -viewed from Sambalat (April 2020)

Plate 10: Wewo Hill and a section of the escarpment below it. The picture also shows a section of the Maron-Sambalat road (April 2020).

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Plate 11: Kapchapai Hill with an ancestral water canal/furrow cutting across its northern slope (April 2020).

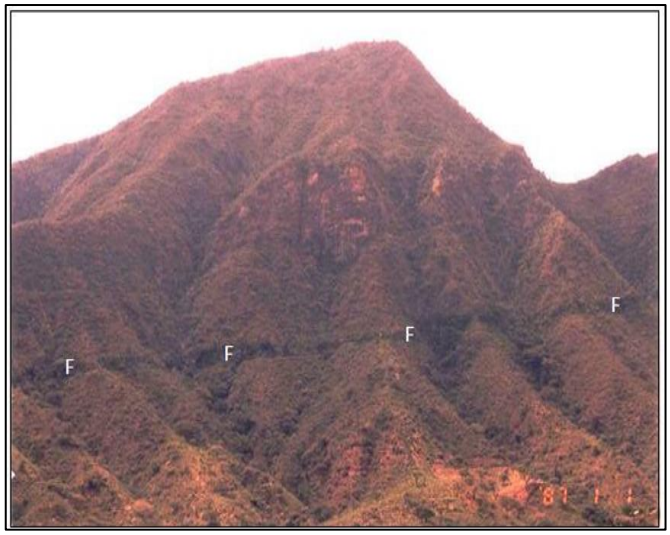

Plate 12: Kapchapai Hill with the ancestral water canal/furrow (F) on it (Kowow water furrow).
Picture adapted from [2].

2 The Nature of the Escarpment Soil

The Lagam escarpment is a young faulted rock mass which was formed at the same time that the Kerio Valley was formed [10] in the early Miocene period (22- 25Ma). This is also about the time that the Kerio River Fault line was formed. Consequently, the escarpment is covered by thin screen soils that are highly eroded.

The soil is chiefly stony and unconsolidated, except in the escarpment's dales where alluvium is predominant.

The thin screen soil has poor water retention capability, meaning that most infiltrated rainwater runs downhill as surface flow (deluge). On the upper parts of the escarpment, however, one encounters the upland plateau, to the west, and an expansive area of loose loam soils. This is where Embobut forest grows. Since 1962, when the people who were affected by the first known Lagam escarpment landslides were allowed settlement in the glades of Embobut forest, the forest has undergone immense degradation and much of it is bare, as can be attested by the photographs and the satellite images presented. The recent landslides, in fact, started right in the exposed bit of the upland plateau (Mosop), where Embobut forest has been cleared.

As stated earlier, the escarpment soils seem to sit on a continuous subsurface rock, which is poorly weathered and relatively smooth and compact, as seen from the landslide scars. This rock could be facilitating the sliding away of materials from the escarpment, especially in areas devoid of vegetation.

3 Faulting on the Escarpment

There are fault lines on many sections of the Lagam escarpment such as the ones shown on Plate 13. Most of the faults could be acting as conduits for seepage of rainwater from the upland plateau (Mosop) to the base of the escarpment. The water then emerges from the base of the escarpment as springs. Indeed, there is a line of springs along

the base of the Lagam escarpment and some of them have created swamps on the Kerio Valley floor.

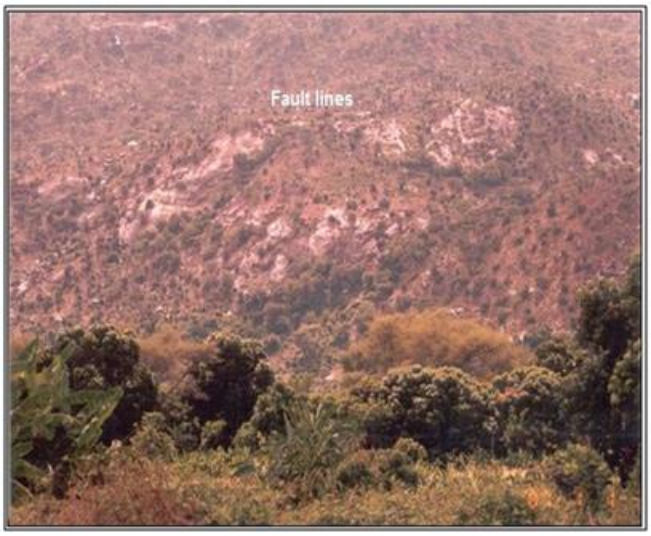

Plate 13: Fault lines on the Lagam escarpment, above Tot Health Centre [2].

Fault lines of lagam escarpment are mostly invisible, having been filled by sediments and vegetation. They can, therefore, be identified through vegetation mapping; by looking for healthy vegetation lines in areas that do not have known surface water ways or through analysing satellite images of the area- such as Plates 14 and 15.

The disjointed nature of the escarpment makes it easy for the escarpment's bare rock to become well lubricated by rainwater, so that it gets too slippery to hold the overlying weathered materials, hence landslides.

4 Destructive Human Activities

A band of environmentally harmful human activities were also found to be responsible for the copious landslides on the Lagam escarpment of Kaben location. These activities include:

1. Deforestation on the Lagam escarpment and the Embobut forest,
2. Detrimental agricultural practices and finally,
3. Poorly done road shoulders.

1) Deforestation of Embobut forest and destruction of the Lagam escarpment woodlands

The Lagam Escarpment has no actual forests. What it has can be described as an arid and semi-arid woodland consisting of thorn trees, among other drought resistant plants such as euphorbia. In recent years, mango plantations have, admirably, taken over the Lagam escarpment, amid a horde of other tree crops such as avocado, lemon, banana, and pawpaw. Natural vegetation, thus, is giving way to man-made forests though in a small portion of the escarpment.

The larger Lagam escarpment is covered by some form of derived woodland that is not fully recovered from slash and burn agriculture. Demand for agricultural land and charcoal burning have escalated deforestation, in the Lagam escarpment and the Embobut forest, to disastrous levels. This has resulted in a receding Embobut forest and an elongation of the escarpment that is stretching way into the upland plateau, a region that was darkly covered by a lush Embobut forest, 60 years ago.

The elevated deforestation on the Lagam escarpment and the Embobut forest can be deduced from plates 14 and 15, which are false colour Landsat images taken years apart (1986 and 2000). They show the Kerio River regime in the two periods [2].

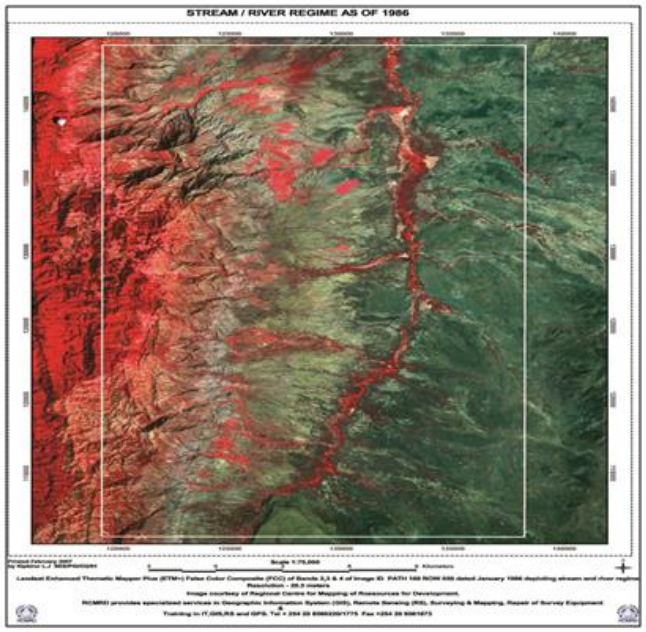

Plate 14: Kerio River regime in 1986 [2].

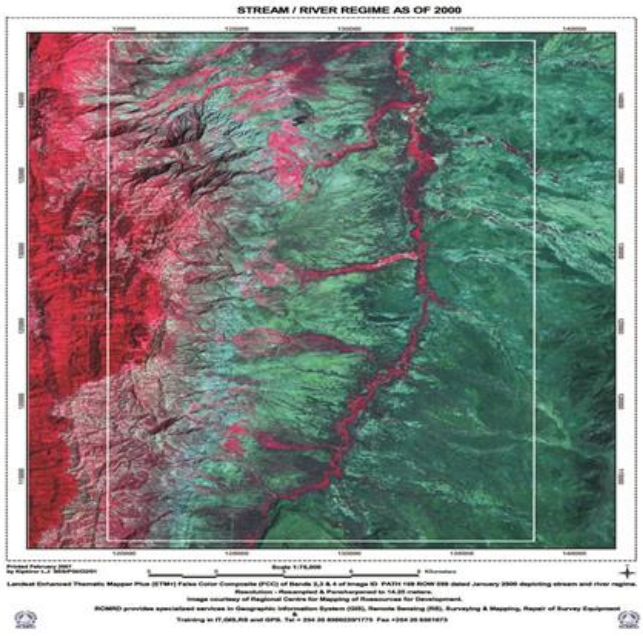

Plate 15: Kerio River regime in 2000 [2].

In the 1986 satellite image (Plate 14), the Embobut forest and the Lagam escarpment have rich plant canopies (deep red) and most of the escarpment rivers were shrouded in

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vegetation. The rivers reaching Kerio River, from the escarpment, were also many. The image shows about 8 countable rivers that had vegetation on their courses, as they wound their way into the Kerio River. Also, from the image, the large rivers appear to have had many tributaries that, themselves, had vegetation on them. The study area's rivers display a dendritic drainage pattern, separated by raised and semi bare divides and interfluves. The rocky areas (grey areas) of the escarpment, in the 1986 image, also appear to be less widespread compared to the rocky areas shown by the 2000 image.

In the 2000 image (Plate 15), the vegetation cover appears to have thinned immensely, both on the Lagam escarpment and in the Embobut forest- as shown by the lightness of the red colour in the two areas. The rivers reaching Kerio River, from the escarpment, also appear to have reduced to 5, with some becoming seasonal. The rivers to the south of the area, covered by the image, have sand and rock trains on their beds-appearing whitish on the image.

The rivers joining Kerio River, from the East, appear to have had some headwaters in 1986 (evidenced by vegetation) but by 2000, the rivers seem to have vanished- inheriting dry valleys (whitish).

The photograph below (Plate 16), which was taken from near Wewo primary school, on the upland plateau, shows a section of the Embobut forest that has been mowed down, to pave way for agricultural land.

Plate 16: A section of the Embobut forest, adjacent to the Lagam escarpment (April 2020).

The clouds hanging on the area shown by plate 17, evidence the cool climate of the upland plateau. The bamboo twigs that make up the screen fence not only provide proof of deforestation of the Embobut forest but testify of the nearness of a bamboo forest. The picture also shows an elongation of the Lagam escarpment into the lower reaches of the upland plateau, besides showing landslide scars, poor farming practices (slash and burn agriculture) and a washed out Chesegon area.

2) Poor Agricultural Practices

Slash and burn farming regime, cultivation across contours, harrowing on steep riverbanks and fallowing are also responsible for the recurrent landslides on the Lagam escarpment in Kaben Location. During the dry season, the farmers of the Lagam escarpment often clear and burn bushlands to prepare land for cultivation. This not only exposes the land to agents of erosion and mass movement but also burn humus and other lithification elements that bind soil particles together. As a result, escarpment soils become loose and are easily carried away by wind and water. Lands on the rugged slopes of the escarpment are also hand-ploughed, vertically, along slope planes. This creates rills that quickly become gullies, where terracing is not done. Unfortunately, terracing does not provide a reprieve for landslides because, while stopping running soil, they also hold running water, percolating a lot of it into the soil. This intensifies soil wetness on the escarpment and encourages landslides.

In the quest for extra farmland, riverbanks, on the Lagam escarpment, are cultivated. This encourages undercutting of the banks by water hydraulic force and easy collapse during flood seasons. The steepness of the riverbanks adds to the quandary of collapsing land, along the rivers, during the rainy season (Plates 17 and 18).

Plate 17: Settlement and cultivation on the Lagam escarpment (April 2020).

Plate 18: Slash and burn farming on the Lagam escarpment together with cultivation on riverbanks (April 2020).

3) Steep road shoulders

Landslides on the Lagam escarpment are also experienced in areas where roads cut deep into the slopes. Road network, in the area, is still on high demand but the hanging road shoulders should be effectively steadied and stability measures applied so as to guard against landslides. The escarpment road shoulders slide onto the road or down the escarpment, from the road surfaces at several localities. Plate 19, shows a road section on the Lagam escarpment. The road shoulders are not only steep, but loose. Deforestation and dangerous farming, on the escarpment, is also evident on the upper parts of the area shown by the photograph. The photograph also shows road instigated landslides.

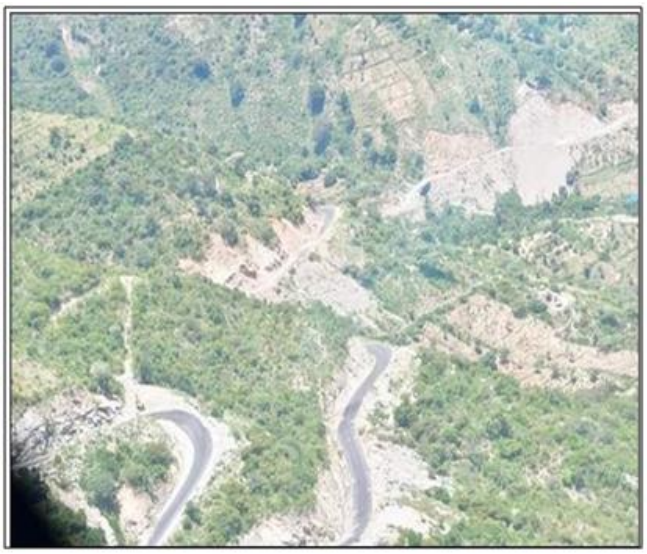

Plate 19: A section of a road on the Lagam escarpment affected by landslides (LS). Source: Unknown

In 2019, a family of four were killed by a landslide that originated from a road above their house, when heavy rains hit Tuturung area of Marakwet East (Plate 20).

Plate 20: The family house where four family members perished in 2019 in Marakwet East. Source: Standard digital news-Kenya (2019).

5 Unquantified Heavy Rainfall during the Wet Season

Climate change, which is a cross border global problem, is one of the factors behind the Lagam escarpment landslides. Global warming, which characterizes the current Climate Change phenomena, is choreographed by ruinous weather demonstrations that include: Haphazard rain patterns, Deviant rainfall intensity, Calamitous winds, High humidity, Supercharged clouds, Killer temperatures and Overcasting prolonged fog. These unforgiving weather exhibitions are trailed by melting of ice and snow, heavy river discharge, enlarged gobs of hailstones that take days to melt, lightning and thunder, poor visibility, disproportionate rain, discomforting gales, sweltering heat waves, freezing temperatures and poor visibility. In turn, these weather hazards lead to disasters of diverse kinds and magnitudes. It must be borne in mind that a hazard is a situation that is not currently causing harm but when it encounters some vulnerability, it transforms directly into a disaster (Disaster = Hazard + Vulnerability).

On the Lagam escarpment/Kerio escarpment, thus, Global Warming has created irregular rain patterns and superabundant downpours, especially in the month of April.

According to [1], the Lagam escarpment and the Kerio valley received less amounts of rain, ranging from 750mm to about 1000mm per year. Rainfall was trimodal with first rains occurring in March, second rains in July/August and third rains in October/November, though the rainfall varies from place to place and is generally unreliable. Evaporation was also high in the area of study being about 2400mm per year. This pattern of rainfall appears to have changed albeit slightly, so that the first rains occur in April and they are unusually heavy, being partially responsible for the recurrent landslides. In all probability, the Lagam escarpment April rains could be hitting a monthly average of over 100mm. In the other months, the area experiences a semi-arid type of climate that is characterised by high temperatures, sparse clouds and gusty

winds. This is broken by the light September - December rains.

III. RESULTS AND DISCUSSION

The following are the possible solutions to the recurrent landslides on the Lagam escarpment of Kaben location, Marakwet East, Elgeyo-Marakwet County:

1. Afforestation
2. Effective land use
3. Adaptation of sustainable agricultural practices
4. Creating environmental awareness

1 Afforestation

This is an exercise that should cover the Embobut forest and the Lagam escarpment; and it can be done in piecemeal. It is no secret that a large section of the Embobut forest has been cleared, especially the areas adjacent to the Lagam escarpment. Clearing of the forest cover has contributed to runoff of considerable volumes of water that goes down the escarpment, as non-percolated rainwater increases in the steep forest margins. This great deluge shoots up the landslide problem.

Afforestation can be done using crop trees, for both the forest and the escarpment. Avocado, plum, pear and other cold temperature fruit trees can be planted on the edges of the forest, where people own land- instead of planting maize, beans, and potatoes. On the Lagam escarpment, the people can plant mango, banana, pawpaw, and lemon, instead of maize, millet, and other grass crops. These crops will not only hold the escarpment soil together but will earn the residents some much needed cash.

2 Effective land use

Maize and seasonal crops can be planted in created plantations in the Kerio Valley. The valley is flat and fertile-much suitable for mechanized farming. The communally owned tracts of valley land can be jointly farmed, weeded, and harvested, then whatever is harvested is shared among the clan families. Such kind of farming will not only make the valley useful but will stop cattle rustling that makes Kerio Valley inhabitable-more so if the joint valley farming practice is replicated across Kerio River, on the Pokot side of the valley.

The entire Lagam escarpment should be greened, from North to South and vice versa.

Currently, there is heavy settlement on the steep slopes and valleys of the Lagam escarpment, which goes hand in hand with extensive farming. Since resettlement has been an arduous task for the government and there is a lot of cultural value attached to land in the study area, the escarpment land can be used in a way that landslides are inhibited.

First, homestead grounds on the Lagam escarpment should be made stable and environmentally safe. Trees and grass should be grown around compounds so that no land is left bare for runoff to act on. Secondly, farming on riverbanks and the very steep areas of the escarpment should be ceased. If farming must be done, then it should be the growing of tree crops, in areas that are well terraced. The tree crops can be intercropped with cereals or legumes to ensure a continuous vegetation cover.

Thirdly, the construction of roads and other infrastructure, on the Lagam escarpment, should be done after much environmental consideration is done. A comprehensive ESIA (Environmental/Social Impact Assessment) should be carried out for all construction projects so that the land is left more stable in the after-project period than in the pre-project time. This way, road construction-initiated landslides will be curbed.

Fourthly, charcoal burning and other forms of deforestation, in the study area, should be stopped. Grass laced terraces should also be constructed across the Lagam escarpment, to stabilize the soil and guard against excessive water runoff, mostly in areas devoid of vegetation and in farmland areas. This was the practice in the past when population explosion was not as high as now and people did not settle haphazardly on the escarpment.

The faulted areas of the Lagam escarpment, together with the areas that have loose rock boulders, should be covered with trees. The trees - root network will hold the soil and rocks together, propagating soil formation as roots and humic acid weather the independent and faulted rocks.

For their own safety, people should avoid settlement on flood paths and river valleys, where they are exposed to flash floods and landslides.

3 Adaptation of sustainable agricultural practices

The people of the Lagam escarpment must do away with slash and burn agriculture, cultivation across contours, keeping large herds of grazers on the escarpment and land fallowing.

Slash and burn agriculture loosens soil, making it vulnerable to erosion and landslides. Cultivation up the slope creates grooves that enhance rill erosion while grazing many animals on the escarpment will cause bareness of land and encourage rock falls. The scars left behind by falling rocks will form the bases for future landslides. Fallowing, on the other hand, causes land redundancy and might expose land to natural agents of land degradation, as land is abandoned for a while. Lack of constant land care means that land might be eroded or mishandled by nature, at will.

4 Creating environmental awareness

The recurrent nature of the Lagam landslides and the devastation that accrues, shows some knowledge/ information gap among the area residents. This calls for environmental education that may be done by the National/County government, experts from relevant national departments or a trained team of locals. This team will act as environmental watch dogs; training people on environmental conservation, scouting for signs of environmental disasters and disseminating information on disaster preparedness and environmental safety.

IV. CONCLUSION AND RECOMMENDATIONS

Some highlighted pertinent issues that need to be addressed in order to avoid re-occurrence of landslides, as geo-environmental hazards [5] include these issues;

- Mapping of a study area so as to identify slopes which are susceptible to landslides,
- More input for applying adequate conservation efforts to vulnerable steep slopes be sought for from stakeholders.

Since 1999, interpretation of satellite images has been undertaken for better understanding of the geotechnical features of the study area such as, faults, tectonic joint systems etc. Furthermore, slopes that are vulnerable to landslides have been also been identified and it can now be concluded, for the present that:

- The main factors triggering landslides are over saturation of soil and rock materials due to heavy downpour, depletion of vegetation on the steep rugged Lagam escarpment and escarpment slopes caused by human activities.
- The slopes of the Lagam escarpment/ridges, that are prone to landslides, are very unstable and not fit for human settlement.
- The most affected areas are Kipchumwa and Kaben Locations, though the effects of the landslides worsen downstream at Kitony, Cheptokou, Sambalat, Liter and Chesegon areas.

Thus, there is need for in-depth research, in the study area, beyond the present initial study, especially along the entire Lagam escarpment and associated ridges.

E. ***Inherent factors***

The following are inherent factors contributing to the landslides in the area covered were considered to be mainly:

(a) Slope gradient: This is a very important factor due to influence of gravity on loose stony and alluvial material. In the area, the slope inclination is generally high along the steep escarpment slopes. Some parts are almost vertical.

(b) Area's geology: The geological characteristics of the Kerio escarpment /Lagam escarpment comprise gneiss rocks with an irregular capping of porphyritic volcanic phonolites. Some phonolites outcrop beneath the metamorphosed gneissic rocks, suggesting uneven lava outpourings during the Kerio Valley extensional tectonic formation. The gneisses on the escarpment belong to the Mozambique Basement System comprising dark hornblende rocks in several areas of the escarpment. The granodiorite gneisses (product of metamorphosed granite) appear to be un-weathered across the Lagam escarpment, making it easy for the thin escarpment soils to slide downhill, during heavy precipitation. This is evidenced by the bare rock scars that were left behind by the recent landslides (mudflows) across the entire location up to Cheptulel Location. Furthermore, according to [6, 9] there is need to take into consideration categorization of slopes in relation to landslides. Slopes between 0^0 and 16^0 are categorized as Relatively Safe, slopping grounds between 16^0 and 32^0 are Moderate Risk and slopes above 32^0 are High Risk. From this analysis, majority of the Lagam escarpment slopes may be of Moderate Risk and High Risk owing to the fierceness of the recurrent landslides.

(c) Hydrologic criteria: The area probably receives over 100mm of rain in the month of April. This translates to abundant moisture in the soil, a precursor to landslides. The excess water lubricates the interface between the weathered loose crust material and the bedrock thereby lowering soil shear strength and triggering debris flows.

In general, geomorphological factors and a wide range of human activities have been found to be the causative agents of landslides, as geohazards of varied magnitudes, on the Lagam escarpment and the adjacent Kerio Valley.

F. ***Recommendations***

The following mitigation measures and restrictions, if addressed positively, should provide a solution for the landslide menace which continues to re-occur in the Lagam escarpment area; especially Kipchumwa and Kaben Locations:

a) Greenery and conservation measures

Mitigation measures to arrest landslides in this present study area are as follows:

i) Completely stopping deforestation while effecting afforestation, especially the planting of deep rooted trees on the escarpment's steep slopes and discouraging cultivation on these slopes.

ii) Discouraging settlement on steep slopes or on ancient debris soil mass as seen on plate 17.

iii) Putting in place soil conservation measures.

(b) Mitigation Measures

Constructing support structures on vulnerable slopes (slope angle greater than 16^0) to prevent landslides or to arrest mudflows. Typical such measures are as shown on Plate 21 [6, 7, 9].

Plate 21: Engineered structures: Combination of steel mesh and concreting (A), Gabion walling in progress (B) and Application of Anchor bolts as well as concreting (C).

iv) Encouraging agro-forestry in the area.

v) Zoning of hill slopes, evacuation of steep areas by residents to less steep areas [8]; and creating terraced surfaces for cultivation purposes. This is well implemented in Rwanda as a remedial measure of landslides (Plate 22).

Plate 22: Landslides (A), Karongi, Western Province and Terracing efforts in Nyabihu district (B), Rwanda [8]. (Photo: Rwanda Red Cross).

vii) Use of Biotechnical Landslide Mitigation: Common biotechnical systems used include nets of various materials anchored by soil nails that hold in place soil which is then seeded with grass. This practice is prevalent in Japan where the Vetiver plant has been found to be effective [6]. Vetiver grass works very well to stabilize slopes against erosion.
viii) Construction of dam structures across Embosumer and Emboreberwo rivers; to harvest their excess water for domestic and agricultural needs. Reservoir water, from the dams, can then be released at a controlled rate during the wet season and periods of heavy downpour, thereby evading possible landslides.

c) Restrictions

Arising from the conclusion adduced, the following recommendations are suitable for the area studied.

(i) Trees planted on steep slopes should be deep rooted. Such trees may also act as wind breakers particularly when located on the windward side of hilly areas. Some cash crops, if mistaken as being deep rooted can easily succumb to landslide hazard as shown by Plate 23 [6].

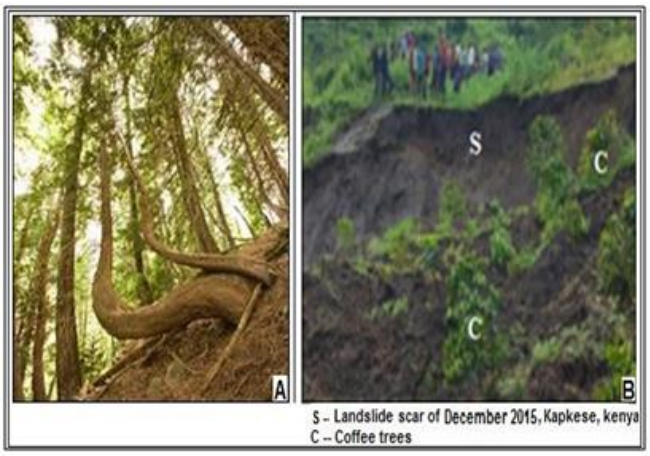

Plate 23: Deep rooted trees for (A) in comparison with Coffee bushes in (B) [6].

(ii) Agricultural practices should not be allowed on steep slopes.
(iii) There should be no settlement on the steep slopes in the area. Steep slopes could be constituted by unconsolidated scree slope material, such as illustrated by Plate 24. The loose material can easily lose shear strength on saturation, thereby resulting to land sliding [6].

Plate 24: A homestead (H) built on land slide debris, Kapkese, Kipkelion District in Kenya [6].

v) Reforestation of the entire Lagam escarpment is necessary in order to restore slope stability.
vi) The residents living on the steep slopes of the escarpment should be relocated to safer ground.
(iv) Soil conservation structures should be constructed in the area.
(v) Sensitization of the local community, on environmental matters, should be done through seminars and workshops.

d) Disaster Preparedness

When a disaster strikes, it creates an emergency. However, effective management of an emergency requires adequate prior preparedness. In that case, disaster preparedness helps everyone to understand what action to take [6]. Often in some instances, it takes several days before vital services reach victims concerned. During such period survival is difficult and unpredictable. In an emergency situation there is excessive anxiety. Thus, disaster preparedness, if in place, reduces these feelings and helps communities and families know where to take refuge and how to utilize and care for basic supplies [8, 9]. Disaster preparedness supplies that should be at hand preferably in an emergency warehouse include;

- Blankets, medical supplies, water and preserved food stuffs, as primary supplies which should be reviewed periodically.
- Some essential tools, clothing, sanitary material as subsidiary supplies.

In the study area, the community should be adequately tooled to be risk conscious and disaster prepared. One way is instituting a team of environmental scouts and educators who will check for the various signs of landslides and warn the people. Landslide indicative signs include: Tilted trees and power lines that are usually vertical, bulging earth especially on road edges and slopes, mounds of soil against house walls and fences, cracks on the earth's surface, cracks on house

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walls and concrete floors (as house foundations shift), sunken sections of road surfaces, cracks on roads and sidewalks, broken water lines, spaces in door jambs and frames, reduced levels of water in ponds and water pools on raised areas (despite continuous rainfall) and displaced rocks [11].

e) Real Time Information Transmission

Since environmental hazards are largely extempore, lives can be saved if information on looming hazards and disasters is communicated to the people on time. In the area of study, there is need to set up a weather station, where the erratic area rains can be monitored, alongside other weather elements and information shared with the people. This way, the people can vacate a risky area, together with their salvageable property. Information indeed is power (see an illustrative communication in Plate 25).

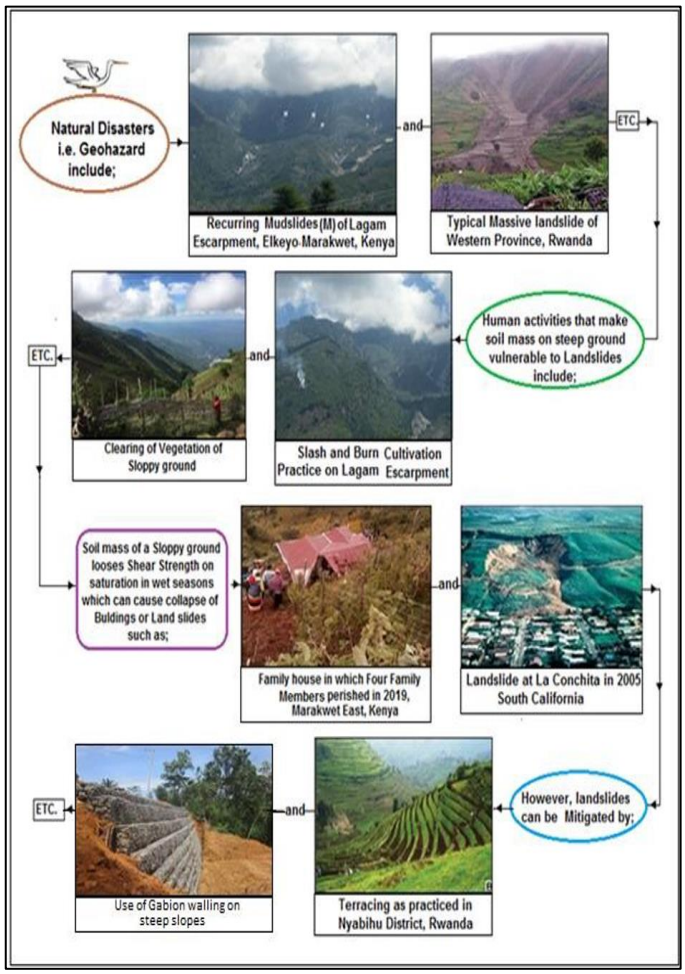

Plate 25: Typical Illustrative communication for Landslides, Preparedness and Mitigation Measures [7, 8, 9].

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