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Full Length Research Paper

Regional scaled mapping of gully erosion sensitivity in Western Kenya

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East African Rift regions suffer from serious gully erosion. As a preliminary step to assess gully erosion and to establish appropriate managements of geological/geomorphological conditions of the East African Rift escarpments, slope gradient, vegetation coverage, and sediment hardness in western Kenya, were used as mapping factors and overlayed to create separate channels in RGB color space. Pixels highlighted in this mapping can be considered as indicators of sediment erosion potential and runoff sensitivity of igneous rocks. The precision of the model for gully erosion sensitivity may be improved by including soil properties and topographic information.

Key words: Gully erosion, East African Rift, Kavirondo Rift, Lake Victoria basin, GIS, remote sensing, RGB color space.

INTRODUCTION

Geology and topography in the East African Rift regions are characterized by the large elevation differences and the occurrence of Precambrian basement rocks and Miocene volcanic rocks. There are basins with Quaternary deposits within the bottom of the rift grabens. Gully erosion occurred in these Quaternary sediments. Several studies related to gully erosion have recently carried out in East African Rift regions: massive gully erosions are egregious in the basins in Ethiopian Rift (Billi and Dramis, 2003; Daba, 2003; Nyssen et al., 2002), and in Eastern Rift (Adams and Watson, 2003; Everard et al., 2002; Jungerious et al., 2002; Rowntree, 1991) and the Lake Victoria basin (Hoshino et al., 2004; Shepherd et al., 2000) in the Kavirondo Rift, westward branch from the Eastern Rift.

Gully erosion process is controlled by a wide range of factors such as topography, soil properties, land use, and climate (Valentin et al., 2005). As for topographic factors, sufficient runoff is produced and concentrated to initiate gully erosion under a condition of a critical slope and a drainage area (Poesen et al., 2003). In relation to land use or land surface conditions, vegetation cover is an important erosion-controlling factor. Vegetation covers absorb some of the energy of raindrops and running water, and also contribute mechanical strength of the soil (Morgan, 1995).

Final target of the study is to assess the gully erosion along the escarpment slopes in the East African Rift regions. This study aims at operating the gully controlling factors in readily-processable methods to ascertain the gullying-sensitive points setting the study area in Kendu escarpment of Nyanza province, Kenya. Three factors such as slope gradient, vegetation coverage, and sediment hardness were obtained from the field survey, topographic map, and remote sensing data, and they were processed with a grid-based map in Red-Green-Blue (RGB) color space.

METHODS

Site description

The study area is located at the Lake Victoria Basin in the Western Plateau in Kenya (Figure 1). The Lake Victoria Basin was formed within Precambrian basement rocks under the tensional tectonics of the Kavirondo Rift since the Miocene age, and filled with thick piles of Quaternary fluviatile and lake deposits (Saggerson, 1952).

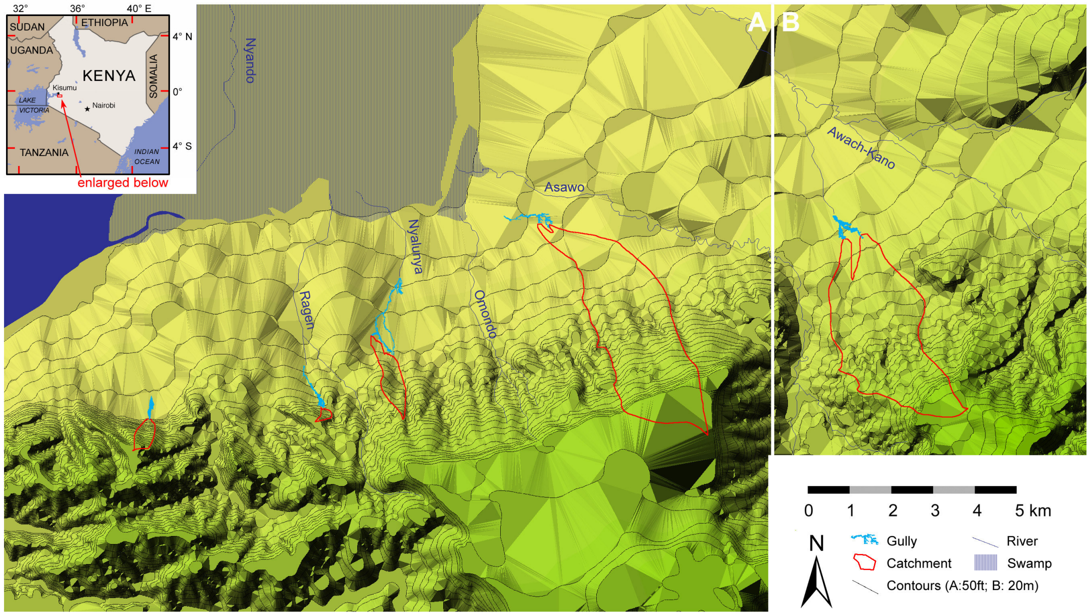

Figure 1. Map showing the location of the study area and the topographical features. Contours, streams, gullies and their upslope catchments were overlain on the DEM. The DEM was produced by converting from the TIN that was generated using the digital contour line data from the two sheets of East Africa 1:50,000 (Kenya) topographical maps (A: Nyakach Series Y731 Sheet 116/4 Edition 5-SK 1982; B: Belgut Series Y731 Sheet 117/3 Edition 5-DOS 1971). Upslope catchments of the gullies were calculated from this DEM and the other DEM that was obtained using another algorithm.

Precambrian basement rocks in the study area are sheared granites. Beds in the Quaternary deposits mainly consist of silt, sand, gravel, and tuffaceous silt beds were found among them and they are covered with black-cotton-soil on top. Their bedding planes show a declination of 4 degrees downstream (Hoshino et al., 2004).

Five localities of massive gullies, formed on the Quaternary deposits distributed in the pediment of Kendu escarpment (1,200 - 1,600 m a.s.l.), were focused on. Four gullied areas are located on upstream or banks of the Awach-Kano, Asawo, Nyalunya and Ragen rivers, that are seasonal/dry rivers in Nyando River system, and one gullied area is located on the slope of Sondu-Miriu dam (hydroelectric power station) construction site. Nyando River that flows into Nyakach Bay of the Lake Victoria forms meandering/braided channel and its wide flood plains are marshy with several swamps (Figure 1). The gullies can be classified to two types in relation to their morphology. Gullies in Sondu-Miriu, Ragen, and the upper part of Nyalunya study sites were characterized by their braided shallow channel beds, and gullies in the lower part of Nyalunya, Paponditi, and Awach-Kano study sites were characterized by deep and narrow single channels (Table 1). According to the retreat measurement carried out by Hoshino et al. (2006), the latter type undergoes severe headcut retreat. The gully heads of Sondu-Miriu are not active, and only the 3 of 14 gully heads in the upper Nyalunya are active (mean retreat is 3.2 m between 2004 and 2005). Twenty of 25 gully heads of the lower Nyalunya are active (mean retreat is 2.7 m between 2004 and 2005), and all of the 44 Awach-Kano gully heads are active (mean retreat is 4.8 m between 2003 and 2004, 1.6 m between 2004 and 2005). Maximum retreat recorded between 2003 and 2004 in Awach-Kano gully heads is 17 m.

It rains all year in this region, but January - February and July - August are drier periods. Total annual rainfall in this region is between 1,000 and 1,500 mm (Waters and Odero, 1986). Erosion occurs mainly in rainy seasons according to the observation in the late 2006. Population density of this region is high, and most of the area is settled and cultivated by local people. Average estimated population density in 2000 in the Nyando River basin, including the study area, is 174 (±127) per square kilometer (Shepherd et al., 2000). Main ethnic group of the inhabitants is Luo in the gully-affected area but those who live in the upper side of the contributing catchment of Awach-Kano gullies are Kipsigis. The study area is governed by the two different districts, Nyando district, Nyanza province, and Kericho district, Rift Valley province.

Contour lines of the topographical maps scaled 1:50,000 were traced and saved as vector polylines. The Triangulated Irregular Network (TIN) was produced from the digitized contours by using 3D Analyst extension of ArcGIS 9 (ESRI, USA), and it was converted to grid data format to obtain Digital Elevation Models (DEM). Upslope catchments for the selected five gullied sites were calculated using the DEMs combining the other DEMs generated from the contour line dilation method (Figure 1, Katsurada et al., 2007). Slope gradient distribution was calculated from the TIN.

The normalized difference vegetation index (NDVI) was calculated from the remotely sensed images of the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) that was scanned on 12 December, 2003, the rainy season. Eight control points were selected in the NDVI image from the field observations, and the image was geo-referenced to the topographical map in Universal Transverse Mercator (UTM) Projection.

There are differences between the sediments in Sondu-Miriu, Ragen, and the upper Nyalunya, and those in the lower Nyalunya,

Table 1. Characteristics of the gullied areas.

Location	Sondu-Miriu	Ragen	Nyalunya	Paponditi	Awach-Kano
Gully morphology	Channel beds are braided and shallow (less than 10 m in general). Banks are from nearly perpendicular to gently decline and plenty of earth pillars develop.		Gullies are comparatively deep (up to 14 m) and narrow single channels. The channel has perpendicular banks and distinct headcuts. Headcut retreat is active.		
Average sediment hardness in kg/cm^2 (S.D.)	247 (293)	1331 (2750)	665 (1531)	81 (76)	90 (155)
Sediment property	Sediments are reddish brown color, porous, poor in matrix and abundant ferric-oxide precipitates. Sandy beds contain abundant detrital grains of angular to sub-angular quartz, feldspars and granitic rock fragment, that would be derived from adjacent basement. Angular to sub-angular shape of the detrital grains also suggest that they are not too far from the source rocks.		Sediments are dark color, porous, rich in matrix and abundant clay minerals. Silty beds are massive and poor in detrital grain, and sandy beds are relatively well sorted with medium sized detrital grains of quartz, feldspars, mafic minerals, and basement granitic and volcanic rock fragments with sub-rounded to rounded in shape. These characteristics show that the sediments have been transported rather far distance from their source rocks.		
Catchment area (ha)	30.3	8.3	75.2	954.5	884.4
Main ethnic groups of inhabitants	Luo	Luo	Luo	Luo	Luo/Kipsigis
Cyan pixels	Covers most of the catchment.	Covers most of the catchment.	Highly appears aro-und the geological boundary, but less in the igneous rocks.	High values on the slopes.	High values on the slopes. More consecu-tively on adja-cent pixels.
Yellow pixels	Low value (located on the basement rocks)	Low value (located on the basement rocks)	Higher values on active gully heads (lower part).	High values right upslope the gully heads	High values right upslope the gully heads.

The catchment areas were calculated from the DEM. Soil hardness was measured using Yamanaka Soil Hardness Te-ster (Fujiwara Scientifics, Japan) in August, 2005. Sediments were sampled from each bed and optically investigated by preparing thin sections. Patterns of Cyan/Yellow pixels were described interpreting the result of RGB mapping (Figure 2) and the other information was based on the field observations and interviews.

Paponditi, and Awach-Kano. In this study, erodibility is approxi-mately considered to be replaced by hardness of the sediments. Hardness of each bed observed in the gully sidewalls was mea-sured (Table 1). Considering these results as that the sediments are softer in the north western part of the study area located near the lake, sediment hardness map was generated as a gradation of SSE-NNW direction, parallel to the fault line.

The three factors (slopes, vegetation coverage and sediment hardness) were converted to 8 bit 256 grayscale images in orders of low to high gradient, dense to scarce vegetation, and hard to soft sediment hardness, respectively. Linear contrast stretches were applied in order to prevent disproportionate brightness levels. This makes it easy to detect the differences visually, although quantita-tive comparison is not possible. They were blended in different channels of Red (R), Green (G), and Blue (B) color space; slope as Blue, vegetation as Green, and sediment hardness as Red chan-nels. Since the blending factors is additive mixture, combination of Red and Green makes Yellow (Y), Green and Blue makes Cyan (C), and Red and Blue makes Magenta (M). Highlighted points in Cyan-Magenta-Yellow (CMY) are counted converting the color space with a formula, (C, M, Y) = 255 - (R, G, B) and the optical features were summarized in Table 1 for each catchment.

RESULTS AND DISCUSSIONS

The visually detected CMY points are quite qualitative but suggestively highlight the gullying sensitivity. Cyan and Yellow are considered that they indicate the points with scarce vegetation and steep slope, and the soft sediment with scarce vegetation, respectively. Scarce vegetation on steep sloped igneous rocks can cause rapid runoff, and erodible soft sediments with scarce vegetation may cause severe gully erosion. These Cyan and Yellow points can be sensitivity factors to gullying detectable in this RGB color space mapping. As shown in Figure 2, large catchment areas of Paponditi and Awach-Kano mean that they are potentially erodible, and their large portions of both Yellow and Cyan pixels signify more gul-lying-sensitive situations. The distribution of Yellow points upslope the gully heads in Nyalunya site is different between the upper and lower gully heads. The active low-er gully heads show more erodible potentials although

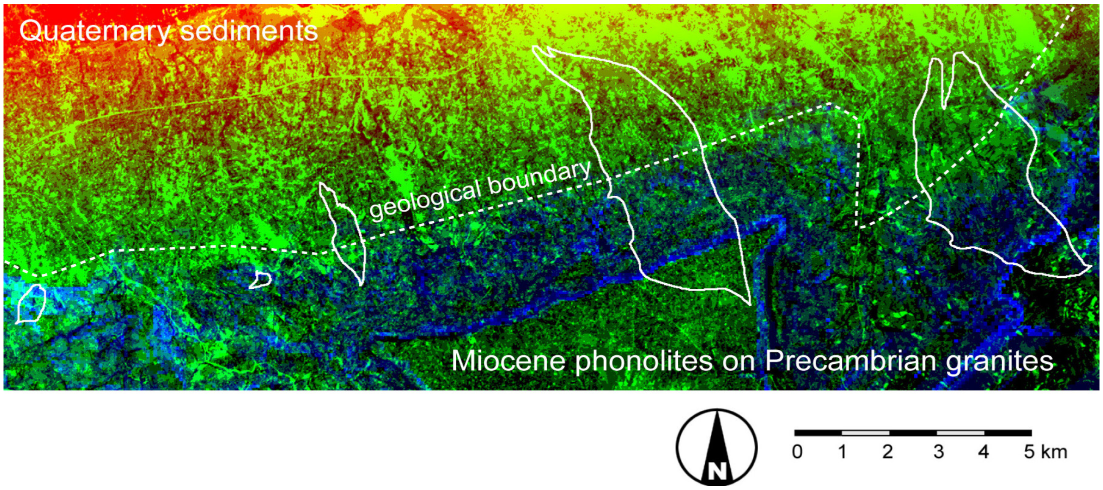

Figure 2. An example of regional scaled gully erosion sensitivity mapping in RGB color space. Three factors; sediment hardness, vegetation coverage, and slope gradient were assigned to the Red, Green, and Blue channels, respectively. The vegetation coverage was NDVI values of remotely sensed data on the rainy season, and the slope gradient was calculated from the DEM. Geological boundary and five studied upslope catchments were indicated with a broken line and solid lines, respectively. The visualized points as Yellow and Cyan bright pixels can be indicators of erosion/runoff sensitivity.

the Cyan pixels uniformly distribute. The catchments in Sondu-Miriu and Ragen sites are occupied by Cyan pixels with few Yellow pixels because they are located in the geological condition of igneous rocks. This indicates the current stable situations of the gully heads and the past processes of severely eroded gullies in these sites. Improving the precision of detection of gully erosion sensitivity with more detailed soil properties and topographical inputs can give the promising approach for the assessment of gully erosion in East African Rift regions.

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