Soil Erosion and Conservation in Western Kenya

Report of the Research Project, No. (A) 15253006 (2003-2005)
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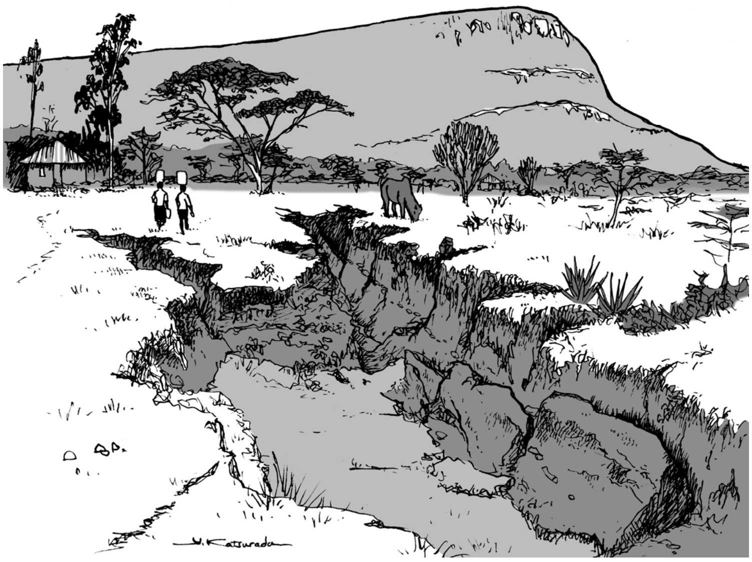
Front Cover:
Photograph of the Ragen gully, Western Kenya.
(August, 2005; Photo by M. Hoshino)
Back Cover:
Vegetation cover classification map of the Kavirondo Rift region, which was obtained from clustering of NDVI (ASTER VNIR). (Image processing by Y. Katsurada)



(Y. Katsurada)

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PREFACE

This publication is the final report of the field research on “Soil Erosion and Conservation in Western Kenya,” which was carried out in the Lake Victoria Basin in Western Kenya from 2003 to 2005, with financial assistance from the Grant-in-Aid for Overseas Scientific Survey, No. (A) 15253006, from the Japan Society for the Promotion of Science. Six researchers from Nagoya University conducted interdisciplinary field work in the gully-erosion belt of Western Kenya in collaboration with six Kenyan researchers.

The Nagoya University African Geological Research Project started in 1962. Since then, twenty-four geological and environmental investigations in thirteen African countries have been conducted, involving seventy-six Japanese researchers (Hoshino and Suwa, 2006). This project forms, therefore, a part of the long history of well-organized research in Africa conducted between 1962 and 2005 by Nagoya University.

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2. Finance

Fiscal Year	Direct Expenses	Overhead Expenses	Total
2003	6,600,000	1,980,000	8,580,000
2004	5,500,000	1,650,000	7,150,000
2005	4,200,000	1,260,000	5,460,000
Grand Total	16,300,000	4,890,000	21,190,000

(In Japanese Yen)

3. Publications

(1) Original Articles

Suwa, K., Hoshino, M. and Oosaki, M, 2003, Diversity of Desert Sand. *Journal of African Studies, Japan*, 63, 17-26. (in Japanese with English abstract)

Hoshino, M., Katsurada, Y., Yamamoto, K., Yoshida, H., Kadohira, M., Sugitani, K., Nyangaga, J. M., Opiyo-Akech, N., Mathu, E. M., Ngecu, W. M., Kinyamario, J. I. and Kang'ethe, E. K., 2004, Gully erosion in Western Kenya. *The Journal of the Geological Society of Japan*, 110(2), iii-iv.

Hoshino, M. and Suwa, K., 2006, Record of the Activities of the Nagoya University African Geological Research Project, 1962-2005. *JAHIGEO Newsletter*, 8, 7-14.

Katsurada, Y., Hoshino, M., Yamamoto, K., Yoshida, H. and Sugitani, K., Gully head retreat of Awach-Kano gullies, Nyanza province, Kenya: field measurement and pixel-based upslope catchment assessment. *African Study Monographs.* (submitted)

(2) Oral and Poster Presentations

Katsurada, Y. and Hoshino, M., 2003, Pattern of bank gullies on erosion-susceptible sediments: case study in Kenya. *Abstracts, the Japan Geoscience Union Meeting 2003*, Y057-044. (in Japanese with English abstract)

Hoshino, M., Katsurada, Y., Opiyo-Akech, N. and Nyangaga, J. M., 2003, Gully erosion in Kenya: A reconnaissance survey. *Abstract, Japan Association for African Studies, 40th Annual Meeting*, 42. (in Japanese)

Hoshino, M., Katsurada, Y., Yamamoto, K., Yoshida, H., Sugitani, K. and Kadohira, M., 2005, Gully erosion in Western Kenya Ⅰ: Relationship between geology and gully Pattern. *Abstract, Japan Association for African Studies, 42nd Annual Meeting*, 20. (in Japanese)

Katsurada, Y., Hoshino, M., Yamamoto, K., Yoshida, H., Sugitani, K. and Kadohira, M., 2005, Gully erosion in Western Kenya Ⅱ: RS Analysis. *Abstract, Japan Association for African Studies, 42nd Annual Meeting*, 21. (in Japanese)

Katsurada, Y., Hoshino, M., Yamamoto, K., Yoshida, H. and Sugitani, K., 2006, Upslope catchment assessment for gully headcut retreat: case study in Kendu escarpment, Kenya. *Abstracts, the Japan Geoscience Union Meeting 2006*, Z234-003. (in Japanese with English abstract)

Hoshino, M., Katsurada, Y., Yamamoto, K., Yoshida, H., Sugitani, K., 2006, Sedimentological of the gully erosion in Western Kenya. *Abstract, Japan Association for African Studies, 43rd Annual Meeting,* 118. (in Japanese)

Katsurada, Y., Hoshino, M., Yamamoto, K., Yoshida, H. and Sugitani, K., 2006, Environmental background of soil erosion in the Kavirondo Rift, Kenya. *Abstract, The Geological Society of Japan, 113th Annual Meeting*. (in Japanese)

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CONTENTS

I. INTRODUCTION

Since the pioneering work of Aubréville (1949) on man-induced land degradation, it has been widely accepted that inappropriate land use under vulnerable environmental conditions triggers serious soil erosion (e.g., Burkard and Kostaschuk, 1995; Morgan et al., 1997; UNEP, 1997; Rienks et al., 2000). An example of this situation is the Lake Victoria Basin (LVB) in Western Kenya. Increasing human populations have exploited the forests spread over the watersheds and catchments of the LVB (Ngecu and Mathu, 1999; Njogu, 2000; Swallow et al., 2005). As a consequence, excessive concentration of overland flow during heavy rains has incised large gullies on both topsoil and underlying unconsolidated sediments. The annual erosion rate is as high as 20 m head cut retreat and the depth of the gully channel reaches 14 m, as described in Chapter III. If the gully erosion proceeds at the current rate, houses and cultivated land located upstream and around the gully will be lost in the near future. Gully erosion threatens not only local inhabitants, but the many people concerned with fisheries in Lake Victoria, which are affected by water quality decline due to large sediment and nutrient load.

To cope with these serious environmental issues in the LVB, the International Centre for Research in Agroforestry (ICRAF) started a research project in 1999 (Shepherd et al., 2000; Swallow et al., 2002). In 2003, the Nagoya University team began a separate environmental research project intending to elucidate the basic process of the soil erosion in the LVB (Hoshino et al., 2004). Our study especially aims at understanding of the gullying situations and proposing ideas of assessment for catchment-scale conservation.

In the dry seasons of July-August 2003, 2004 and 2005, we carried out geological, geographical, ecological and agricultural field work in a quadrangle area of 30 × 10 km that covers the Kendu escarpment in the LVB from foot to slope (Fig. 2-1). M. Hoshino, K. Yamamoto, H. Yoshida, K. Sugitani, Y. Katsurada, N. Opiyo-Akech and E. M. Mathu mainly conducted the geological and geographical field work, and Y. Katsurada analyzed remotely sensed images. M. Kadohira and S. M. Amuhaya conducted the ecological and agricultural field work. Meteorological data were collected over the years by J. M. Nyangaga.

Field work was much facilitated by the Ministry of Education, Science and Technology, Kenya; the United Nations Environmental Programme (UNEP), Nairobi Headquarters; the International Centre for Research in Agroforestry (ICRAF); and the Japan International Cooperation Agency (JICA), Nairobi Office. To these supporters we express our sincere thanks. We are also grateful to the local people in the surveyed villages for sharing with us their experiences, and to government officers in Nyando District, provincial agricultural officers and provincial geologists in Kisumu for their cooperation.

Thanks are also extended to the Graduate School of Environmental Studies, Nagoya University, for its financial support in purchasing the aerial photography, to Prof. K. Suwa for his useful discussion and comments, and to Mr. T. Nagaoka for providing many thin sections of soil and sediment.

Field and laboratory studies were made possible by the Grant-in-Aid for Overseas Scientific Research, Grant No. (A) 15253006 (2003–2005), from Japan Society for the Promotion of Science, to which we express our deepest gratitude.

The articles printed in this volume are generally résumés, as publication of the full text is left to the respective author's choice.

Author: Mitsuo Hoshino

II. ENVIRONMENTAL SETTING

2.1. Landscape

The area of the massive gully erosion is located at the Lake Victoria Basin in the Western Plateau in Kenya (Fig. 2-1). The Lake Victoria Basin has been forming within Precambrian basement under the tensional tectonics of the Kavirondo Rift since the Miocene age. Thick piles of Quaternary fluviatile and lake deposits infill the basin area and they are covered with black-cotton-soil (Saggerson, 1952; Hoshino et al., 2004).

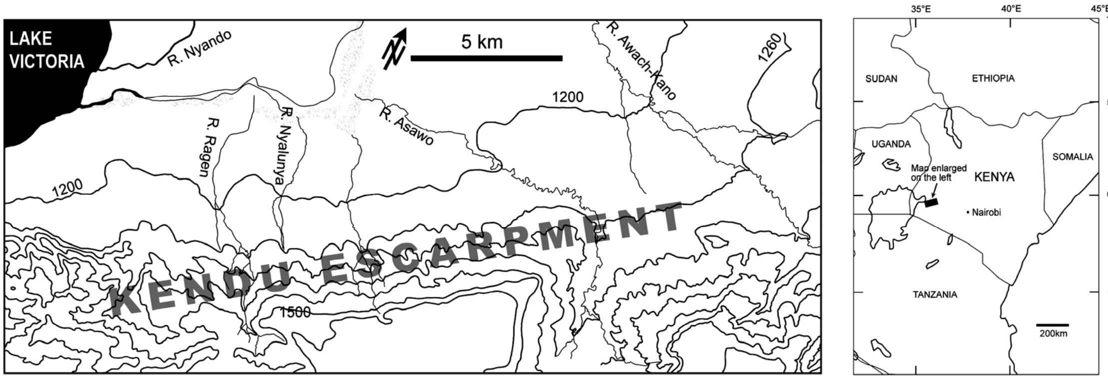

Fig. 2-1. Map showing the study area along Kendu escarpment in the Lake Victoria Basin, Kenya.

We focused on several erosion gullies developed on the pediment of Kendu escarpment (1,200–1,600 m a.s.l.) and selected five localities (Fig. 2-2). 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 (Fig. 2-3) and one gullied area is located on the slope of Sondu-Miriu dam (hydroelectric power station) construction site. Nyando River that flows into Winam Gulf of Lake Victoria, forms meandering/braided channel and its wide flood plains are marshy with several swamps.

Topographic information of the upslope catchments for 5 localities was collected from the 1:50,000 scaled topographic maps. The topographic maps were scanned and digitized. Digital Elevation Model (DEM) with enough resolution is not available for this region and it is impossible to generate high resolution DEM from these topographic maps, then we generated original DEM to estimate the upslope catchment areas for the gullies. The method to build the DEM is described in Chapter VI. The topographic information of the upslope catchments of the gullies is shown in Table 2-1.

Distributions of gullies in each catchment and gullying patterns were defined and depicted mainly by the analyses of remotely sensed images and aerial photographs as described in Chapter VI. Field investigations such as topography measurement, stratigraphic exploration and sediment sampling have been carried out as described in Chapter III, and the samples were analysed in the laboratory as shown in Chapter III as well.

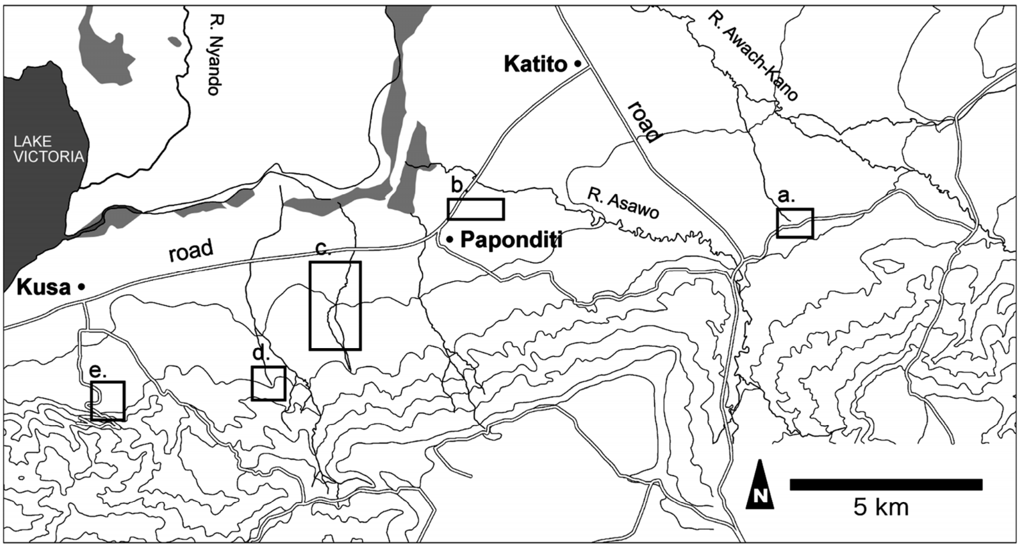

Fig. 2-2. Map showing the locations of the study sites. (a): Awach-Kano, (b): Paponditi, (c): Nyalunya, (d): Ragen, (e): Sondu-Miriu. Detailed gullying patterns are given in Chapters III and VI.

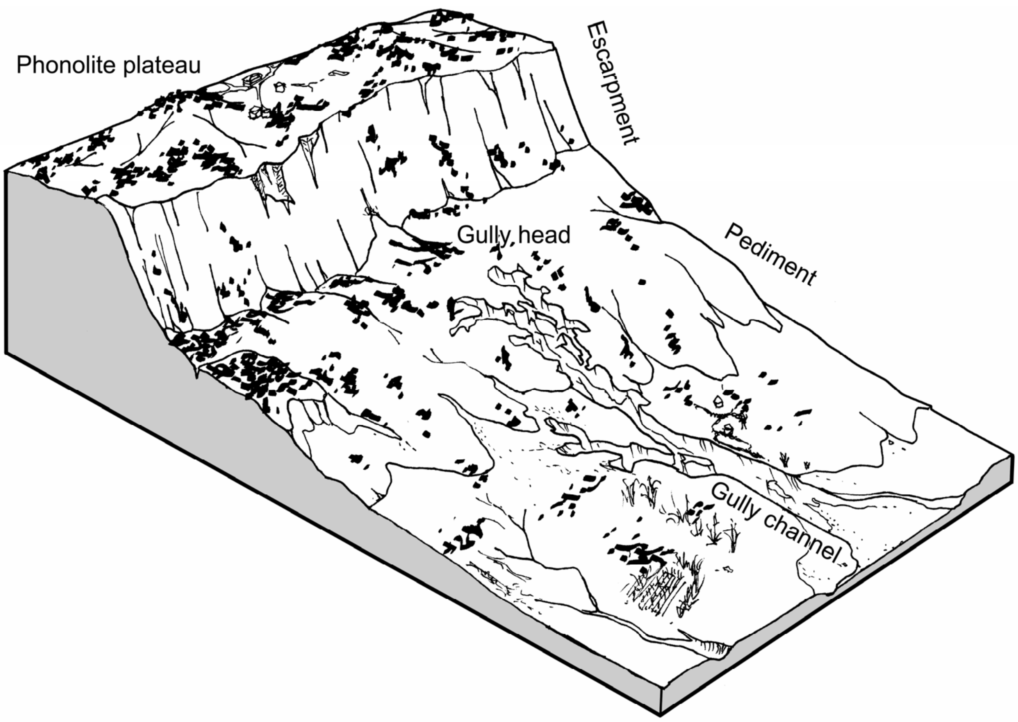

Fig. 2-3. Schematic diagram of the Kendu escarpment gully erosion.

Table 2-1. Upslope catchment dataset.

Study site	Upslope catchment area (ha)	Erosion type*
Awach-Kano	884.4	A
Paponditi	954.5	A
Nyalunya	75.2	A+S
Ragen	8.3	S
Sondu-Miriu	30.3	S

* A: Awach type, S: Sondu type

Gullies were classified into two types from their patterns; Awach type (Plates II-1, II-2, II-3, II-4 and II-5) and Sondu type (Plate II-11, II-12 and II-13). Awach type gully is characterized by comparatively deep single channel (Plate II-4), perpendicular banks (Plate II-5) and distinct headcuts probably formed by streamflow and mass wasting (Plate II-3). Sondu type gully has the characteristics of braided channel bed and plenty of earth pillars (Plates II-12 and II-13). Gullies in Awach-Kano and Paponditi (Plate II-6) study sites belong to Awach type, and gullies in Sondu-Miriu and Ragen (Plate II-10) belong to Sondu type. As for the gullies in Nyalunya study site, both types were observed; gullying pattern upstream was Sondu type (Plate II-7) and downstream was Awach type (Plate II-9). Geographical details in the study area are given in Chapter V.

2.2. Vegetation

The study area used to be vast grassland with scattered trees in the past. In the pre-colonial period, the area was important habitat for wild animals and was also used for grazing purposes for both Luo and Kalenjin (Kipsigis) communities. Then, most of the indigenous tree species have been cleared for various purposes such as fuel wood and charcoal burning. This is because of the increasing demand for fuel wood and land for cultivation as a result of the increasing population. There are however several trees and shrubs (Table 2-2). The dominant tree is *Euphorbia tirucalii* that was planted in 1970s as a boundary marker during land demarcation by the government. Other wild tree species include various types of acacia. Koguta forest found near Sondu-Miriu hydroelectric power station is the only surviving forest in the area. It covers an area of 320.5 ha.

Table 2-2. Wild and planted tree species in the area and their uses.
(Compilation: S. Amuhaya)

Tree/shrub species	Local name	Main uses
Euphorbia tirucalii	Qjuok	Fuel wood, Boundary marker, Medicinal, Timber
Euphorbia candelabrum	Bondo	Fixing spear heads
Psidium quajava	Mapera	Food, Fuel wood, Charcoal, Shade
Acacia lahai	Alaktar	Fuel wood, Charcoal
Acacia tortilis	—	Fuel wood, Charcoal
Acacia seyal Del.	Ale	—
Acacia polyacantha	Ogongo	Fuel wood
Aloe species	Ogaka	Soil conservation, Medicinal
Scutia myrtina	Osiri	Fuel wood, Fodder
Lantana camara	Nyabenda	Fuel wood, Boundary marker, Soil fertility improvement, Fodder
Acacia species	Koduo	Food, Fuel wood
Rhus natalensis	Sangla	Food, Fuel wood, Charcoal
Balanites aegyptiaca	Otho	Fuel wood, Fodder, Charcoal
Grewia trichocarpa	Powo	Fuel wood, Fodder, Charcoal, Timber
Tamarindus indica	Chwa	Fuel wood, Fodder, Charcoal, Shade
Ficus capensis	Ng'ou	Fuel wood, Shade, Medicinal
Ipomea kituiensis	Obinchu	Soil conservation

2.3. Climate

The region experiences tropical climate that consists of continuous rainfall throughout the year, with little distinction between long and short rains. The climatic characteristics experienced are due to the effect of the westerly winds from Lake Victoria, which converges with the south-east trade winds causing the air to rise, and thus producing heavy showers in the afternoons.

Annual rainfall quantity ranges between 900 mm and 2,000 mm in the region. The mean annual rainfall is 1,245 mm, and monthly evaporation ranges between 53 mm and 120 mm. January and February are the driest months while April and May are the wettest months.

2.4. General Geology

The study site is situated at the base of the Kendu escarpment. This is in the southern flank of the Kavirondo Rift (Figs. 2-1 and 2-4a). The gullies are on the down faulted side of the main Kendu fault system. The studies indicate that the building of the dam has greatly increased the gully erosion by channelling water to particular areas, rather than spreading it out in a wider area as was the case previously.

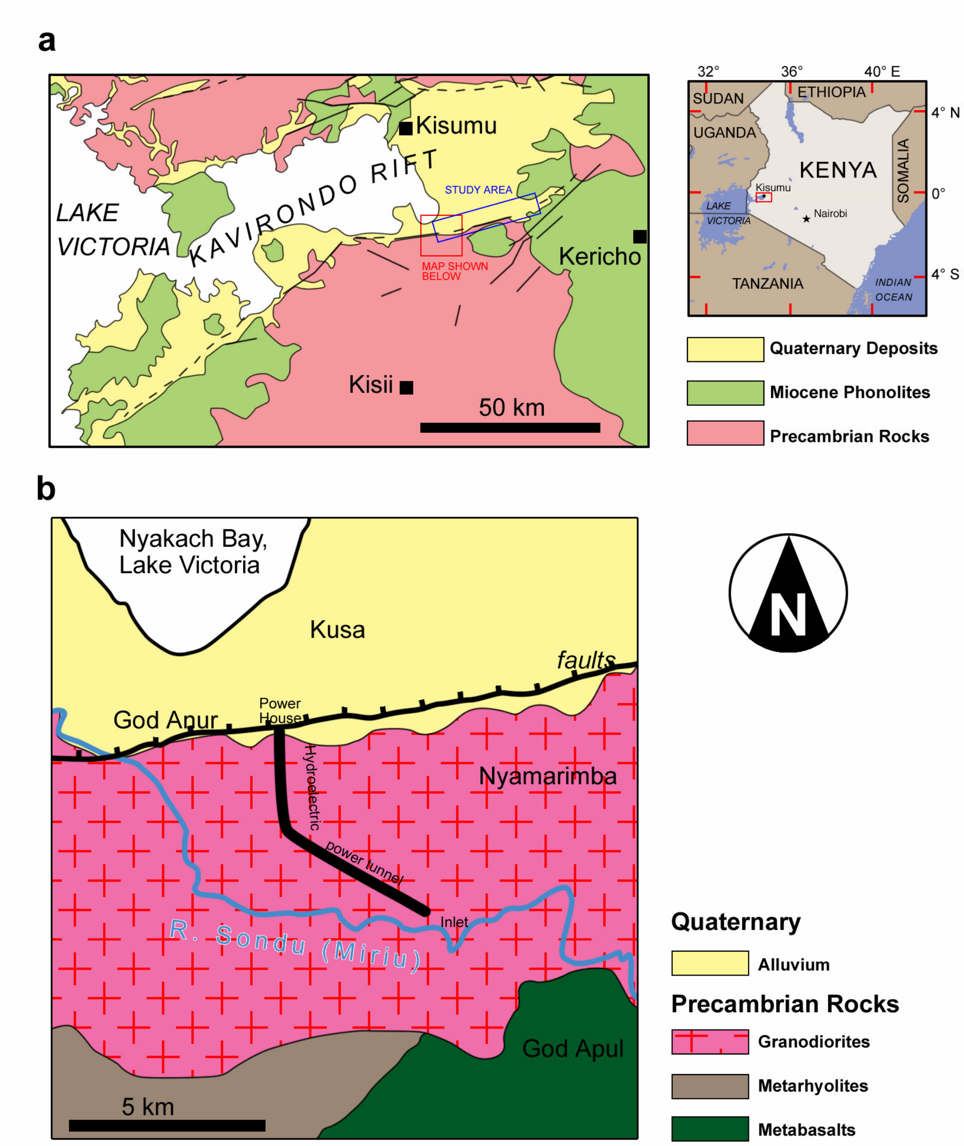

Fig. 2-4. Geological map of the Kavirondo Rift region (a) and Sondu-Miriu hydroelectric power station construction site (b). Data sources: a) Ministry of Energy and Regional Development of Kenya (1987), b) Ingana (2002).

Gullies are incised on the Quaternary sediments. Beds of the Quaternary sediments mainly consist of silt, sand and gravel with minor intercalations of tuff and tuffaceous silt. There observed calcrete concretion in some beds which show alternations of sand and silt. Although their bedding planes are almost horizontal, slight inclination of the plane up to 4 degrees towards downstream is observed in places.

The Kavirondo Rift (Shackleton, 1951) branches from the Gregory Rift at the centre of the Kenya domal uplift (Baker and Wohlenborg, 1971) with EW and ENE–WSW trend lines towards the Kavirondo Gulf of Lake Victoria (Yairi, 1975). The Nandi and Kendu faults bound the northern and southern edges of the Kavirondo Rift, respectively and many other faults tend to run parallel to form east-west fault zone (Saggerson, 1952). Elevation at the bottom of the Kavirondo Rift is approximately 1,200 m a.s.l. and the highest elevation of Nandi and Kendu escarpments are ca. 1,800 m and ca. 1,700 m a.s.l., respectively.

The oldest rocks in the area are the Nyanzian metavolcanics, here predominantly represented by metabasalts and metaryolites (Hoshino et al., 1983; Opiyo-Akech et al., 1999). These supracrustal rocks have been intruded by granodiorites and granites, although within the proximity of the study area granodiorites predominate (Fig. 2-4b). These rocks including the earlier granodiorites have been intruded by minor dolerite veins which in most cases have also undergone similar deformation to the older rocks. It is also postulated that there might have been more than one episode of deformation and granite intrusion as is seen by the presence of deformed dolerites and pegmatites that cut across older pegmatites and other intrusives.

In this area surrounding the Sondu-Miriu hydroelectric power station, the rocks comprise of Nyanzian metavolcanics that have been metamorphosed and reworked by several tectonic events (Saggerson, 1952). The Nyanzian rocks and the intrusive granodiorites have been subjected to faulting, shearing, jointing, fracturing and deep weathering along the lines of tectonic movement (Ingana, 2002). The main rock body to the south of the area greatly affected by gullies are granodiorite-tonalite that have been deformed extensively. It consists of feldspars, quartz, hornblende and biotite. The other important rocks are the metabasalts that have been reworked to a relatively high grade of metamorphism to form amphibolite schists along the shear zones. Also found are minor intrusions of dolerites, pegmatites and quartz veins distributed un-evenly within these rocks.

The area is faulted with the initial compressional stage affecting the granodiorites with the resultant transverse north-south faults and shear zones. The major fault runs from main town in the area of Kendu Bay to the west and runs through God Anur eastwards.

The structural geology of the gully erosion area is constituted of soft rock sedimentary structural features of the Quaternary to Recent age and those of the hard rock geology of the Archaean greenstone metavolcanics and associated granitoid plutonic bodies (Plate II-8).

The soft rock sedimentary structural features are dominated by the fascinating horizontal sedimentary bedding planes and graded bedding as shown in Plate II-14. These are demonstrated by an approximately 15 m thick succession of alternated lithological units of sand and gravel at the bottom of the succession which pass upwards into silt and sand, tuff, sand and a repeated similar sequence which is finally capped by black-cotton-soil at the top (Plate II-14).

Although the escarpment is of Cainozoic age, it occurs along an almost east-west Precambrian shear zone which has strongly mylonitized the Achaean granitoid rocks and associated greenstone rocks. Both the granitoids and the greenstones form the basement to the gully eroded sediments. The mylonite foliation strike varies between N60°W and N80°W with dip of about 45° to 60° to the north-east. The granitoid mylonites are also highly jointed with three major orientations of the joint sets. These joint orientations are N30°–50°E, 0°N–N10°E and N20°–40°W. A more comprehensive regional geology of the broader Kisumu district, that is currently Kisumu, Nyando and Rachuonyo districts, Nyanza province, has been documented by Saggerson (1952).

2.5. History of Lake Victoria

The earlier lake named as Lake Karunga (Wayland, 1931) was formed during the Early Miocene by volcanic blockage, and included the area of the present Kavirondo Gulf (Winam Gulf) and extended over the Kano Plains to the east and some distance beyond Rusinga Island to the west (Kent, 1944). Kent suggested that this lake was finally drained westward by faulting and erosion during the mid-Pleistocene. The present Lake Victoria is estimated to be newly formed after the decline of Lake Karunga (Beadle, 1981). Estimated location of Lake Karunga (Miocene) is shown in Fig. 2-5.

There are some lines of evidence that show Lake Karunga existed at least between 22 Ma and 16.5 Ma BP. However, no stratigraphical evidence for the period between the decline of Lake Karunga and the birth of Lake Victoria is found (Bishop et al., 1969; Couvering and Miller, 1969). Whatever the extent and connections of the former Lake Karunga, the configuration of the land and water systems in this region during the Miocene, before the major uplift and faulting was totally different from now (Schlüter, 1997). The best interpretation of all the data would seem to be that the main drainage by a series of rivers was flowing westwards from highland across the regions of the future Lake Victoria Basin and Kavirondo Rift graben during the period since Miocene to the early Pleistocene (Beadle, 1981).

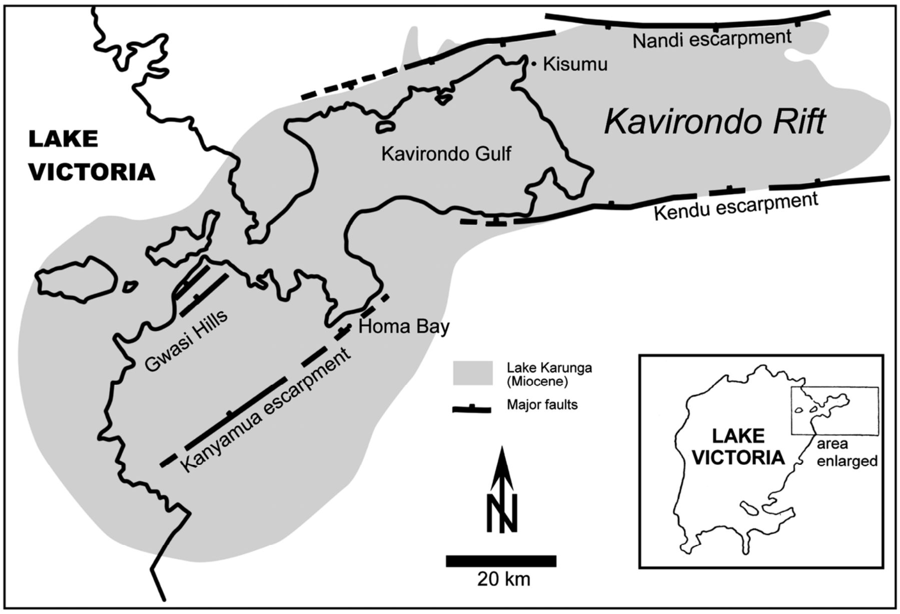

Fig. 2-5. Estimated location of Lake Karunga, the earlier lake formed in Early Miocene. Map is modified from Kent (1944).

The birth of Lake Victoria is estimated about 0.4 Ma BP, and is substantially younger than the other major lakes in East Africa (Johnson et al., 1996). For example, Lake Tanganyika Basin was formed 9–12 Ma BP and the basin was deepened to fuse into a single deep lake about 5–6 Ma BP (Tiercelin and Mondeguer, 1991; Cohen et al., 1993). Transgression and sedimentary evolution in Quaternary period have been discussed for East African lakes by various studies. Lakes Malawi and Tanganyika were severely affected by the climatic change in the late Pliocene/early Pleistocene. Lake Malawi had been almost completely dry during the period between 1.6 Ma and 1.0–0.57 Ma BP (Delvaux, 1995), and the water level of Lake Tanganyika dropped by 650–700 m about 1.1 Ma BP(Lezzar et al., 1996). Lakes Malawi and Tanganyika rose to their present levels 0.17–0.04 Ma and 0.25–0.12 Ma BP, respectively. The water levels of Great East African Lakes (Lakes Tanganyika, Malawi and Victoria) were considered to have been substantially lower during the late Pleistocene ice ages, when the climate in much of north and equatorial Africa became progressively more arid (Sturmbauer et al., 2001). Johnson et al. (1996) carried out analyses of seismic reflection profile and piston cores from Lake Victoria and suggested that Lake Victoria had been almost dry

17,300–12,400 years BP. Sturmbauer et al. (2001) estimated that the water levels of these East African lakes seemed to have been influenced in a similar way by the same global climatic changes, i.e. they were generally low 18,000–12,000 years BP and quickly rose to the present levels in Holocene.

2.6. Past Events of Soil Erosion

The area is said to have been covered by grass before settlement started in the early 1800s, and it was used for cattle grazing. Most of the early settlers were Kalenjins (Kipsigis) and Luos. In the 1920s Kalenjin were pushed upwards to the present day border near the Belgut hills in Kericho. Crop farming using traditional tools started in the 1930s. Migration continued through the 1960s and the gully had started though with a very small head. In 1961 the area experienced serious flooding which enhanced the gulling. Because of water related conflicts and need for soil and water conservation, dams and water pans were established by the colonial government to store flood water for use during the dry season. They included Amboka, Koyombe, Kokuto and Cherwe dams.

All these dams were meant to reduce flooding and gully erosion apart from storing water for domestic and livestock. But due to poor farming methods upstream, all the dams got silted up and so they could not hold any flood water. With the increased surface runoff due to the impervious nature of most parts of the Belgut hills, together with steep gradient, much of the flood water got its way into the gully and increased its development.

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III. RESULTS OF FIELD RESEARCH OF GULLIES

3.1. Morphology of Gullies

During the dry seasons in 2003, 2004, and 2005, we performed field research of gullies in the Nyando district, Nyanza Province. Five locations (Awach-Kano, Paponditi, Ragen, Nyalunya and Sondu-Miriu) were selected (Fig. 3-1) from the analyses of remotely sensed images, aerial photographs and topographic maps.

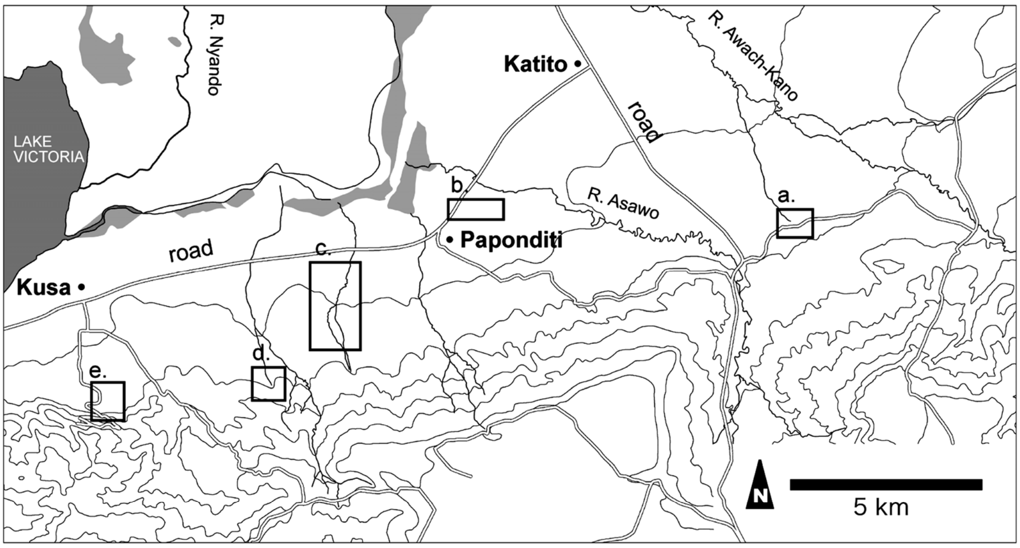


Fig. 3-1. Locations of the study sites in the Kendu escarpment and Kano plain. (a): Awach-Kano, (b): Paponditi, (c): Nyalunya, (d): Ragen, (e): Sondu-Miriu.

Tape measure, compass, laser range meter (Bushnell Yardage Pro 20-1000) and GPS receiver (Garmin e-trex) were used to collect spatial information on gully pattern. Distance and direction between the selected neighbouring points along the gully edges were measured to depict the spatial gully patterns. Positions of these measuring points were calibrated by measuring from the third point, and absolute position was obtained by GPS receiver. The whole shape of the gullies in Awach-Kano site was depicted in July and August 2003 (Hoshino et al., 2004). Results of field-based examinations of morphology of gully and gully erosion during 2003–2005 are presented below.

In Figs. 3-2 and 3-3, illustrations of gullying pattern depicted from aerial photographs and/or field survey are shown. Gullies were classified into two types from their morphological characteristics and patterns. One type is characterized by comparatively deep and narrow single channel. The channel has perpendicular banks (Plate II-5) and distinct headcuts (Plates II-1, II-2 and II-3), that was probably formed by streamflow and mass wasting. Gullies in Awach-Kano and Paponditi study sites represent this type, which is therefore called hereafter “Awach type”. In particular in the Awach-Kano site (Fig. 3-2a), significant portion of the gully exhibits its depth up to 14 m and width less than 15 m. Due to its steep geomorphic condition, slumping of bank wall occurs in places (Plate II-5).

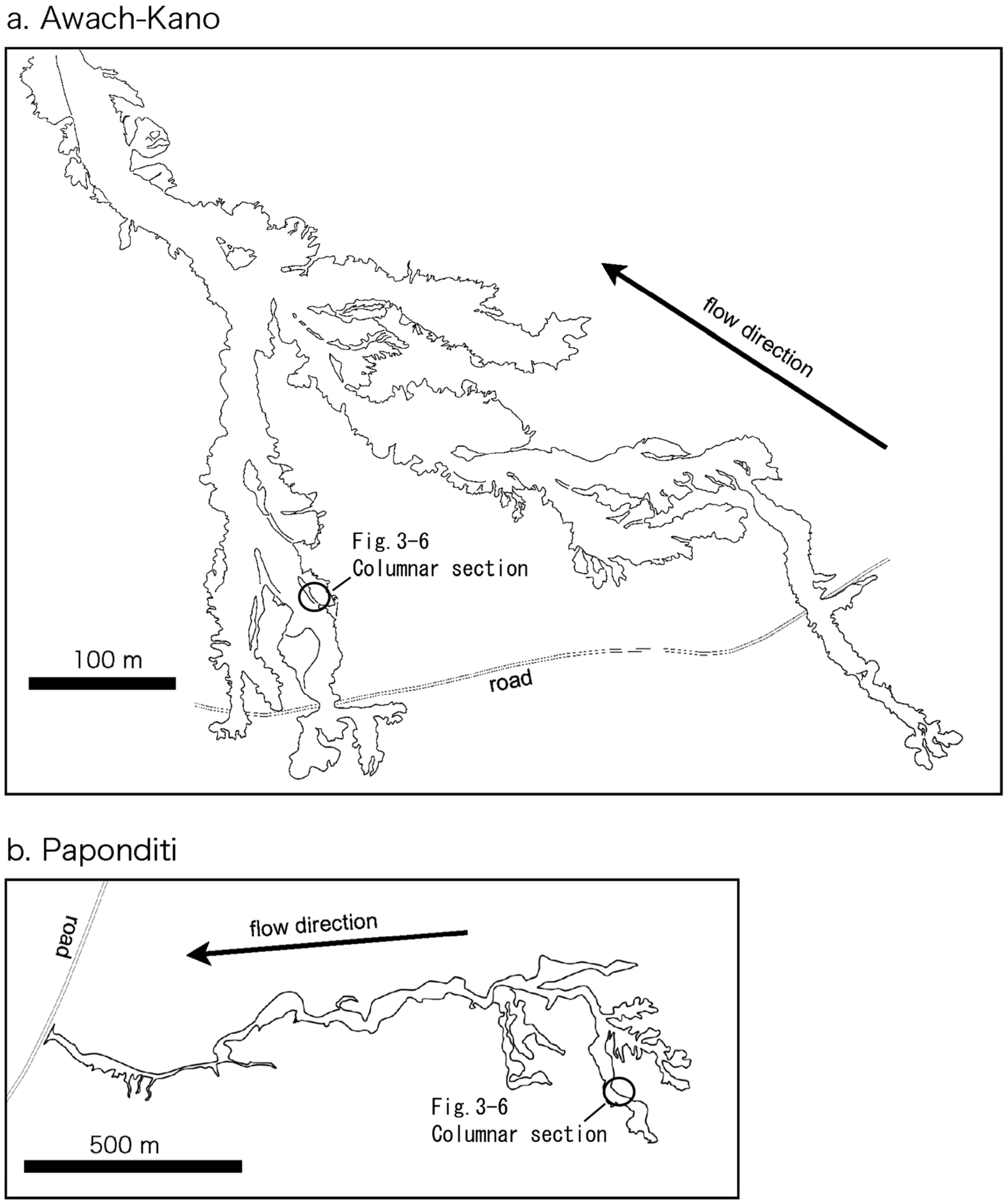


Fig. 3-2. Gullying patterns depicted from aerial photographs and/or field survey. (a): Awach-Kano study site, (b): Paponditi study site. Open circles indicate the localities of columnar section in Fig. 3-6.

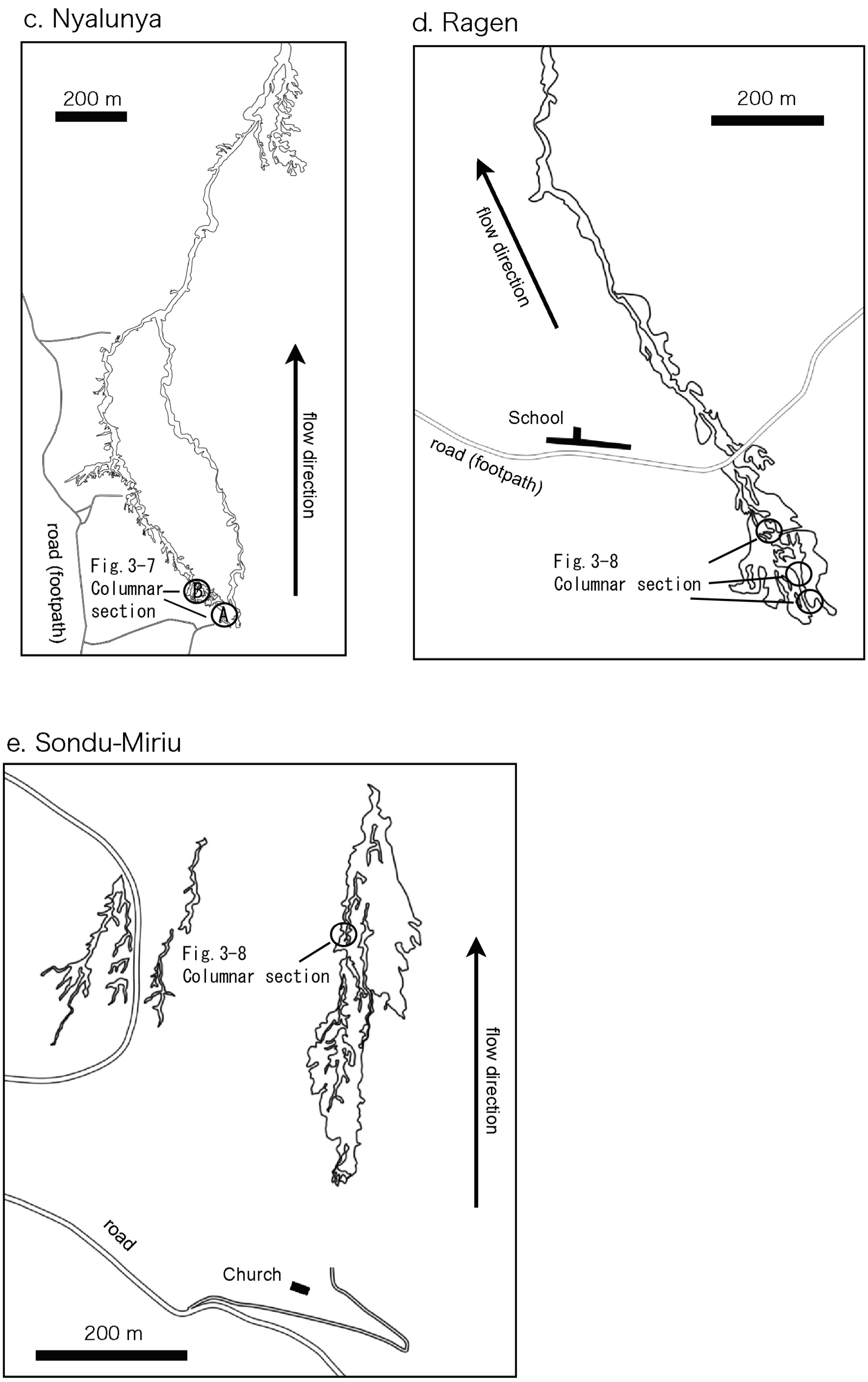


Fig. 3-3. Gullying patterns depicted from aerial photographs and/or field survey.
(c): Ragen study site, (d): Nyalunya study site, (e): Sondu-Miriu study site.
Open circles indicate the localities of columnar section in Figs. 3-7 and 3-8.

Another type is characterized by their braided shallow channel beds (Plate II-12). This type is shallower compared with Awach type; it is in general less than 10 m in depth from the local land surface. Banks are from nearly perpendicular to gently decline. Plenty of earth pillars develop (Plate II-13). Gullies in Ragen and Sondu-Miriu represent this type, which is thus called hereafter “Sondu type”.

In Nyalunya site, the two types of gullying pattern can be seen; the Sondu type in the upstream, whereas Awach type in the downstream. In the upstream (near Fig. 3-5e), the basement granitoid rocks is exposed (Plate II-8). The basement is unconformably overlain with sediments. The development of these two gully types could be interpreted in the context of physical properties of soils and locations of gullies, which will be discussed in the following section.

3.2. Rate of Gully Erosion

Erosion rates at individual sub-gully heads were examined at selected two sites, Awach-Kano and Naylunya. Annual changes in the distance between the measured absolute positions of the sub-gully heads and the given datum points were obtained. The original data are presented in Tables 3-1 and 3-3.

Awach-Kano site

Photographs of some examples of gully heads are shown in Plate II-3 and illustrated progress in headcut retreat from 2003 to 2005 are shown in Fig. 3-4. Measurements of four gullies at Awach-Kano study site show that annual length of individual gully headcut retreat varies from 0 to 17.0 m (Table 3-1). This variation may be related to the various patterns of headcut retreat of individual gullies. As shown in Fig. 3-4, headcut retreat of the gully C is largely attributed to bank wall slumping, whereas that of the gully A appears to be retreated thoroughly.

In general, the length of retreat during 2004 to 2005 is less than that during 2003 to 2004. This trend is enhanced by the gully headcuts that experienced large erosion during 2003 to 2004. Estimated projected areas of the gully head retreat for each gully (Table 3-2) are generally consistent with the trends of retreat length.

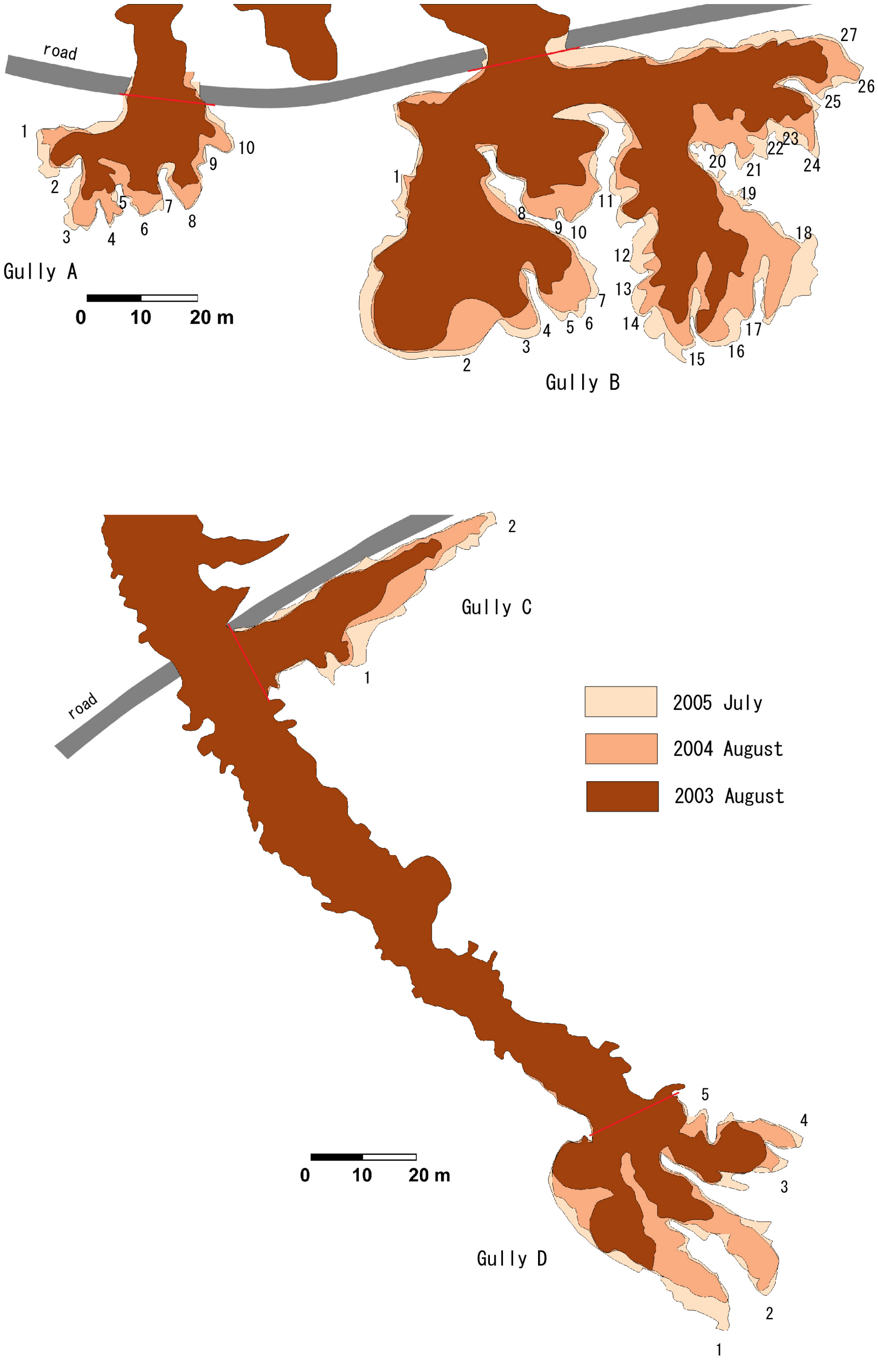


Fig.3-4. Illustrated progress of headcut retreat at the Awach-Kano site from 2003 to 2005. See also Fig.3-2a for the location. Numbers in the figure correspond to each measured sub-gully head (see Table 3-1).

Table 3-1. Length of gully headcut retreat for each sub-gully head (m), Awach-Kano site.

Gully	Sub-gully head	2003-2004	2004-2005
I	A01	3.7	1.2
	A02	1.7	2.4
	A03	4.7	1.4
	A04	5.5	0.9
	A05	2.0	0
	A06	4.4	0.5
	A07	1.0	0.4
	A08	3.8	0
	A09	2.2	0.5
	A10	4.0	0.6
	aver.	3.3	0.8
I	B01	1.9	0.5
	B02	4.8	1.2
	B03	4.0	1.9
	B04	3.9	2.1
	B05	3.9	1.8
	B06	6.3	1.4
	B07	6.3	1.4
	B08	2.8	0
	B09	4.9	0
	B10	7.3	0
	B11	3.0	1.3
	B12	2.2	3.4
	B13	2.5	0.7
	B14	3.8	0.5
I	B15	4.4	3.2
	B16	5.3	2.2
	B17	8.0	0.4
	B18	9.5	3.4
	B19	2.8	2.4
	B20	5.1	1.7
	B21	6.5	2.2
	B22	2.1	3.7
	B23	1.7	2.9
	B24	8.0	1.8
	B25	2.4	1.8
	B26	6.0	1.7
	B27	2.9	0.5
	aver.	4.5	1.6
II	C01	10.3	1.5
	C02	1.0	3.7
	aver.	5.6	2.6
II	D01	15.7	5.7
	D02	17.0	1.5
	D03	3.2	3.7
	D04	7.5	2.1
	D05	3.3	1.1
	aver.	9.3	2.8

Table 3-2. Projected areas of the gully headcut retreat for each gully (m^2), Awach-Kano site.

Gully	Gully head	2003-2004	2004-2005
I	A	122.28	70.44
	B	687.64	500.65
	Total	809.92	571.10
II	C	111.88	120.99
	D	344.93	158.03
	total	456.81	279.02

Nyalunya site

Photographs of some examples of gully heads are shown in Plates II-7 and II-9 and illustrated progress in headcut retreat from 2004 to 2005 is shown in Fig. 3-5. At the Nyalunya site, headcut retreat measurements were performed for five individual gully heads, from 2004 to 2005. Three of the 23 sub-gully heads are Sondu type, and the others are Awach type. There can be seen no significant difference between the length of headcut retreat between these two gully types (Table 3-3). The length ranges from 1.6 to 4.6 m, which is not significantly distinct from retreat length for the Awach-Kano site from 2004 to 2005. In the case of Awach type gullies, the variation of retreat between gullies in the Nyalunya site (1.6–4.3 m) is smaller in comparison with the Awach-Kano site (0–5.7 m).

Table 3-3. Measured gully headcut retreat (2004－2005) in Nyalunya study site.
*A: Awach type, S: Sondu type

Sub gully head	Gully type*	Retreat length (m)
E1	S	2.7
E2	S	2.4
E3	S	4.6
F1	A	1.8
F2	A	3.1
F3	A	2.8
G1	A	1.6
H1	A	2.3
H2	A	2.9
H3	A	2.5
H4	A	2.8
H5	A	1.7
H6	A	2.5
H7	A	3.0
H8	A	2.1
I1	A	3.6
I2	A	4.3
I3	A	3.5
I4	A	1.9
I5	A	2.1
I6	A	2.6
I7	A	2.9
I8	A	2.5

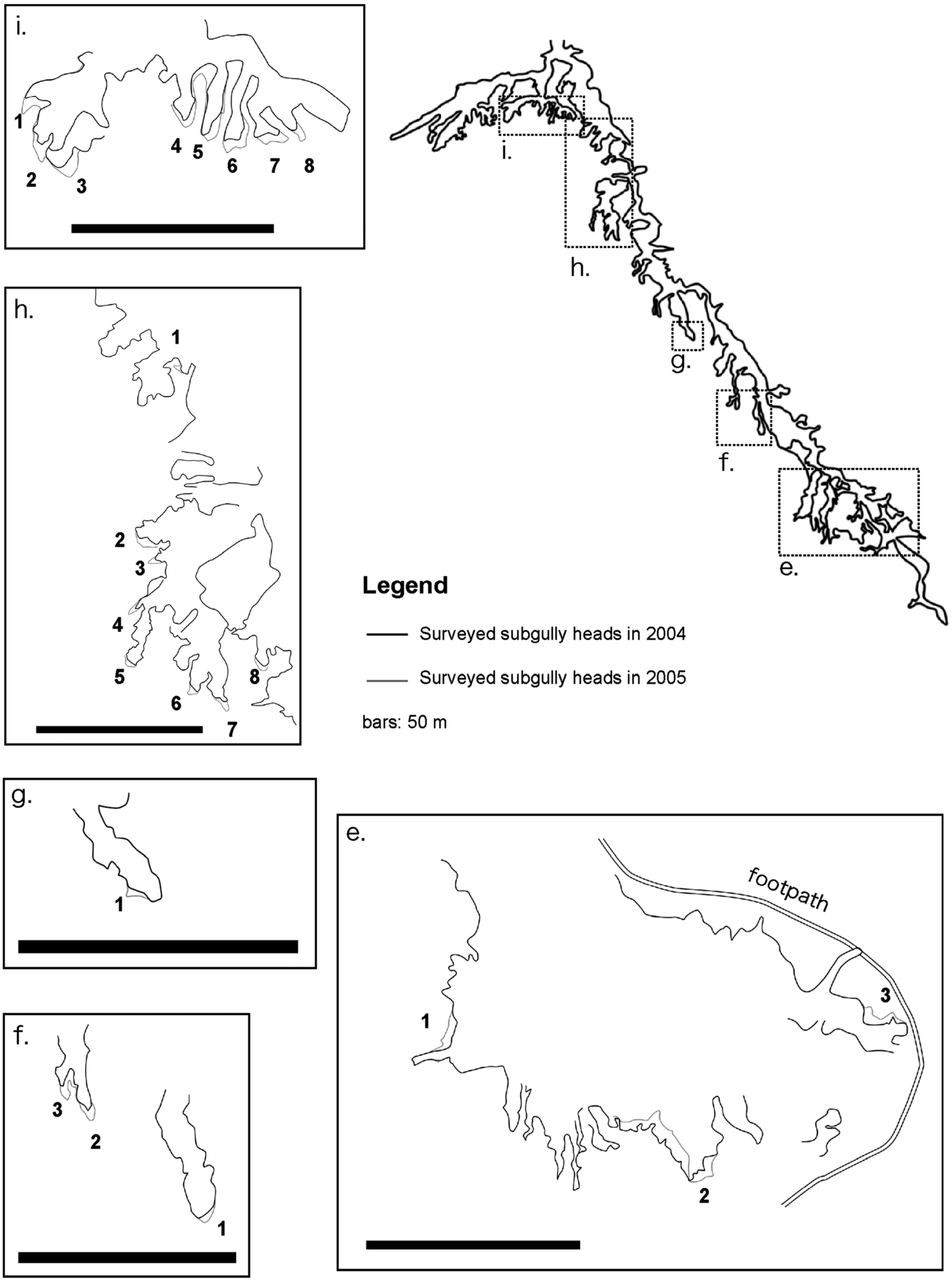


Fig. 3-5. Illustrated progress of headcut retreat at the Nyalunya site from 2004 to 2005. Numbers in the figure correspond to each measured sub-gully head (see Table 3-3).

3.3. Stratigraphy of the Sediments

Figures 3-6, 3-7 and 3-8 exhibit the columnar sections of the Quaternary sediments and top soils observed at the gully erosion sites of Figs. 3-2 and 3-3. Our field survey confirmed that the sediments are comprised mostly of clastic materials derived from the Precambrian basement rocks and the Miocene phonolites. Thin intercalations of tuffaceous bed are also found. Throughout the surveyed area, the bedding planes are almost horizontal, and no well-defined unconformities between the stratigraphic units are found.

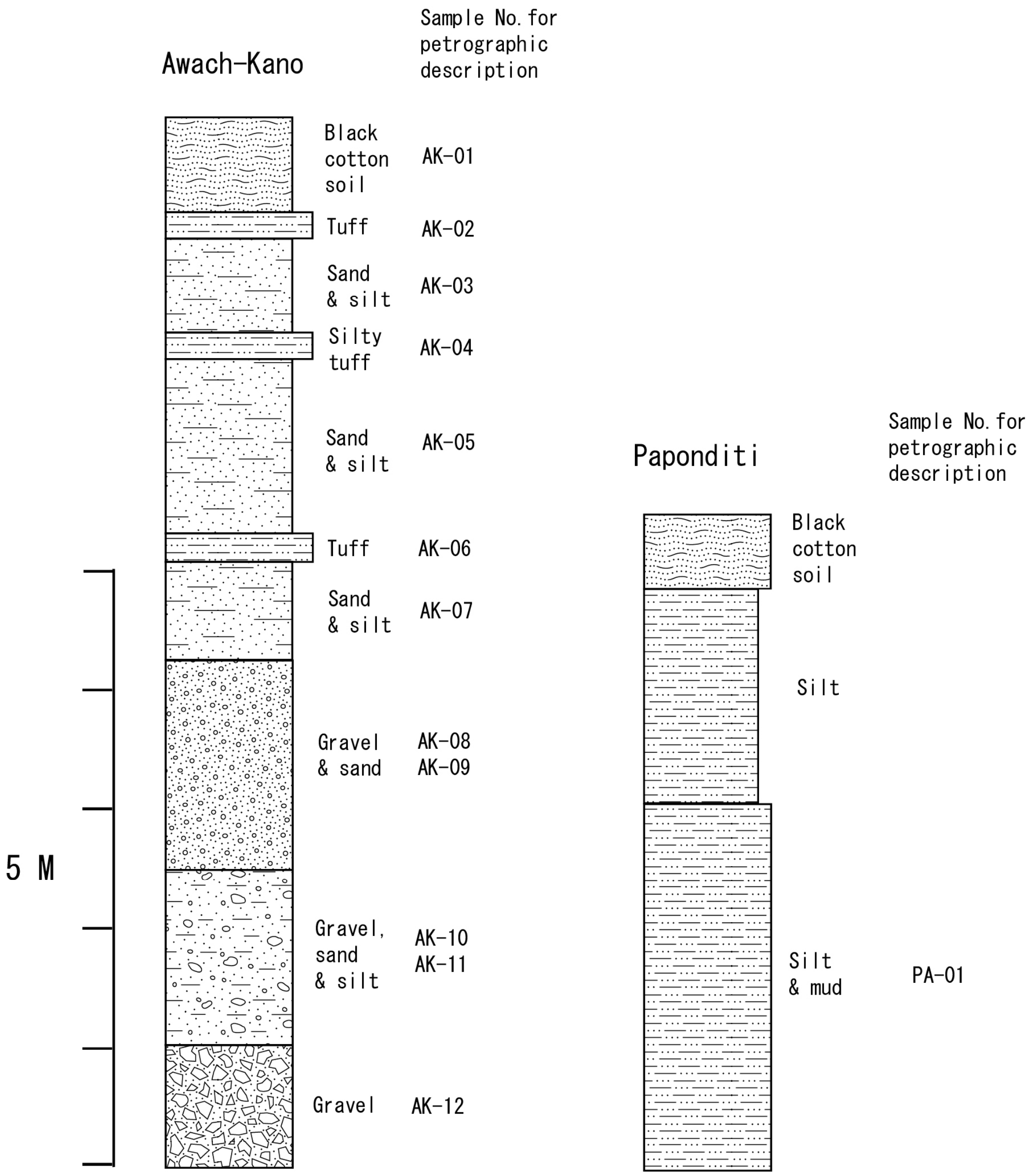


Fig. 3-6. Columnar sections at the Awach-Kano and Paponditi study sites.

Saggerson (1952) regarded these sediments as both lacustrine and fluviatile in origin. The sedimentary facies observed at the Awach-Kano study site, however, shows that the sequences are mainly formed by flood-type deposits rather than lake deposits. This is strongly supported by some lines of evidence observed in the lower part of the columnar section (Fig. 3-6), i.e. the cyclic gravel deposits with 5 to 30 cm sized cobble－boulder layers, slightly dipping of the bedding planes towards downstream and the imbrication of the gravels.

At the upstream of Nyalunya (Nyalunya-A in Fig. 3-7), Ragen and Sondu-Miriu (Fig. 3-8), the sediments deposited unconformably on Archaean granitoid (Plate II-8).

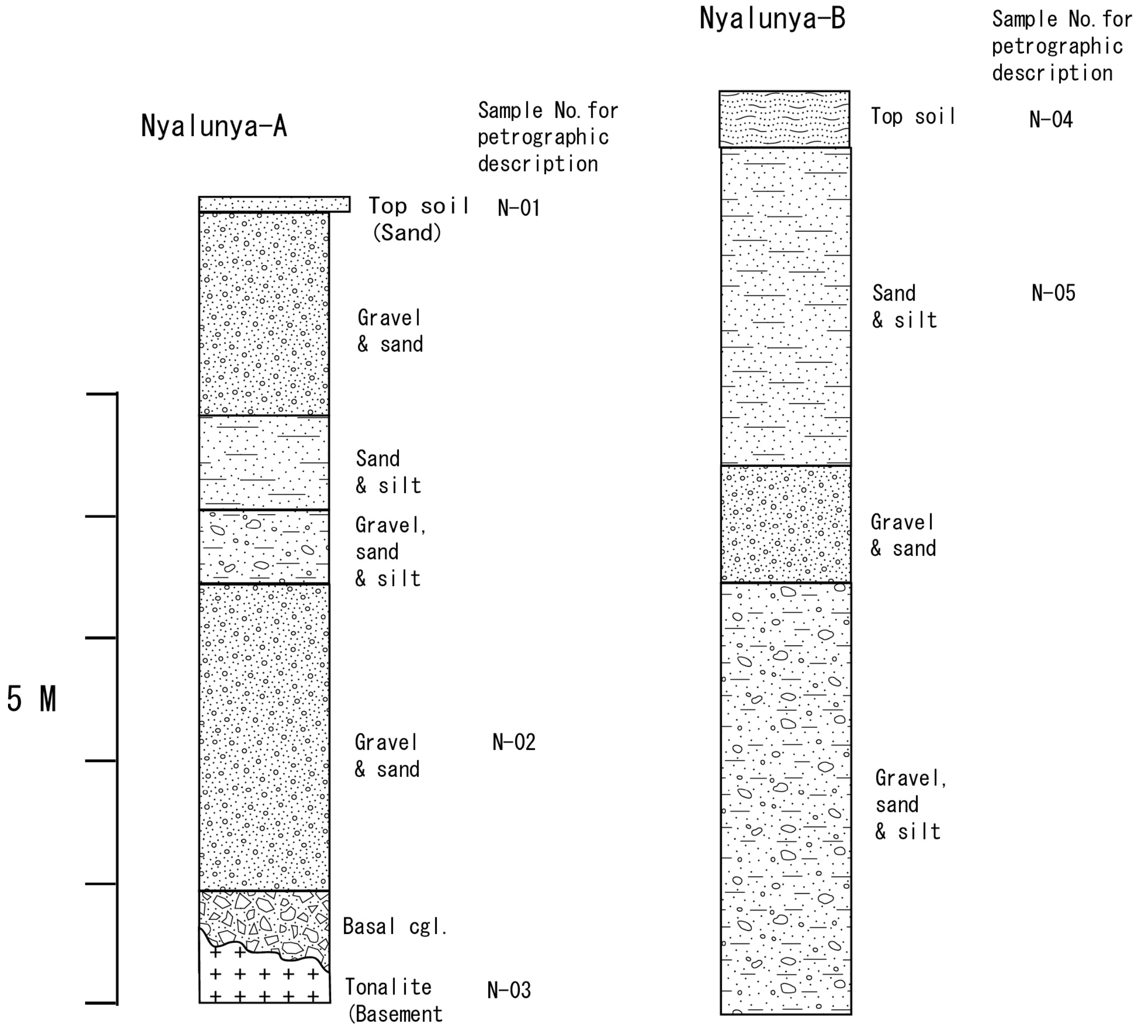


Fig. 3-7. Columnar sections at the Nyalunya study site.

Just above the unconformity, basal cobble—boulder beds are found at Nyalunya-A and Sondu-Miriu, which beds contain almost only granitic basement rocks. Therefore, the sediments of Nyalunya-A, Ragen and Sondu-Miriu form the lowermost part of the Quaternary sediments.

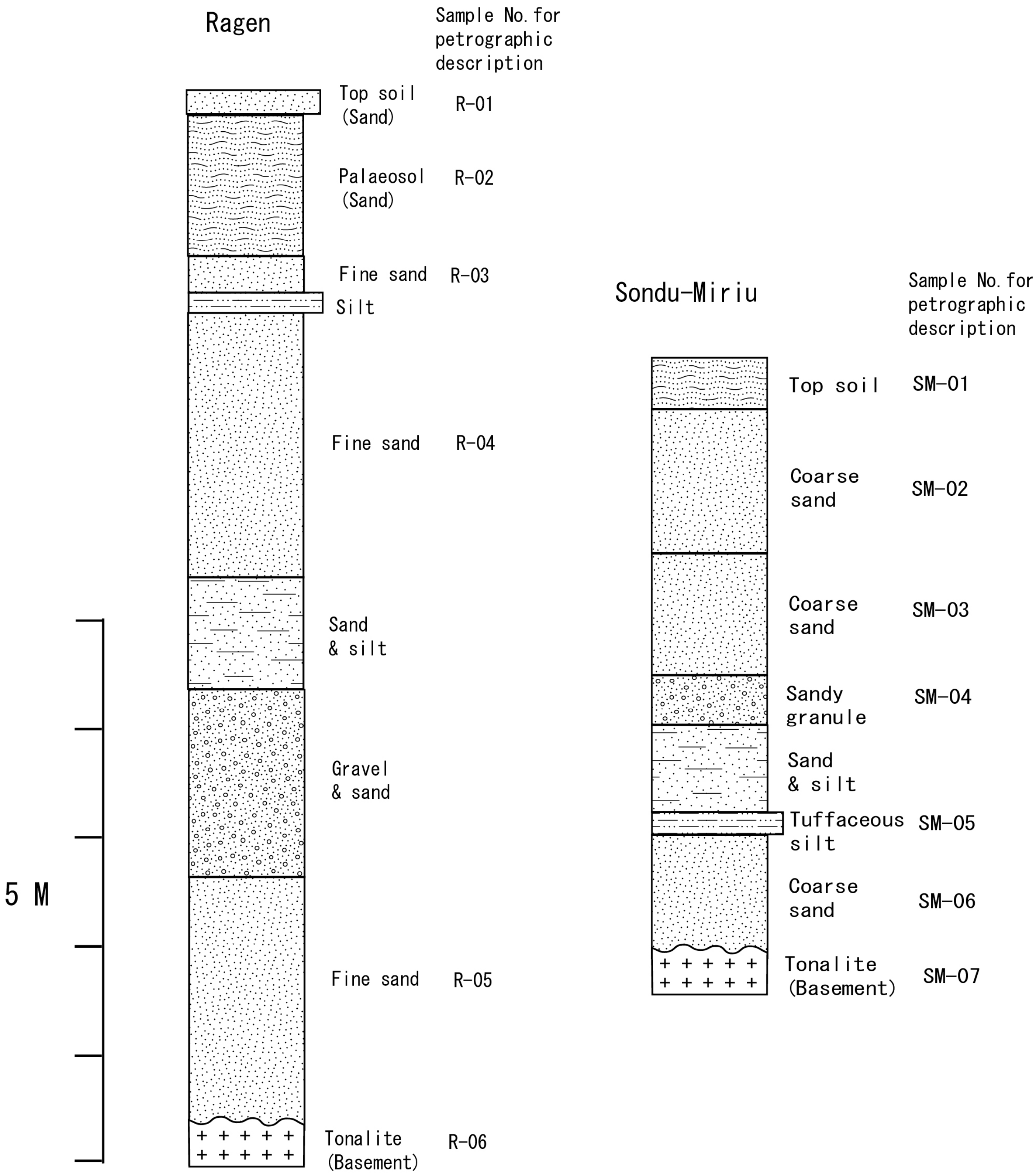


Fig. 3-8. Columnar sections at the Ragen and Sondu-Miriu study sites.

3.4. Lithological and Petrographical Characteristics of the Sediments

We have collected almost 100 samples of soils, sediments and basement rocks in the field and then prepared thin sections in order to investigate their optical properties. We also measured the hardness of the sediments in the field using the Yamanaka soil hardness tester (Fujiwara Scientifics). Lithological and petrographical characteristics of the soils, sediments and basement rocks are summarized in Table 3-4 and the sediment hardness are shown in Fig. 3-9.

Based on the lithostratigraphic evidence, we tentatively classified the Quaternary sediments in the study area into 'Awach member' and 'Sondu member'. The Awach member constitutes the upper horizon of the Quaternary sediments and the Sondu member constitutes the lower horizon, as schematically shown in Fig. 3-14. The sediments occurring in Awach-Kano, Paponditi and downstream part of Nyalunya study sites belong to the former member, while the sediments in Sondu-Miriu, Ragen and upstream part of Nyalunya study sites belong to the latter member.

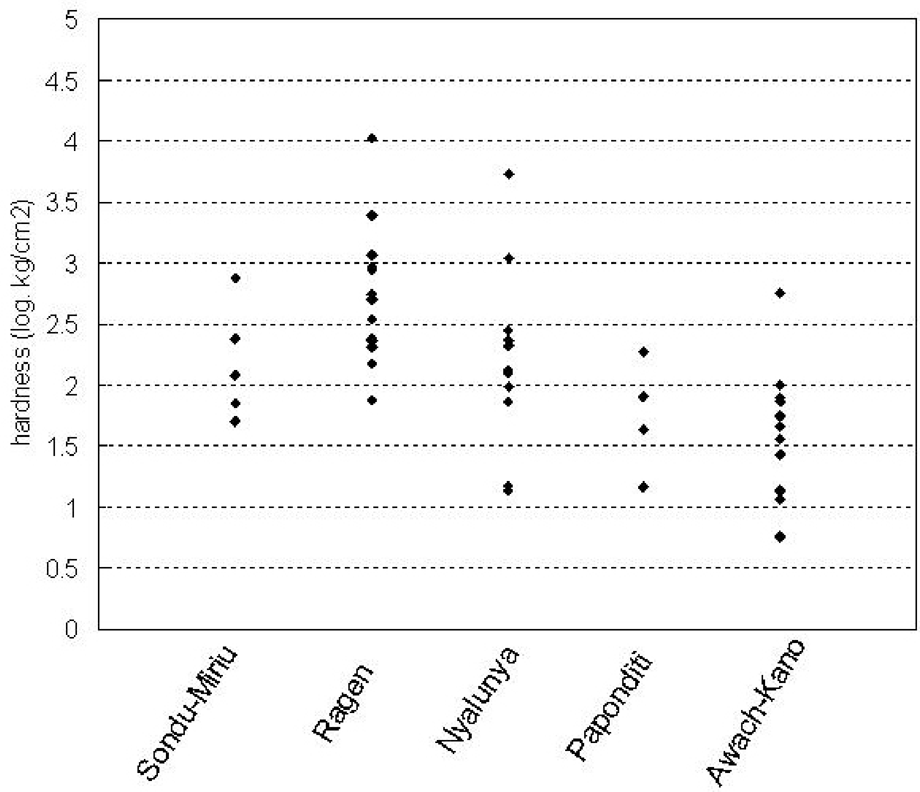


Fig. 3-9. Hardness of the sediments in the study sites.
Notice the logarithmic scale of the ordinate.

Table 3-4. Petrography of the soils, sediments and basement rocks.

Sample No.	Sample Name	Diagnostic features	Mineral grains	Matrix
AK-01	Black cotton soil	Rich in plant detritus	ϕ<2.0 mm, Mode: 10 % Granite fragment, Quartz, Feldspars, Carbonate nodule, (Plant detritus)	ϕ<0.1 mm, Mode: 90 % Quartz, Clay minerals, Carbonaceous matter, Fe-oxides, (Plant detritus)
AK-02	Tuff	Porous	ϕ<0.1 mm	Glassy matrix
AK-03	Calcrete nodule in sand-silt bed	Cryptocrystalline～very fine-grained		
AK-04	Silty tuff	Distinct volcanic glasses, Sporadic Fe-oxide cementation	ϕ<0.1 mm, Mode: 5 % Quartz, Granite fragment	Mode: 95 % Glassy matrix with clay minerals
AK-05	Silty sand	Dark-coloured, Porous, Angular grains, Interstitial clay minerals	ϕ<2.0 mm, Mode: 60 % Quartz, Granite fragment, Fe-oxide concretion, Altered mafic rock fragment, Feldspars, Mafic minerals, Carbonate	ϕ<0.1 mm, Mode: 40 %
AK-06	Tuff	Porous	ϕ<0.2 mm, Mode: 2 % Fe-oxide concretion, Quartz, Mafic minerals	Mode: 98 % Very fine-grained volcanic glass
AK-07	Sandy silt	Dark-coloured, Porous, Rich in Fe-oxide cementation and clay minerals	ϕ<1.2 mm, Mode: 10 % Quartz, Plagioclase, Granite fragment, Fe-oxide concretion	ϕ=<0.1 mm, Mode: 90 %
AK-08	Calcrete nodule	Concentric growth texture	Mode: 95 %-Carbonate Mode: 5 %-Quartz, Granite fragment, Olivine, Plagioclase	
AK-09	Coarse sand	Sub-rounded,	ϕ<2.0 mm, Mode: 95 % Quartz, Granite fragment, Plagioclase, K-feldspar, Fe-oxide concretion, Allanite, Amphibole, Olivine, Pyroxene, Mafic minerals	Clay minerals, Fe-oxide cementation

Table 3-4. (Continued)

Sample No.	Sample Name	Diagnostic features	Mineral grains	Matrix
AK-10	Sandy loam	Porous, Rich in Fe-oxide cementation	ϕ<1.2 mm, Mode: 60 % Quartz, Feldspars, Granite fragment, Olivine, Fe-oxide concretion, Pyroxene, Amphibole, Epidote, Biotite	ϕ<0.1 mm, Mode: 40 % Quartz, Clay minerals, Fe-oxide cementation
AK-11	Silty sand (Fine-grained part)	Porous	ϕ<0.8 mm, Mode: 40 % Quartz, Granite fragment, Feldspars, Fe-oxide concretion	ϕ<0.1 mm, Mode: 50 % Quartz, Clay minerals, Fe-oxide cementation, Mafic minerals
AK-12	Coarse sand (Matrix part of gravel bed)	Gravel: Sub-angular～sub-rounded, ϕ<30cm, Imbricated,	ϕ<3.0 mm Granite fragment, Quartz, Plagioclase, Fe-oxide concretion	
PA-01	Silt-Mud	Greyish brown coloured, Porous	ϕ<0.4 mm Quartz, Feldspars, Granite fragment, Biotite, Mafic minerals, Fe-oxide concretion	Very fine-grained, Fe-oxide cementation, Clay minerals
N-01	Granule	Porous, Similar to tonalitic mineral composition	ϕ<8.0 mm, Mode: 80 % Granite fragment, Plagioclase, Quartz, Fe-oxide concretion, Pyroxene, Amphibole,	Mode: 10 %
N-02	Altered tonalite	Highly weathered	Plagioclase, Quartz, K-feldspar, Biotite, Hornblende	Chlorite, Vermiculite? Fe-oxide concretion, Epidote, Secondary minerals
N-03	Fine-grained granodiorite ～ tonalite	Basement, Equigranular, Saussuritized plagioclase, Polycrystalline quartz	ϕ<3.0 mm Plagioclase, Quartz, Biotite, Opaque oxide	Fe-oxide, Secondary minerals
N-04	Fine sand	Top soil, Dark-coloured, Rich in Fe-oxide cementation, Plant detritus	ϕ<2.0 mm Granite fragment, Quartz, Feldspar, Mafic minerals	Fe-oxide cementation, Clay minerals

Table 3-4. (Continued)

Sample No.	Sample Name	Diagnostic features	Mineral grains	Matrix
N-05	Silty sand	Awach member sediment	ϕ<2.0 mm, Mode: 70 % Granite fragment, Feldspars, Quartz, Amphibole, Mafic minerals, Fe-oxide concretion	Mode: 30 % Quartz, Fe-oxide cementation, Mafic minerals, Clay minerals
R-01	Sand	Top soil	ϕ<3.0 mm, Mode: 90 % Granite fragment, Plagioclase, Quartz, Amphibole, Fe-oxide concretion	Mode: 10 % Fe-oxide cementation, Clay minerals
R-02	Sand	Palaeosol?	ϕ<2.0 mm, Mode: 90 % Granite fragment, Plagioclase, Fe-oxide concretion, Mafic minerals, Quartz, Amphibole	Mode: 10 % Fe-oxide cementation, Clay minerals.
R-03	Fine sand	Dark-coloured, Rich in Fe-oxide cementation	ϕ<1.0 mm, Mode: 90 % Granite fragment, Feldspars, Quartz, Fe-oxide concretion, Mafic minerals	Mode: 10 % Fe-oxide cementation, Clay minerals
R-04	Fine sand	Reddish-coloured, Rich in Fe-oxide cementation	ϕ<1.0 mm, Mode: 90 % Granite fragment, Plagioclase, Mafic minerals, Quartz, Fe-oxide concretion,	Mode: 10 % Fe-oxide cementation, Clay minerals
R-05	Fine sand	Light-coloured	ϕ<1.0 mm, Mode: 90 % Granite fragment, Feldspars, Quartz, Fe-oxide concretion, Mafic minerals	Mode: 10 % Fe-oxide cementation, Clay minerals
R-06	Medium-grained tonalite	Rich in saussurite and vermiculite	Plagioclase, Quartz, Biotite, Amphibole, Opaque oxide, Epidote, Fe-oxide concretion	
SM-01	Fine sand	Top soil	ϕ<1.5 mm, Mode: 90 % Granite fragment, Plagioclase, Quartz, Fe-oxide concretion	Mode: 10 % Fe-oxide cementation, Clay minerals

Table 3-4. (Continued)

Sample No.	Sample Name	Diagnostic features	Mineral grains	Matrix
SM-02	Coarse sand	Poor in matrix	ϕ<2.5 mm, Mode: 95 % Granite fragment, Quartz, Feldspars, Epidote, Fe-oxide concretion, Mafic rock fragment, Mafic minerals	
SM-03	Coarse sand	Ill-sorted, Porous, Fresh in mineral grains	ϕ<2.0 mm, Mode: 95 % Granite fragment, Quartz, Plagioclase, Mica, Mafic minerals	Fe-oxide cementation, Clay minerals
SM-04	Sandy granule	Reddish-coloured, Rich in Fe-oxide cementation	ϕ<5.0 mm, Mode: 95 % Quartz, Feldspars, Granite fragment, Fe-oxide concretion, Mafic minerals	Clay minerals, Fe-oxide cementation
SM-05	Tuffaceous silt	Volcanic glass in matrix	ϕ<0.4 mm, Mode: 30 % Granite fragment, Quartz, Fe-oxide concretion, Epidote	Mode: 70 %, Tuffaceous
SM-06	Coarse sand	Reddish-coloured	ϕ<2.0 mm, Mode: 80 % Granite fragment, Quartz, Plagioclase, Mafic minerals, Fe-oxide concretion	Clay minerals
SM-07	Tonalite	Basement rock, Sheared	Quartz, Plagioclase, Biotite, Opaque oxide	

Dark colour, porous, rich in matrix and abundant clay minerals characterize Awach member sediments. Silty beds of the Awach member are generally massive and poor in detrital grain as shown in Fig. 3-10. They also contain organic or clayey patches and secondary formed carbonate concretions with few mm to cm in size. Sandy beds of the Awach member have a relatively good sorting of medium sized detrital grains as shown in Fig. 3-11. The detrital grains are quartz, feldspars, mafic minerals and basement granitic and volcanic rock fragments with sub-rounded to rounded in shape. These characteristics show that the Awach member sediments have been transported rather far distance from their source rocks.

Sondu member sediments are characterized by reddish brown colour, porous, poor in matrix and abundant ferric-oxide precipitates (Fig. 3-13). Sandy beds of the Sondu member contain abundant detrital grains of angular to sub-angular quartz, feldspars and garnitic rock fragment, which would be derived from adjacent basement (Fig. 3-12). Angular to sub-angular shape of the detrital grains are also suggesting that the Sondu member sediments are not too far from the source rocks. The reddish coloured matrix is formed probably as weathering products of the mixture of basement granitic rocks and organic materials of the surface plant.

Hardness values of the Sondu member sediments are relatively higher than the Awach member sediments, though there are some overlaps. This would be due largely to the different content of ferric-oxide that cements the detrital grains (Fig. 3-13) and to the different porosity.

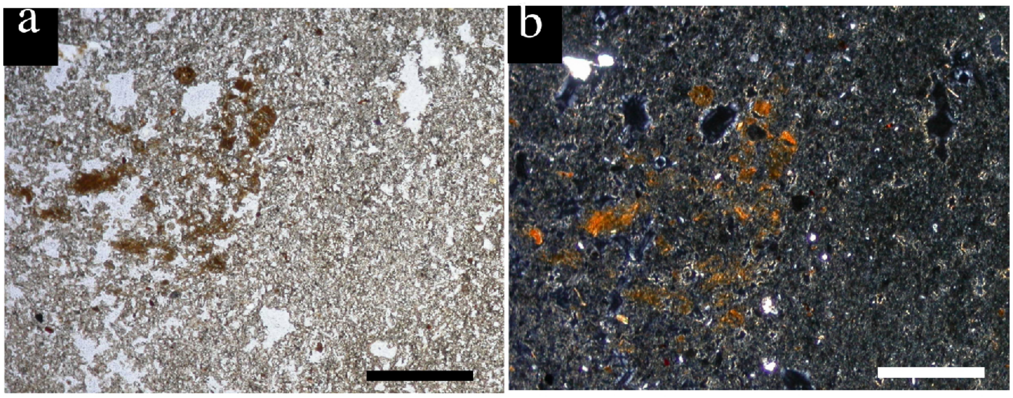


Fig. 3-10. Photomicrographs of a typical silt of the Awach member. Reddish part is ferric-oxide precipitates. (a): open, (b): cross, Scale bar: 0.1 mm.

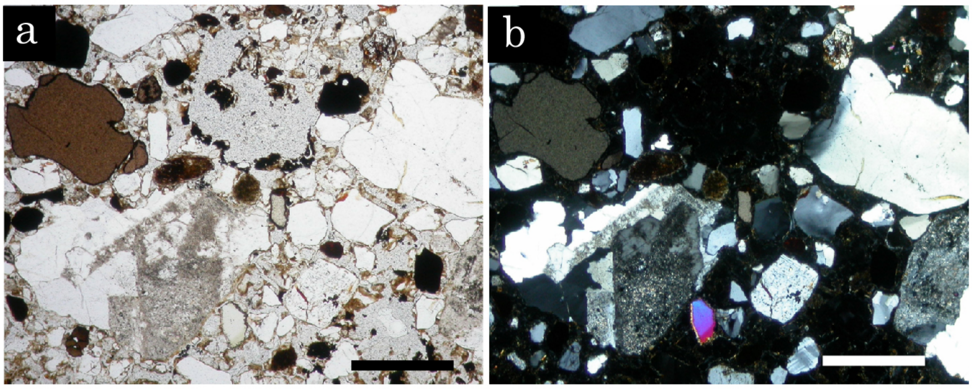


Fig. 3-11. Photomicrographs of a typical sand of the Awach member. Rounded to sub-rounded detrital grains are quartz, feldspars and mafic minerals. (a): open, (b): cross, Scale bar: 0.1 mm.

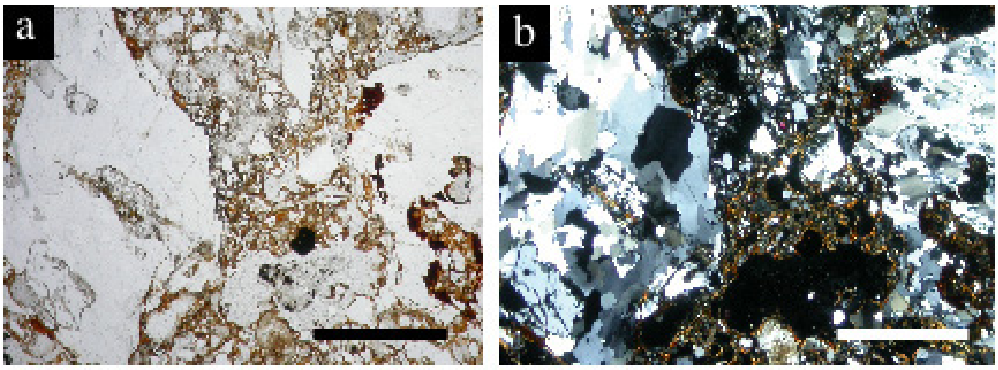


Fig. 3-12. Photomicrographs of a typical sand of the Sondu member. Reddish colour is ferric-oxide. Angular detrital grains are quartz, feldspars and granitic rock fragments. (a): open, (b): cross, Scale bar: 0.1 mm.

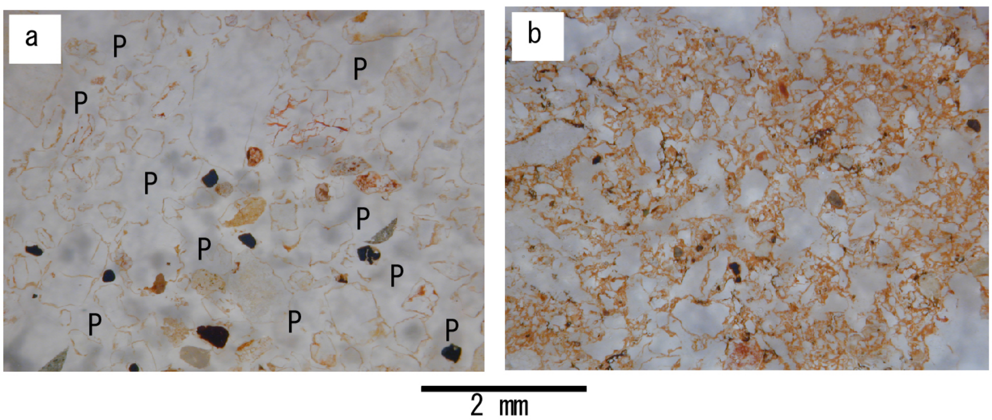


Fig. 3-13. Photomicrographs of both Awach member sand (a: AK-12 in Fig. 3-6) and Sondu member sand (b: SM-06 in Fig. 3-8) under incident light. Notice a contrastive abundance of ferric-oxide (reddish colour) and porous structure (indicated by "P").

As stated in the previous sections, the Awach type gullies develop on relatively softer Awach member sediments and the Sondu type gullies on relatively harder Sondu member sediments. A model for the formation of two types of gully due to the sedimentary facies changes is presented in Fig. 3-14. The differences of the upslope catchment area (Table 2-1) and the gradient (Fig. 6-11 and Table 6-2) are also significant factors controlling the gully morphology.

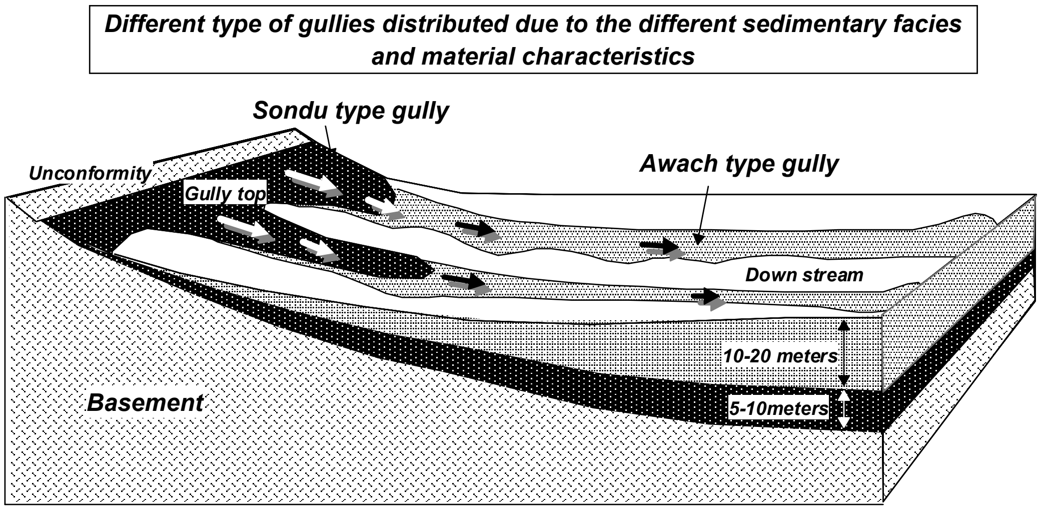


Fig. 3-14. A schematic view of the different types of gully.

Authors: Mitsuo Hoshino, Yusuke Katsurada, Hidekazu Yoshida, Koshi Yamamoto and Kenichiro Sugitani

IV. CLIMATE AND HYDROLOGY

4.1. Hydrology in Nyando and Sondu-Miriu Sub-Basins of the Lake Victoria Basin

General climate of Western Kenya was already described in Chapter II. In addition to those which were previously shown, detailed climatic and/or hydrological surveys have been done for the catchments of gullies in the Awach-Kano and Sondu-Miriu study sites and the surrounding areas. Climate of this region has a bearing on the hydrology of the region (Ellison, 1947; Morisawa, 1968; Emmett, 1970; Gregory and Walling, 1973).

The region is drained by the Lake Victoria drainage basin as already discussed, and due to the climate it is well endowed with both surface- and ground-water resources (Ongwenyi, 1979; Jaetzold and Schmidt, 1982; Shepherd et al., 2000; Swallow et al., 2002). It consists of the following sub-basins (Fig. 4-1).

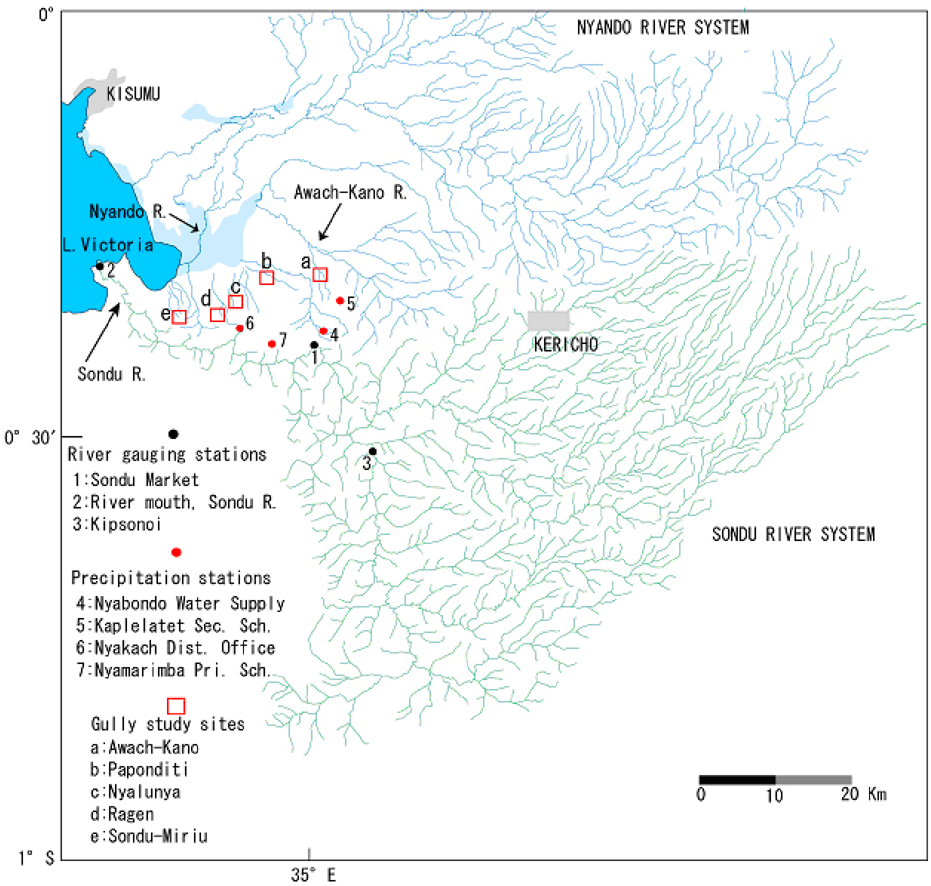


Fig. 4-1. Map showing the Nyando river system (light blue) and Sondu river system (light green), in which river gauging stations, precipitation stations and the study sites are indicated.

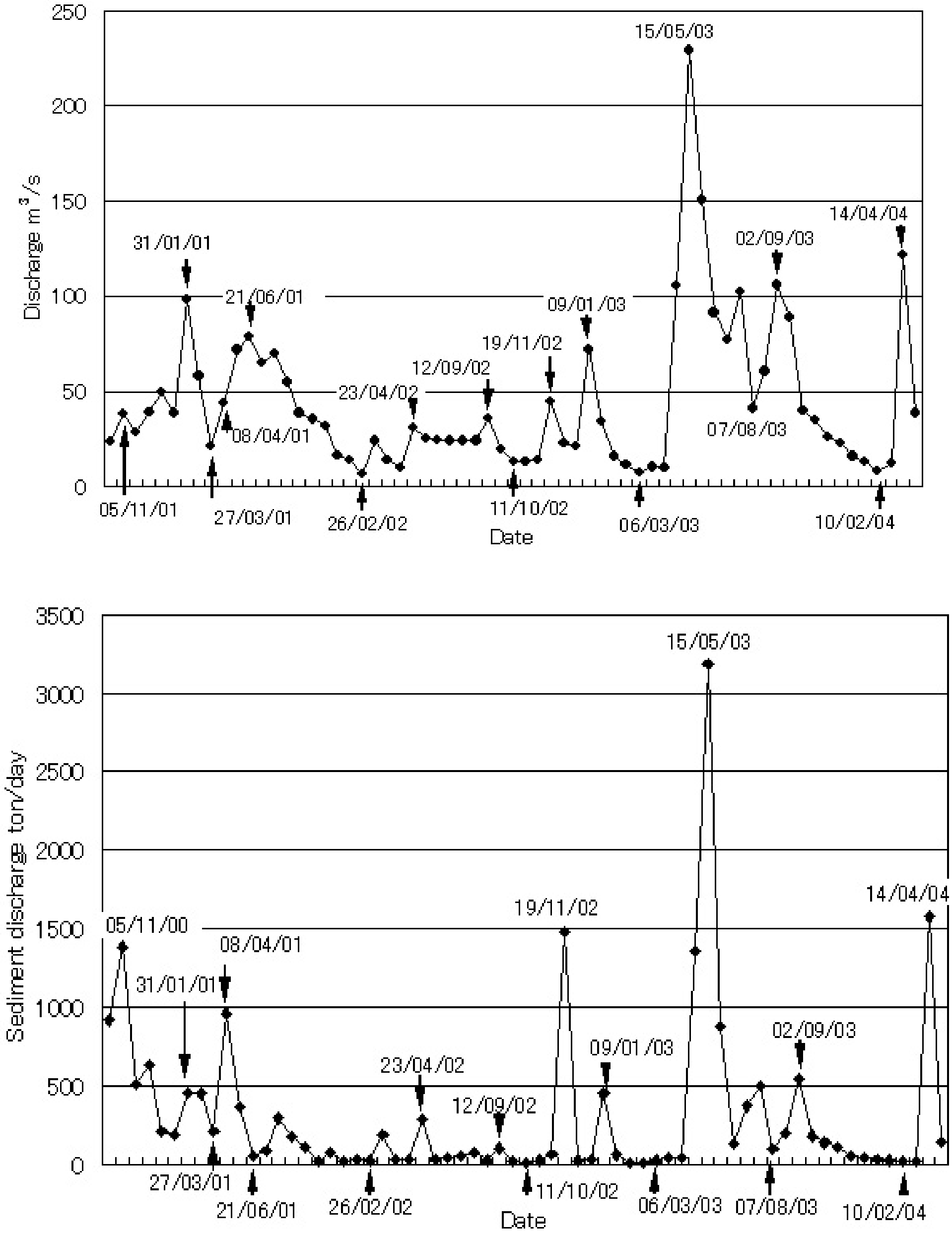
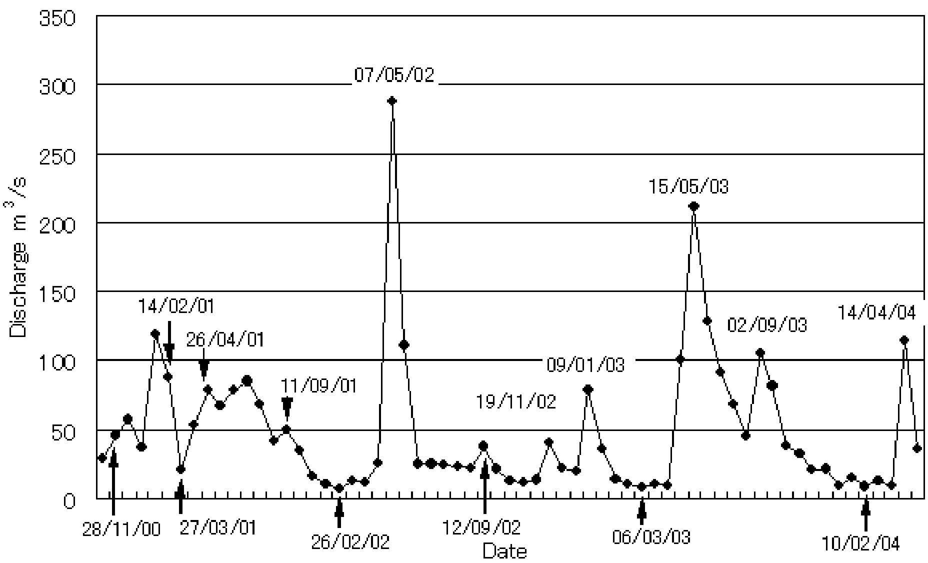


Fig. 4-2. Water and sediment discharges measured at the Sondu Market river gauging station (Station No. 1 in Fig. 4-1). Data collection: J. Nyangaga.



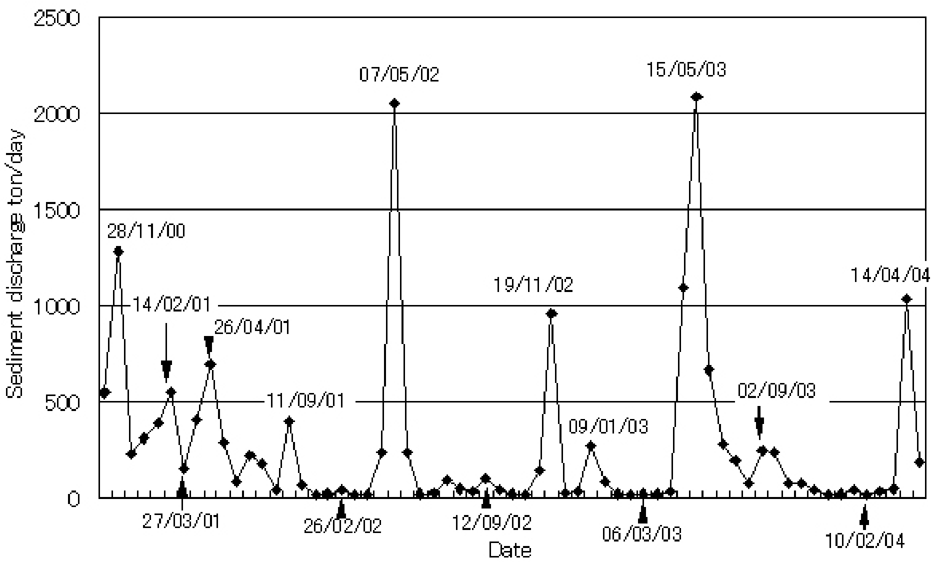


Fig. 4-3. Water and sediment discharges measured at the River Mouth river gauging station (Station No. 2 in Fig. 4-1). Data collection: J. Nyangaga.

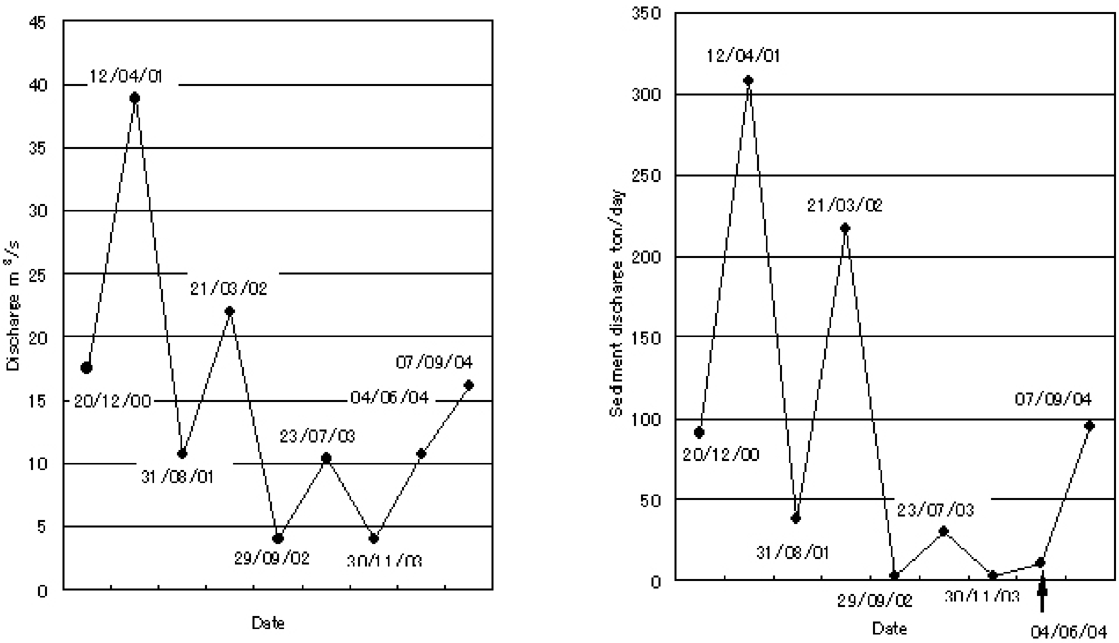


Fig. 4-4. Water and sediment discharges measured at the Kipsonoi river gauging station (Station No. 3 in Fig. 4-1). Data collection: J. Nyangaga.

Nyando sub-basin consists of the rivers Nyando, Awach-Kano, Namuting, Mbogo, Malaget and Kipchorian, draining some parts of Kericho and Nyando districts, with a total discharge of 2,118 million m^3/y.

Sondu-Miriu sub-basin consists of the rivers Sondu, Kipsonoi and Chemosit/Yurith draining Kericho, Bomet, Buret and Nyando districts, with a total discharge of 1,620 million m^3/y. Due to soil erosion in the catchment, sedimentation rates are high in response to the water discharge (Figs. 4-2, 4-3 and 4-4). Note the variations in the suspended sediment concentrations of the different sub-catchments of river Sondu, this indicates the effect of soil erosion in the catchment.

4.2. Characteristics in Awach-Kano Study Site

The Awach-Kano gully falls within the Awach-Kano river catchment of an area of 392km^2, it covers a catchment area of 19 km^2 within Nyanza province, stretching from the Kericho –Nyando district boundary to its outlet in the Awach-Kano river which then drains into the Nyando, then to Lake Victoria. The surface water, which is causing the gully, is from the Belgut hills of Kericho district. The gully is within the Asawo sub-basin (Fig. 4-1).

The gully falls within an area of low rainfall, e.g. 21－54 mm in January, the highest in April－May 184－329 mm (first season) and second season in August－October 70－189 mm. For climatic data, the rainfall data for Nyabondo water supply, which is just next to the gully, and Kaplaletet rainfall station at Kaplaletet secondary school within Belgut hills, which is in the upstream of the gullies, are informative (Tables 4-1 and 4-2; Plate VI-1).

Table 4-1. Monthly precipitations (mm) in 1980－1990 at the Nyabondo Water Supply rainfall station (Station No. 4 in Fig. 4-1). Data collection: J. Nyangaga.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	21.6		103.3	184.5	290.9	107	57.5	140.4	45.4	70	128.2	89.6
1981	37.3	81.6	160.8	275.4	132.9	55.2	129.4	127.2	205		45.2	90.6
1982	188.4	42.5	120.7	300.9	295.3		58	234.2	64.1	106.4	183	114.4
1983	106.3	51.3	41.3	211.1	161	123.5	104.2	213.9	155.3	192.8	107	
1984	107.4	67.1	63.5		116	118.7	128.9	91	54.8	105.8	163.7	45.9
1985	106	74.9	105	238	171.6	231.3	191.1	162.8	126.4	80.2	231.5	115.3
1986	186.2	195.7	168.2	210.8	134.4	89.9	74.7	76.6	201.4	101.9	56	164.9
1987	52.4	114.4		170.4	248.5	199.4	38.8	128.1	88.8			187.4
1988	102.2		195.5	299.2	271.9	113.1	146.2	261.1	175.3	0	144.7	75.3
1989	21.3	151.3	275.6		238	102.9		125.6	164.1	189.8	178.2	251.3
1990	54.1	217.7	261	329	217.3	75.8	41.5	144.4			48.6	139.7

Table 4-2. Monthly precipitations (mm) in 2004－2005 at the Kaplaletet Secondary School rainfall station (Station No. 5 in Fig. 4-1). Data collection: J. Nyangaga.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	122.4	15.6	98	98	98.1	20	100.1	193.1	210.7	156.3	184.2	100.1
2005	74.6	47.6	134.6	248.6	261.7	253.3	224.4	198.2	212.1	160.2	179.2	106

4.3. Characteristics in Sondu-Miriu Study Site

The gullied area falls within the Nyamarimba catchment, where ephemeral streams emanates from the steep Nyabondo escarpment (eastern part of Kendu escarpment) and drains the catchment into the marshes of the Nyakach bay.

The climate is bimodal: January–February being the driest months and April–May being the wettest months. See table 4-4 for precipitation data in upper Nyakach rainfall station. The climate is heavily influenced by the lake (Thompson, 1964; Seginer, 1966).

See the data for upper Nyakach D.O. (Table 4-3) and a new station at Nyamarimba (Table 4-4).

Table 4-3. Monthly precipitations (mm) in 1990－2000 at the Nyakach District Office rainfall station (Station No. 6 in Fig. 4-1). Data collection: J. Nyangaga.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990			226.8	349.4	227.1	30.3	4.8	59.5	69.2	51.4		82
1991				154.4	240.3	213.7	37.4	192.5	40.9	104.4	33.1	23.4
1992	18.7	61	73.8	172.3	145	151.7	91.1	123.4	59.4	127.5	62.3	89.1
1993		41.3	52.1	71.8	337.8	84.8	39	81.2		39.1	77	33.8
1994	10.5	17.8	226.7	314.9	158.1	104.4	111.8	67.1	47.7	79	164.2	35.1
1995	26.7	62.7	181.4	191.2	59.9	158.2	41.5		172	104.7	149.4	30
1996	116.6	116.9	161.3		130.9	75.7	104.3	77.8	79.6	116.9	139.9	21.3
1997	0	0	101.1	143.6	208.3		54.3	85.9	36.1	216.6	223.2	287.2
1998	143.5	78.6	90.2	204.2	285.9	98.2	80.9	79.4	78.3	136.9	70	18
1999	81.8	4.1	198.4	155.6	141.4	69.8	93.3	214.7	98.8	171.7	32.1	35.3
2000	10.5	30.5	87.2	164.8	185.1	48.0	70.1	125.2	79.3	72.7	123.7	96.4

Table 4-4. Monthly precipitations (mm) in 2004－2005 at the Nyamarimba Primary School rainfall station (Station No. 7 in Fig. 4-1). Data collection: J. Nyangaga.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	40.9	26.3	56.3	140	133.4	124.6	131.0	100	100.4	96.3	87.5	50.3
2005	36	30	70	155	144	120	135	102	100	98	90	56

Authors: John M. Nyangaga, Mitsuo Hoshino and Yusuke Katsurada.

V. RURAL LIVELIHOODS AND LAND USE

5.1. General Setting

Land degradation is a process that lowers the current and/or potential capability of land to produce goods for humanity such as crops, livestock, and timber or to provide services such as unpolluted water. Causes of land degradation include; soil erosion (by water and wind); fertility degradation that comprises the loss of plant nutrients, chemical, physical and biological degradation; degradation of vegetative cover, and degradation of water resources (GOK, 1997). Soil degradation is a form of land degradation that refers to processes induced or accelerated by human action, which changes the properties of the soil in such a way that the potential for plant growth is lowered (SARCCUS, 1981). Soil degradation in the tropics has been a major concern by scientists internationally due to its effect on the livelihoods of rural communities (Bewket and Stroosnijder, 2004; Tegene, 2003; Ovuka, 2000). While many studies attribute water erosion to physical factors such as rainfall erosivity, soil erodibility, topography and vegetation, socio economic parameters such as land tenure systems, land use patterns and cultural aspects are emerging as significant (Ovuka, 2000; Mati, 2004). Land use activities that reduce vegetation cover accelerate soil erosion due to enhanced energy of the rain-splash as well as encouraging runoff.

In Kenya, soil degradation is threatening the sustainability of agricultural systems on which a large proportion of the population depend for survival. The capacity by rural communities to deal with this problem is minimal due to widespread poverty. Severe gully erosion is particularly widespread in arid and semi-arid lands due to the fragile nature of the soils (Tiffen et al., 1994; Kinlund, 1996; FAO, 1999). Likewise the humid uplands of Kenya that form the food basket of the country are also threatened by erosion (Ovuka, 2000). On-site mitigation measures that are not only in tune with the physical environment but also the socio-cultural and economic situation of the communities are urgent.

Gully erosion refers to the removal of soil resulting from the excessive concentration of run-off water that causes the formation of relatively large channels or gullies. The gullies are difficult to cross by man, animals or even farm machinery. Gullies mainly occur in drainage ways or lower slope positions where they spread in fan-like pattern, leaving small islands of land too small for efficient farming (SARCCUS, 1981).

The Nyando river basin experiences some of the most severe problems of agricultural stagnation, environmental degradation and deepening poverty. The basin has been a major source of sediments and phosphorus flow into Lake Victoria over the last 50 years (Swallow et al., 2002). Sediments date 100 years with major sedimentation periods being 1914, 1961, 1986, 1998, which are associated with major floods in Kenya (Swallow et al., 2002). Approximately 1,443–1,932 km^2 (39.5–52.9 %) of the river basin is affected by visible soil physical degradation leaving only an estimated 862 km^2 that is not affected by soil physico-chemical degradation or soil nutrient deficiencies (Swallow et al., 2002). This remaining area is found on the remnants of Tindaret, South Nandi and NW Mau Forests. Erosion rate in Nyando basin is estimated by ICRAF to be 41 tons of soil per hectare per year (Swallow et al., 2002)

As shown in Chapter 1, one of the objectives of our study is to explicate the basic process of gully erosion in Western Kenya based on geological, geographical, ecological and agricultural field studies. Other aspects of the study include; effect of erosion on agricultural productivity as well as the soil conservation techniques employed by the farmers and their limitations. In this chapter, we present farmer's views on soil erosion at the sites and discuss future activities for achieving productive agriculture.

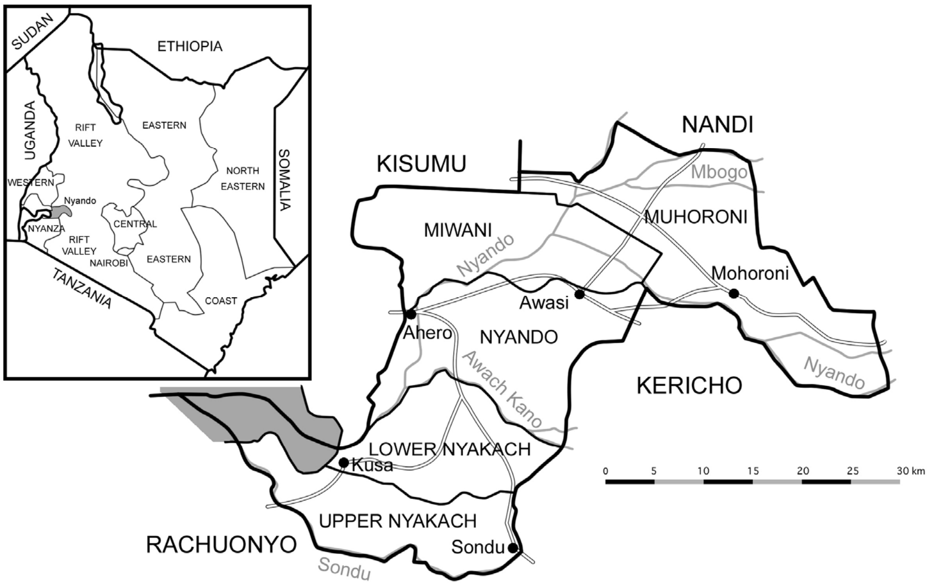


Fig. 5-1. Location of the study area.

5.2. Materials and Methods

5.2.1. Study Area

Nyando district, found in the Lake Victoria Basin with an area of 184,200 km^2, was calved from Kisumu district in 1998. It is one of the twelve districts that form Nyanza province in Western Kenya and lies on longitudes 34°4' east, and latitudes 0°23' and 0°50’ south of the equator. The district is found in the eastern part of the large lowland surrounding the Nyanza Gulf (Fig. 1). The district is divided into five administrative divisions namely Upper Nyakach, Lower Nyakach, Miwani, Muhoroni and Nyando.

The district can be divided into three main topographical land formations, namely the Nandi hills, the Nyabondo plateau and the Kano plains. The Kano plains which forms most parts of the district comprises of black-cotton-clay soils with moderate fertility and poor drainage. The rest of the district has sandy clay loam soils derived from igneous rocks. The district is made up of varied relief features with the altitude ranging from 1,800 m a.s.l. in Nyabondo plateau to 1,100 m along the Kano plains. The heterogeneous topography affects rainfall and temperature regimes in the district. The rainfall falls twice a year with long rains received from March to May while the short rains are received between September and November. The annual rainfall ranges between 600 mm to 1,630 mm while temperature ranges between 20°C to 35°C (Jaetzold and Schmidt, 1983). The rainfall is quite erratic and is a contributor to severe soil erosion experienced in the area although human induced factors are also significant.

Two major rivers Nyando and Sondu-Miriu, and two smaller rivers Awach-Kano and Ombeyi-Oroba drain the district. Nyando River is prone to flooding along the banks since it originates from the Nandi Hills where the rainfall is high; River Awach-Kano also causes a lot of floods and erosion especially in the Lower Nyakach division. Sondu-Miriu River provides water for hydro electric power production, which is under construction in Nyakach. The power station is expected to generate 60 megawatts of electricity. The district has a shoreline of 11 km along Lake Victoria with several beaches where fishing takes place (GOK, 2001).

The district has a population of 332,137 people and about 64,000 farm families (GOK, 2001). Due to high demand for land for settlement and agriculture most of the hitherto forested areas have been cleared. Koguta forest that covers an area of 320.5 hectares is the only surviving forest in the area. Agricultural production is low; for example in 1996, the average annual value of crop output per hectare was Ksh. 6,761 (92.6 USD) (Swallow et al., 2002). This has amplified the poverty situation in the district that currently stands at 68.9 % (GOK, 2001).

5.2.2 . Village Selection

Three villages were purposely selected for the study, namely; Kotuk-Kodeyo, Koguta and Kandaria within the Awach-Kano, Sondu-Miriu and Nyalunya river catchments. These areas exhibit severe gully erosion (Awach-Kano, Sondu-Miriu and Nyalunya study sites described in the previous chapters). Comparisons were made between the three gullies in terms of geographical location and land use variation. Sondu-Miriu gully is found near the newly constructed Sondu-Miriu hydroelectric power station and the study explored the linkage between the power station and land degradation in the area. Kotuk-Kodeyo and Nyalunya, on the other hand, are found in fragile ecosystem with erratic rainfall and high incidences of poverty.

5.2.3. Data Collection

The fieldwork was conducted in August 2003, August 2004, and July 2005. A total of 30 households were visited for in-depth interviews using questionnaires (see Appendix). The informants included 10 men and 20 women. The reason why women comprised a larger percentage of the sample is because they are easily found at home while men leave their homes in the morning to look for off-farm employment. The questionnaire covered wide area including; crops and livestock combinations, causes and effects of erosion, conservation techniques and possible solutions to the problem. In addition, old people were interviewed separately on the historical development of the gullies and land use changes.

Focus Group Discussions (FGD) were carried out in the three villages. The FGD included both men and women and selection was based on proximity to the gullies. Young adults from the villages helped in facilitating the discussion in the local language with guidance from the researchers.

Land use was delineated using aerial photographs taken in 2005 and ASTER satellite images recorded in 2001. Information on changes on land use was gathered through the questionnaires and interviews.

5.3. Results and Discussion

5.3.1. Farmer and Farm Characteristics

An analysis of the questionnaires and interviews revealed that the farmers in the area are purely subsistence. However, there are very few farmers who grow cotton even though the cotton industry in the Lake Victoria Basin collapsed. The average size of the household was 8 persons, which is large compared to small degraded farms that support them. The majority of the farmers fall within 48 and 60 age bracket .The women form the majority of farmers in the area due to labour migration involving men.

The income from agricultural activities was very meagre with the highest annual income being 448 USD (Ksh. 32,704) while the mean was 49 USD (Ksh. 3,577). This means that the majority of the farmers live on less than a USD per day. Comparing the three study sites, Sondu-Miriu area had the highest annual income of 45.3 USD (Ksh.

3,306.9), followed by Nyalunya area with 37.8 USD (Ksh. 2,759.4) while Kotuk-Kodeyo had 10.2 USD (Ksh.774.6). This explains the poverty situation not only in the study area but also in the larger Nyanza province. The farmers therefore combine farming with other activities in order to obtain extra income. Such activities include weaving, masonry and business.

5.3.2. Land Use and Land Cover Change

There has been substantial change in land use and land cover since the last 40 years. The area was initially grassland that served as grazing land until 1970s when the land was demarcated for agricultural activities. To some extent land demarcation acerbated erosion problem since it restricted animal movement to narrow paths in between the farms. Continuous movement of the animals on the fragile soils encouraged severe runoff. Furthermore, the demarcation was done along the slopes such that these paths extended to the watering points downstream. Land fragmentation is a serious problem in the area due to the land tenure system where a father subdivides the land amongst his sons. This has reduced the farm sizes to uneconomical units as well as rendered many people landless.

The farmers still keep indigenous cattle even though the number of cattle per household has reduced to an average of ten per household. Despite the fact that farm sizes have reduced tremendously due to increase in population, the farmers still use open grazing method for feeding their animals. This not only contributes to further erosion but also makes the conservation efforts futile due to the destruction of gabions and soil cover by the animals.

The types of crops grown in the area were initially indigenous such as sorghum and millet. These crops are well adapted to the area because of their resistance to drought and poor soils. However with the introduction of maize in the country during colonial period, many farmers discarded the indigenous crops despite the fact that maize does not do well in the area. The indigenous crops rarely experiences crop failure, on the contrary maize frequently suffers from crop failure due to long dry spells. It's ironical that the farmers prefer to grow maize.

The majority of the farmers combine maize with millet and groundnuts while others grow maize, sorghum and groundnuts together. Intercropping is a common practice in the region as a security against droughts. Other crops grown in the area are cassava, cowpeas, and sweet potatoes. Extensive areas of forests have also been turned into farming lands as the demand for land increases. Forests in the area and many others in neighbouring Kericho district have been cleared and this has increased runoff. This is coupled with the fact that the farmers hardly plant trees due to limitation of land, lack of water and frequent floods that wash away the seedlings (Mugo, 1999; Mugo et al., 2004; ICRAF, 2004).

5.3.3. Production Trends

The production of maize, the staple crop together with other cereals has been decreasing over the years. In the 1970s the farmers said they produced several bags of maize (one of the farmers said she produced five bags on 2.5 acre of land), however this has been reduced to an average of 88 kg (a bag is 90 kg) per household. The highest yield recorded in the study area was 450 kg that is equivalent to 5 bags. This is inadequate given the large family sizes of about 8 members and limited off-farm income generating activities. When asked about the cause of declining food production, 90 % of the farmers attributed it to low rainfall. Even though all the farmers agree that soil erosion is a major problem they do not consider it as a cause for reduced yields. The farmers believe that rainfall patterns have changed over the years. Despite this perception however over 95 % of the farmers practice some form of soil erosion control methods.

5.3.4. Soil Erosion and Conservation Techniques

Increasing pressure on land has led to intensive cultivation of steep slopes and exploitation of ecologically fragile areas. Many people have shifted to drier areas due to deterioration of soil fertility in hitherto productive land. In early 1800s the study area was open grassland that was used for grazing purposes for both the Luo and Kalenjin (Kipsigis) communities. Settlement begun around 1900 and there was a lot of fighting between the two communities and amongst Luo clans. By 1940 the colonial government had introduced boundaries to reduce conflict and there was already evidence of land degradation. This prompted the colonial government to compel farmers to start soil conservation structures especially building of gabions, digging of terraces (locally known as *fanya juu* (they are trenches dug about 30 m along the contours and soil thrown uphill, sisal and grass are planted on ridges).

After independence in 1963 there were very little conservation efforts since it was associated with the coercive policies of colonial government. The leaders who had fought for independence had promised the local communities that they would do away with forced labour associated with gabion construction by colonial masters. The study sites are severely affected by soil fertility deterioration caused by gully erosion with serious repercussion on agricultural productivity and people’s livelihoods (Tables 5-1 and -2). The farms have not only reduced due to encroachment of the gullies but all the fertile soils have been washed downstream into the lake.

Table 5-1. Focus Group Discussion (FGD) at three study sites.

Study site	No. FGD participants	Period of erosion progressed	Chronological findings of erosion development
Kotuk-Kodeyo Plain	18 (9 women, 9 men)	1970－80	In 1960s, there were lots of cattle path and land demarcation. In 1970s erosion was smaller scale, but in 1974－1978 this branched. In 1980s expanding rapidly and agricultural productivity declined. In 1990s, roads broken at 3 points.
Kandaria gently sloping	14 (6 women, 8 men)	1940－50	In 1940 only at around up-stream. Water went to underground and reached the river Nyalunya. In 1950s started at lower part of the hill and was growing gradually. Sisal was planted.
Sondu-Miriu Hill at Kaguda Forest	Households visited and interviewed	1940－50	Erosion started in 1940s. Soil conservation activity implemented under colonial law. Building of gabions (ukuta) along Koguta hill.

Kotuk-Kodeyo gully has been growing sideways at a rate of 20–50 m per year (Swallow et al., 2002) and is now 7 km long. It increases backwards through a process known as slogging. It has cut off the 10 km road linking Pamba in lower Nyakach to Kapsorok livestock market in Kericho. The gully has also severed water supply from Nyakach station. This has affected the economic activities in the area and the neighbouring Kericho district further accelerating poverty. The people of Lower Nyakach now depend on relief food. Swallow et al. (2002) estimates that more than 100 hectares of arable land has been affected by the gully. Millions of tones of fertile soils from Kipsigis hills, the Awach watershed and parts of Kano plains have been washed into Lake Victoria. The farmers identified the major causes of erosion as being runoff, deforestation and the nature of the landscape (Fig. 5-2).

There is a high degree of awareness of land degradation problem. All the respondents said that they experience soil erosion on their farms and use soil conservation methods. The farmers attributed gully erosion in the area to deforestation, frequent floods, poor farming techniques, cattle grazing and the topography of the area. There is another common practice of grazing cattle in the harvested fields. This also loosens the soils making them more vulnerable to erosion. Other causes are charcoal

Table 5-2. Key informants interview at Kotuk-Kodeyo.

	Key informants*	Solution
1	She got married in 1946, moved to this place in 1955, and found no gullies. In 1970, there were paths for both people and animals. Gullies gradually developed and expanded and agricultural productivity went down to 1/10. In 1994&1995, gabion was created but washed away.	Make a big dam and send water to Awach and Asawo rivers.
2	She got married in 1972 and moved to this site on the same year. Gully was there, but in a very small scale. In 1988 and 1989, gully was still passable. In 1992 roads collapsed.	The government to build a large dam to trap run-off from the hill.
3	After a heavy rain in 1961(uhuru floods), he noticed erosion everywhere. In 1974 the gully was divided into two branches. Government built a dam in 1974, but this was not big enough to stop the run off. In 1994 road got broken at 3 places.	Encourage the farmers to enforce gabions (locally referred to as 'ukuta').
4	She married in 1953 and moved to this site in 1974. The gully got worse in 1983 and 1984. Sudden decrease in production (10 bags of sorghum → 2 bags) was observed in 1988. Recently gully progressed rapidly and she thinks she might have to move to another place.	Plant trees on the hill slopes to reduce runoff.
5	She got married in 1940 and moved to this site in 1965. There used to be a water pan and then this became a gully near the house in 1978.	Build a dam and divert water to the neighbouring rivers.
6	She got married in 1960 and moved to this site in 1984. In 1960s this gully was just a small path. In 1978 a man got drowned in the gully – this time she realized the enlargement of gully and decrease in crop production (8 bags of maize → 0.5 bag)	Fence off gully with wire mesh to reduce accidents.

* Key informants are those who live next to the gully at Kotuk-Kodeyo

burning and sand harvesting. It is not surprising to find people harvesting sand not only in the river valleys but inside the gullies as well. The Awach-Kano catchment comprises of black-cotton-soils that swell after absorbing water during rainy season and crack during dry season. This makes them vulnerable to erosion. The high clay content in the soil also impedes infiltration resulting in massive runoff. Farmers around Sondu-Miriu electric power station gave dam construction as one of but not the major cause of erosion in the area. They blamed the dam constructors for piling rock debris along the hill thereby encouraging runoff. Various channels that had been dug by the dam constructors also encouraged the washing away of soils. However some farmers argued that afforestation programme undertaken by the project would in the long run reduce erosion in the area.

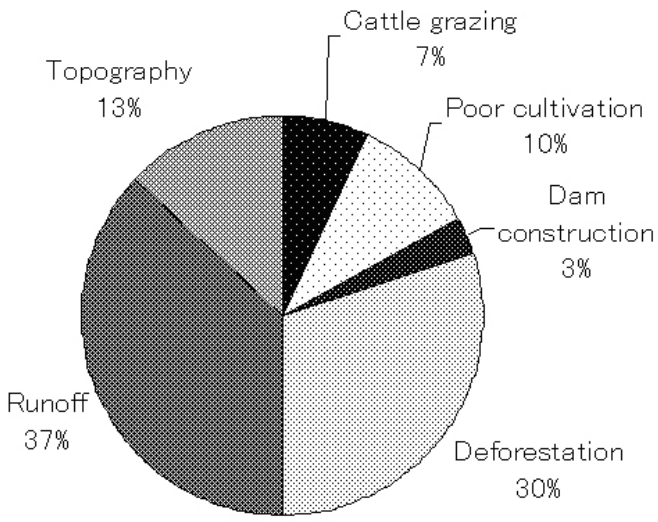


Fig. 5-2. Major causes of erosion identified by farmers.

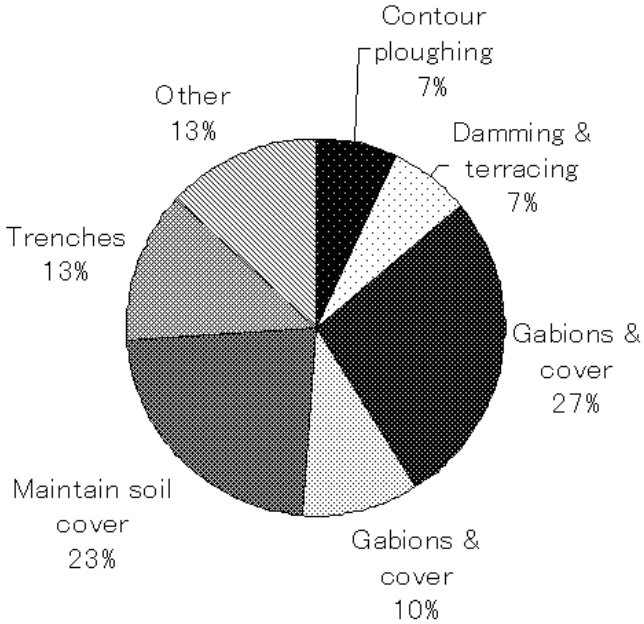


Fig. 5-3. Methods used to control soil erosion.

Quite a number of conservation methods introduced in the colonial period failed to win the acceptance of the local community (Fig. 5-3). Some of the methods such as gabions demand skilled personnel as well as requiring huge labour force and capital for their construction and maintenance (Veihe, 2000; Ovuka 2000; Tegene, 2003). The farmers also complained that a lot of land, which would otherwise be used for agriculture, is used. Other problems include spread of weeds, and shelter for rodents and destruction by cattle. The women also use sisal, which is commonly used to fence the gullies, for weaving mats, ropes, brooms etc. The women therefore cut the sisal in order to weave so as to earn some income. It is important therefore to diversify the income generating activities in the area not only as a means of reducing poverty but also as a solution to conservation efforts.

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Appendix

RESEARCH QUESTIONNAIRE

This interview is part of a study being carried out on the effects of gully erosion on rural livelihoods in Awach and Sondu Miriu river basins. Any information you give to us will be confidential. You are giving us this information on voluntary basis.

Your cooperation is very much appreciated

Questionnaire No……………………………………………………………
Interviewer:……………………………………………………………….
Respondent:……………………………………………………………….
Date:……………………………………………………………………….
District:…………………………………………………………………….
Division:……………………………………………………………………
Location:………………………………………………………………….
Sub-location……………………………………………………………….

PERSONAL INFORMATION

1. *Age (years)……………………….*
2. *Gender:*
   Female (01)
   Male (02)
3. *Marital status:*
   Married monogamous (01)
   Married polygamous (02)
   Widow/widower (03)
   Divorced (04)
   Separated (05)
   Single (06)
4. *Please indicate the age and gender of Members (M) of your household.*

	M1	*M2*	*M3*	*M4*	*M5*	*M6*	*M7*	*M8*	*M9*	*M10*
Gender										
Age										

Key on gender: F.A = Female Adult, F.C = Female Child, M.A =Male Adult, M.C = Male Child

5. *What do you do for a living?*
   ……………………………………………………………………………………………………
6. *a) When did you settle here?(Yr)*
   ……………………………………………………………………………………………………

   b) Is this your ancestral land or did you buy the land

Ancestral land (01)
Bought (02)

SOURCE OF LIVELIHOOD

7. Indicate the crops you grow starting with the most important

Long rains crops	**Short rains crops**

8. List the main cash crops that you grow in order of their importance
   ……
9. Which of these crops are indigenous?
   ……
10. Why do you plant the indigenous crops?
    ……

16. Why don’t you plant the indigenous crops?
    ……

17. What is your staple crop?
    ……

18.Please indicate the quantity and sales of crops you produced last year

Crops	Total production (Specify units, debes, Kgs, bags etc)	Total sales last year (kshs.)	Price per unit (kshs.)	Total revenue last year (kshs.)

19. What did you do with the money from crop sales?
………
21. Was the crop harvest enough to meet your food requirement?
Yes (01)
No (02)
22. If no in **(Q21)** why was this the case?
………
23. In the last five years do you think crop production has increased or decreased? (**Explain**)
Increased (explain)
………
Decreased(explain)
………
24. What do you think is the cause of the change mentioned above?
………
25. Please indicate how often you experience crop failure during the long rain season?

Crop type	Sometimes	Often	Rarely	Never

26. Please indicate how often you experience crop failure during the short rain season?

Crop type	Sometimes	Often	Rarely	Never

25 a) What are the causes of crop failure in this region?
………
b) How do you cope in case of crop failure or drought?
………
27. Please indicate the quantity, cost and source of inputs you use on the cultivated fields per year?

Input	Quantity (Specify units)	Cost per unit (kshs.)	Total cost (kshs.)	Source
Farm manure				

Chemical fertilizers				
Hybrid seeds				
Local varieties				
Pesticides				
Other inputs(specify)				

27. (A) Do you keep any livestock?

Yes (01)

No (02)

(B) (If yes) indicate the following

Livestock	**Number**	**Income from sale of livestock products last year**
Indigenous Cattle		
Upgraded cattle		
Sheep		
Goat		
Hens		
Pigs		
Others (specify)		

28.How do you provide the animals with feed?

Grow own feed (01)

Open grazing (02)

Zero grazing (03)

Buy feed (04)

Others (05)

29. Why do you keep livestock?

……

30.Where do you sell the food produced on the farm?

Local market (01)

Middleperson/trader (02)

Cooperative (03)

State Corporation (04)

Other specify (05)

31. How do you transport the food to the market?

Human transport (01)

Bicycle (02)

Matatu/bus (03)

Others specify (04)

32. (A) Can you tell me the main challenges you face in meeting the day to day food requirements for your households

……

33. (B) please tell me how you think these challenges could be solved.

……

SOIL EROSION AND CONSERVATION

34.a) Do you think soil erosion is a problem in this area?

Yes (01)

No (02)

b) If yes for how long has soil erosion been a problem in this area?

……

35.Do you experience soil erosion on your farm?

Yes (01)

No (02)

35. (**If answer to Q 35 is yes, if No go to Q 36**) when did you start experiencing soil erosion on your farm

……

36.What do you think are the causes of erosion?

……

38.Who do you think is responsible for causing soil erosion?
………
39.Have you taken any measures to control soil erosion on your farm?
Yes (01)
No (02)

If yes go to Q40 a, b , c if no proceed to Q41

40. **a) If yes** please tell us the measures undertaken
………
b) Have these methods been successful in combating soil erosion?
Yes (01)
No (02)

c) Whose initiative was it to control soil erosion on your farm?
Own (01)
NGO (02)
Government (03)
Others (specify) (04)

d) What problems do you experience in controlling soil erosion
………
41.Why haven't you practiced soil erosion control methods?
………
43.What role has the government played in combating soil erosion in this area?
………
44. How has your livelihood been affected by soil erosion? (**Explain**)
………
44.How do you think poverty could be eradicated in this area?
………
35.Compared to five years ago do you think your lifestyle has improved or worsened?

Improved (**explain**) (01)
………
Worsened (**explain**) (02)
………
(For farmers around Sondu Miriu)

36 a). Do you think dam construction has had any effect on soil erosion in this area?
Yes (01)
No (02)
36 b). If yes in what way has dam construction affected soil erosion?

37. What measures do you think the dam constructors have taken to conserve soils in this area?

38. Do you think these measures have been successful?
Yes (01)
No (02)

Thank you for your cooperation

VI. IMAGE ANALYSIS

Three types of image analysis have been carried out for three purposes. Analyzed image data are topographic maps, remotely sensed satellite imagery and aerial photographs. Results of the analyses of these image data were combined to produce the distribution map, gullying patterns and information of the upslope catchments. Overlay analysis has finally been carried out to produce hazard warning maps for eroding/contributing zones as described in Chapter VII. The schematic diagram of the image analyses is shown in Fig. 6-1.

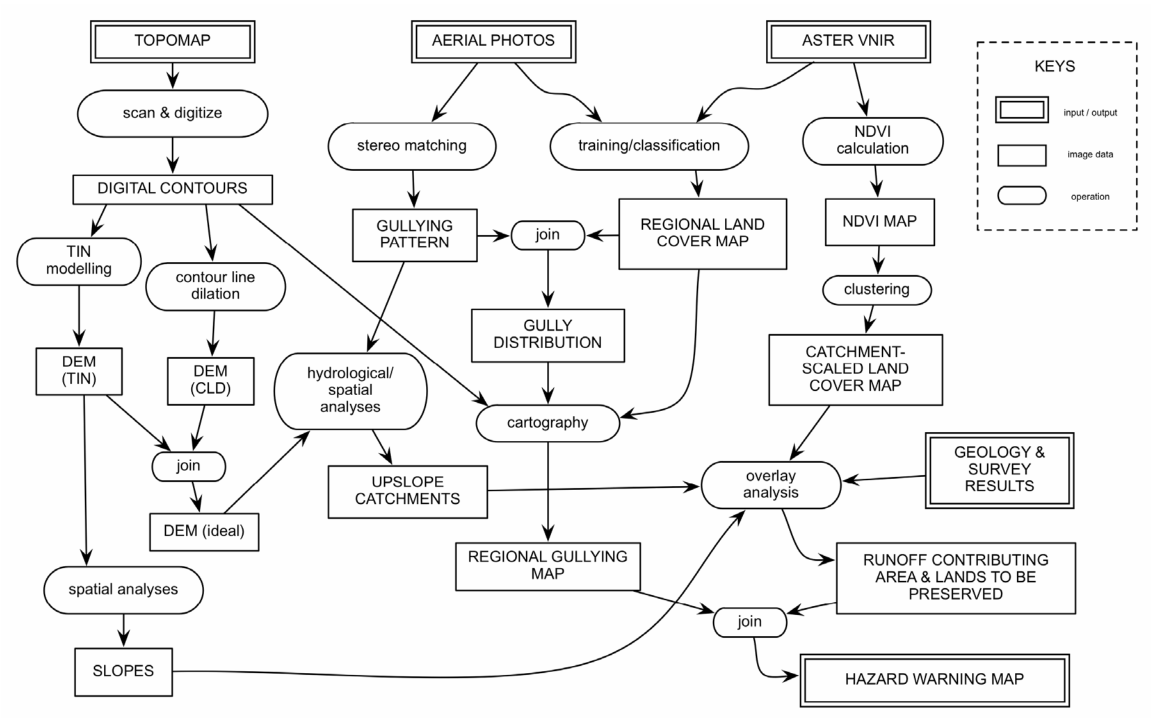

Fig. 6-1. Schematic flow diagram of the image analyses.

6.1. Analytical Methods

6.1.1. Topographic Maps

The topographical maps, East Africa 1:50,000 (Kenya) Belgut Series Y731 (D.O.S. 423) Sheet 117/3 Edition 5-D.O.S. 1971 (Directorate of Overseas Surveys for the Kenya Government, 1971) and East Africa 1:50,000 (Kenya) Nyakach Series Y731 Sheet 116/4 Edition 5-SK (Surveys of Kenya, 1982), were selected for the basemap.

These topographical maps have technical problems to manage the escarpment as a consolidated topography because the contour units are different, i.e. eastern part of the study area is delineated in metres (Belgut sheet) and western part is in feet (Nyakach sheet). Contour lines (20 m and 50 ft interval for Belgut and Nyakach, respectively) of the study area were traced and saved as vector polylines (Fig. 6-2). The Triangulated Irregular Network (TIN) was produced from the digitized contours by using 3D Analyst extension of ArcGIS 9, and it was converted to grid data format to obtain DEMs (Fig. 6-3a) and contour line dilation (CLD) method (Taud et al., 1999) was applied to obtain another DEM (Fig. 6-3b). These modelling methods have advantages for generating DEM from limited topographic information. However, these DEMs have respective difficulties. TIN-based DEM has difficulty on representing the ridge shapes because of its truncated triangular modelling. CLD (contour line dilation)-based DEM represents ridge shapes better than TIN, but it poorly represents slope angles because of its simple complementing algorism —adding extra contours between existing two contours. These DEMs were joined to produce ideal DEM to collect the topographical information of the upslope catchments of the gullies (Fig. 6-4).

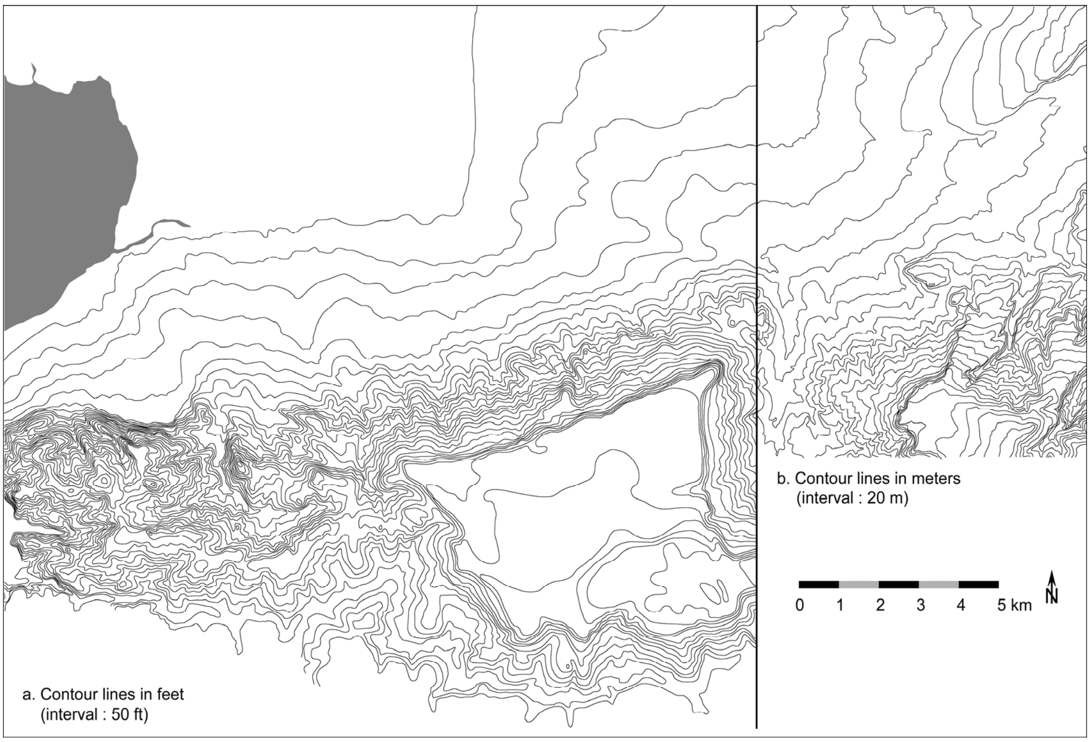

Fig. 6-2. Digitized topography (contour lines).

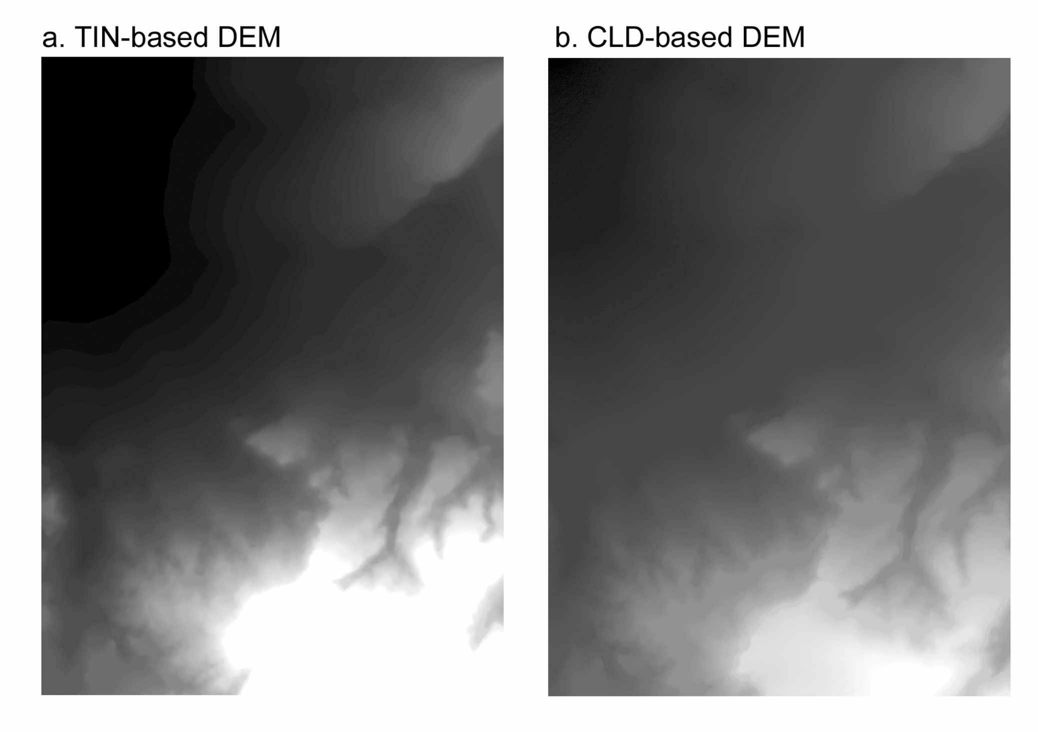

Fig. 6-3. DEMs generated using Triangulated Irregular Network (a) and Contour Line Dilation (b). The area shown in the figure covers Awach-Kano gully catchment. Elevation is shown in greyscale.

6.1.2. Aerial Photographs

Aerial photographs were taken on the 27th of January, 2005. The flight has been carried out with 6 runs covering the eroded slopes along the escarpment and the photography scaled 1:10,000 (Fig. 6-5). Lens cone is UAG 1053 with focal length of 153.30 mm. Numbers in brackets are the numbers of photographs taken along each run.

We used geo-reference feature to depict the gullying patterns in GIS since the gullies are incised on the low-gradient pediments, although these aerial photographs were not ortho-corrected then it was impossible to be imported to GIS directly. Aerial photographs of the gullies were stereo-analysed to define the gully edges for gully pattern mapping. The produced gullying pattern maps were compared to the NDVI maps. Stereopairs of non geo-referenced aerial photographs are shown in Plates VI-1, VI-2, VI-3, VI-4 and VI-5.

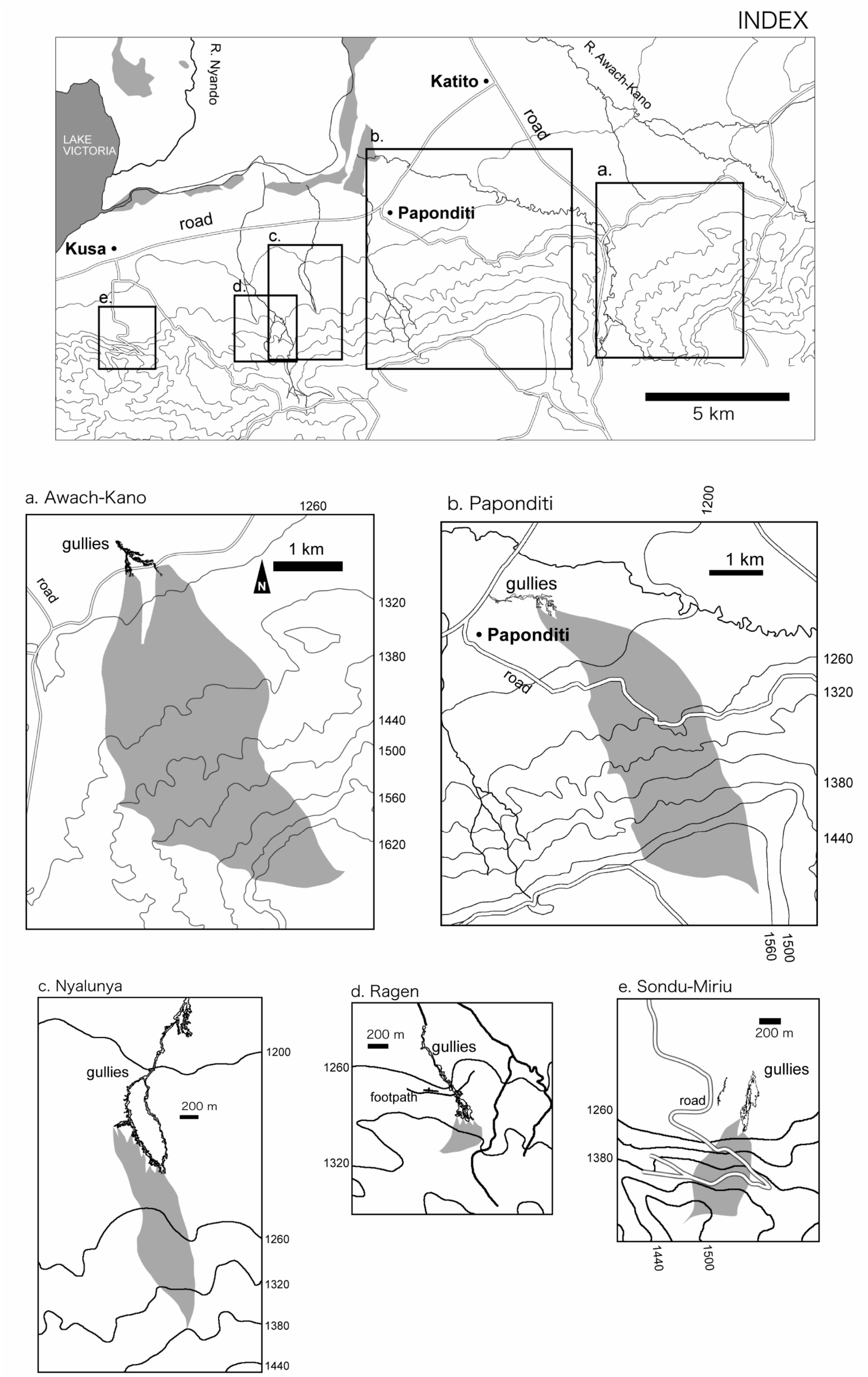

Fig. 6-4. Maps of the upslope catchments of gullies.

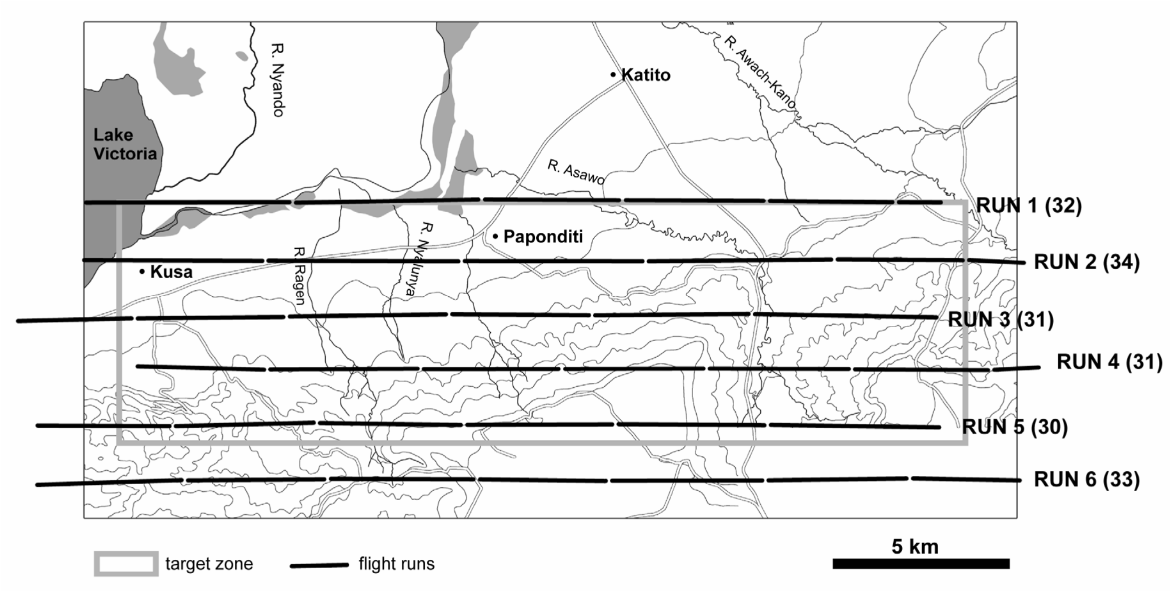

Fig. 6-5. Flight courses of the aerial photograph session on 27 January, 2005 (Based on flight data by Photomap Kenya Limited).

6.1.3. Satellite Imagery

Vegetative cover of the upslope catchment is obvious and an important factor in erosion discussions because runoff rate is affected by vegetation (Morgan, 1986). Remote sensing techniques have recently been applied in soil erosion assessments (Pahari et al., 1996; Singh et al., 2004). A variety of vegetation indices, which have linear relationships with leaf area index (LAI), biomass, leaf water content, chlorophyll and other biophysical characteristics of vegetation, have been developed (Wiegand et al., 1991; Curran et al., 1992), but the most commonly applied index is the normalized difference vegetation index (NDVI). The NDVI has been widely used in describing relationships between vegetation characteristics such as above ground biomass, green biomass and chlorophyll content (Tucker et al., 1985), and it has been applied in African studies—for example, FAO ARTEMIS and NASA PAL archives cover African continent (FAO/UNEP, 1984; Sannier et al., 1998a; Sannier et al., 1998b). But the spatial resolution of these NDVI archives is not suitable for this study. Therefore, we selected remotely sensed images of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

ASTER is a research instrument provided by the Ministry of International Trade and Industry (MITI), Japan, and launched on NASA's Earth Observing System Monitoring (EOS-AM1) platform in 1998 (Yamaguchi et al., 1998). The ASTER instrument has three separate optical systems of visible and near-infrared (VNIR) radiometer, shortwave-infrared (SWIR) radiometer and thermal infrared (TIR) radiometer. There are three spectral bands in the VNIR regions with 15 m ground resolution. These high-resolution data can help to discriminate a variety of surface materials (Yamaguchi et al., 1998). False colour processed image of one scene of an ASTER granule covering Kendu escarpment is shown in Fig. 6-6.

Remotely sensed data of ASTER SWIR and TIR are useful in defining lithological differences of surface materials by their reflection/emission analyses (Yamaguchi et al., 1998; Rowan and Mars, 2003). However, the dense vegetation of the study area is main obstacles for applying these systems. We have then used only VNIR images for our study.

Eight classes of the land surfaces, that are ‘lake’, ‘swamp’, ‘pond’, ‘bare land’, ‘artificial object’, ‘vegetated land’, ‘forest’ and ‘cloud’, were selected from the field survey and aerial photographs. Supervised classification was carried out to obtain the regional land cover map qualifying these classes as training fields (Fig. 6-7).

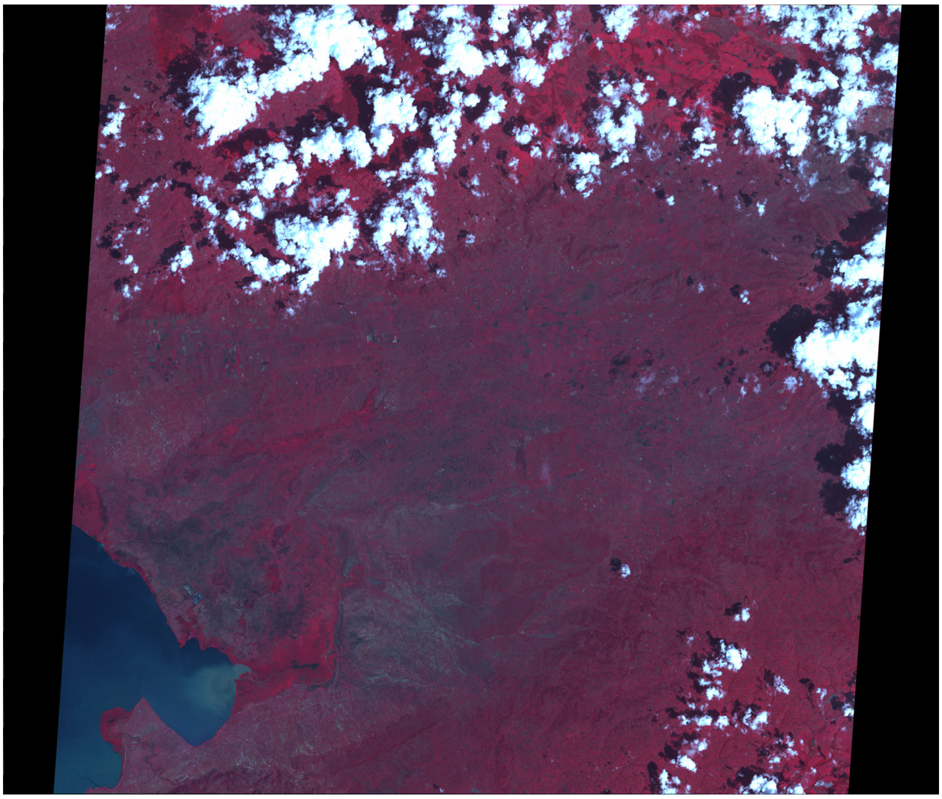

Fig. 6-6. False colour satellite image of ASTER VNIR that covers Kavirondo Rift region.

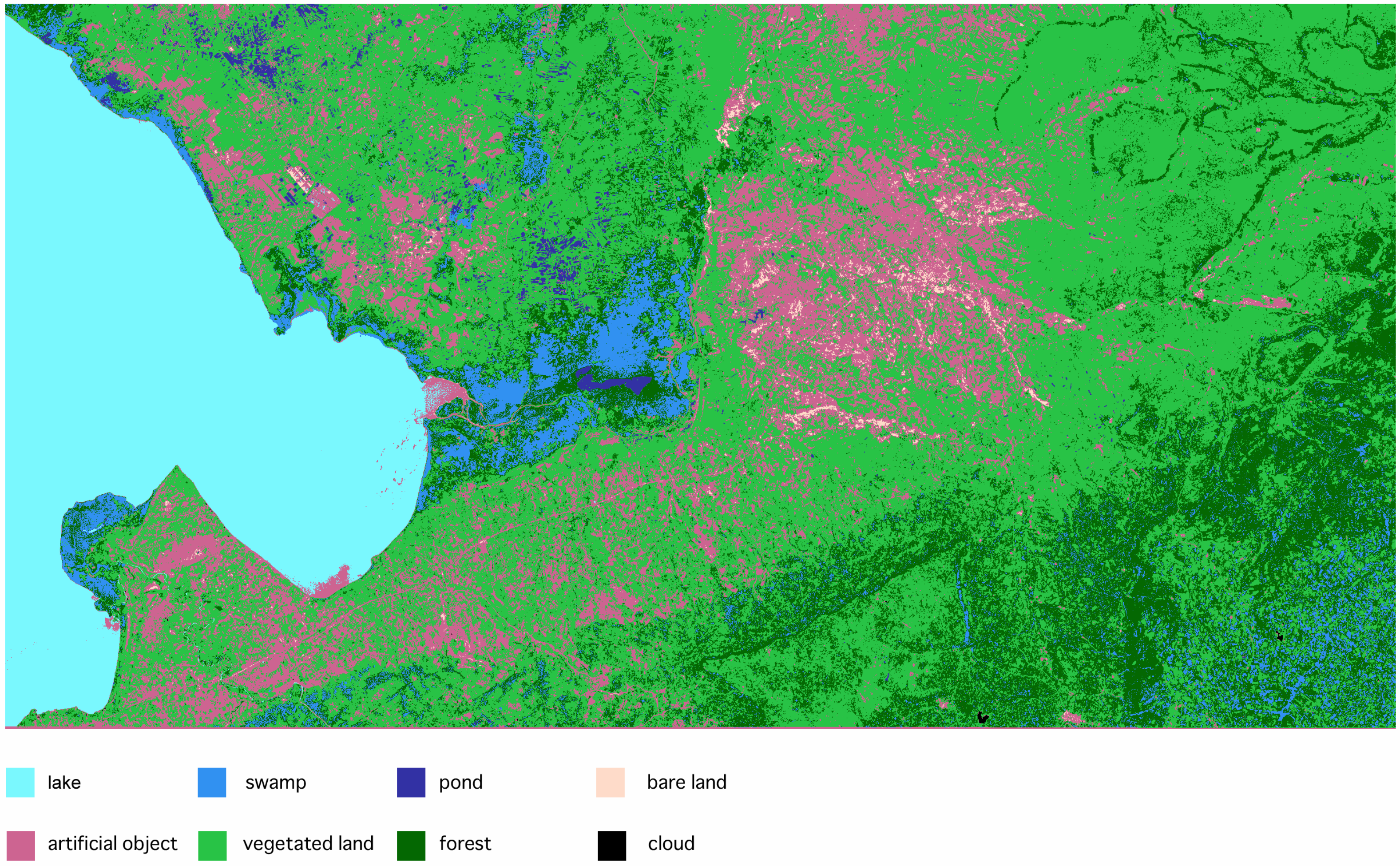

Fig. 6-7. Land-cover classes obtained by supervised classification of ASTER VNIR bands.

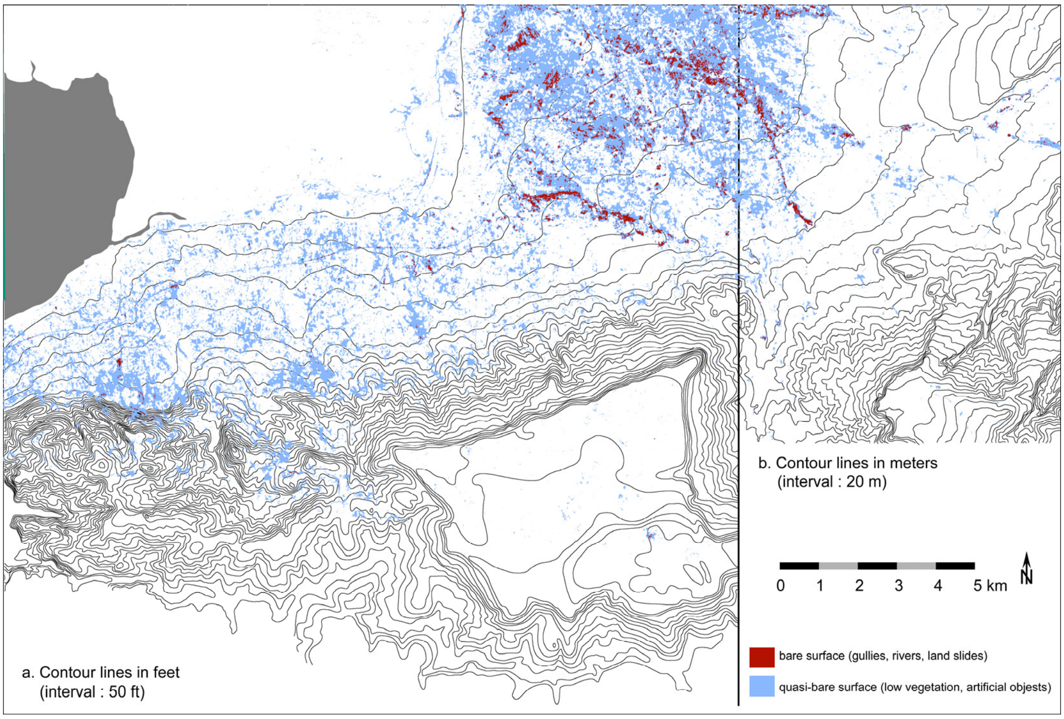

Fig. 6-8. Regional gullying map.

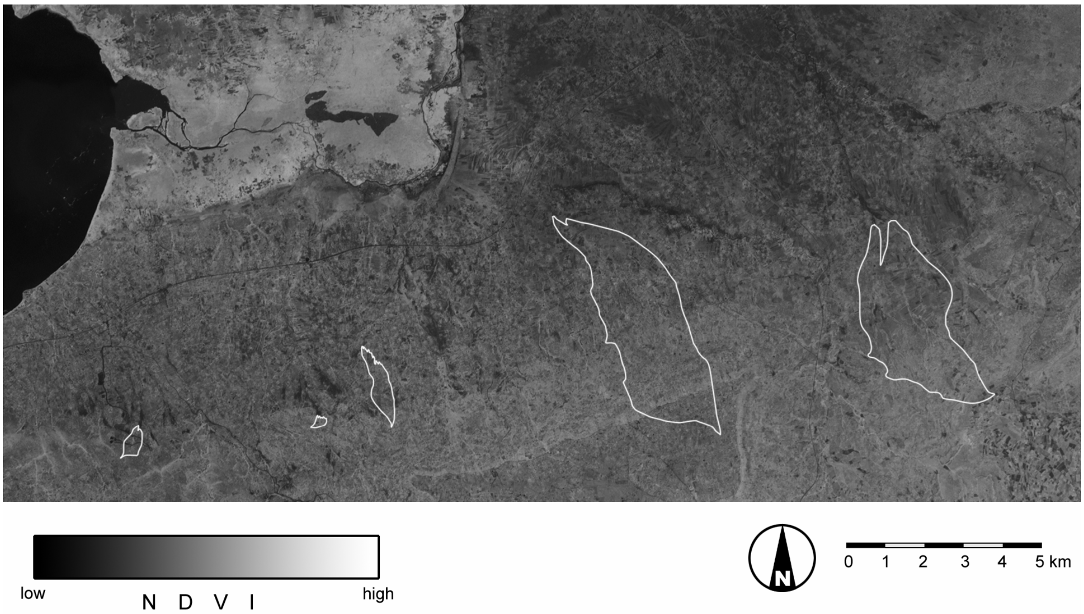

Fig. 6-9. NDVI map along the escarpment. The upslope catchments for each gully system are shown with white outlines.

The regional land cover map, that was generated by supervised classification of multispectral bands of ASTER VNIR images taken on 12 December 2003, shows spatial distribution of eroded surfaces. But as for the vegetated lands, only two classes of ‘vegetated land’ and ‘forest’ are not enough to know detailed patterns inside the upslope catchments of the gullies. Therefore, we introduced NDVI for upslope catchments because most of all pixels in the catchments contain vegetation.

As for the Advanced Very High Resolution Radiometer (AVHRR) band range that overlaps with ASTER VNIR bands, Purevdorj et al. (1998) showed that the NDVI and the transformed soil-adjusted vegetation index (TSAVI) most accurately estimated vegetative cover for grasslands from in situ spectral reflectance data in Japan and Mongolia. We applied the NDVI map generated from ASTER VNIR images to the study site.

NDVI values were calculated from bands 2 and 3 of ASTER VNIR images scanned on 12 December 2003, the same scene as the images used for supervised classification to obtain the regional land cover map. Catchment outlines for 5 gullied locations were superimposed on the NDVI map, and pixels inside the catchment watersheds were carefully clipped out (Fig. 6-9). NDVI map of the escarpment, which covers all of the gully upslope catchments, were classified into four classes by clustering. These four classes are considered as representatives for vegetation types. Therefore, expediential names of land cover types were given for each class —nonvegetative, croplands, shrubs and forests. The land cover maps of the upslope catchments were developed through the classification (Fig. 6-10).

Overlay analysis, one of the spatial GIS operations, integrates spatial data with map feature attribute to infer a principle or behaviour. For the same purpose as overlay analysis, the NDVI pixels were set as basic grids and slopes and geologies were layered on the pixels in order to relate topographical and geological properties to the land cover classification. Regional gullying map (Fig. 6-8) is also compared to the result of the analysis to generate hazard warning map as described in the next chapter.

6.2 . Results

6.2.1. Distribution of Gully Erosion

Regional land cover map, which was obtained by supervised classification of remotely sensed multispectral image, clearly shows unvegetated land surfaces (Fig. 6-7) but there are several exceptional pixels where vegetation grows in gully beds and unvegetated surfaces appear on croplands/bushes for example. These exceptional pixels were deleted as non-gullies by checking disputable pixels comparing with aerial photographs, and then we obtained gully distribution map of Kendu escarpment as shown in Fig. 6-8.

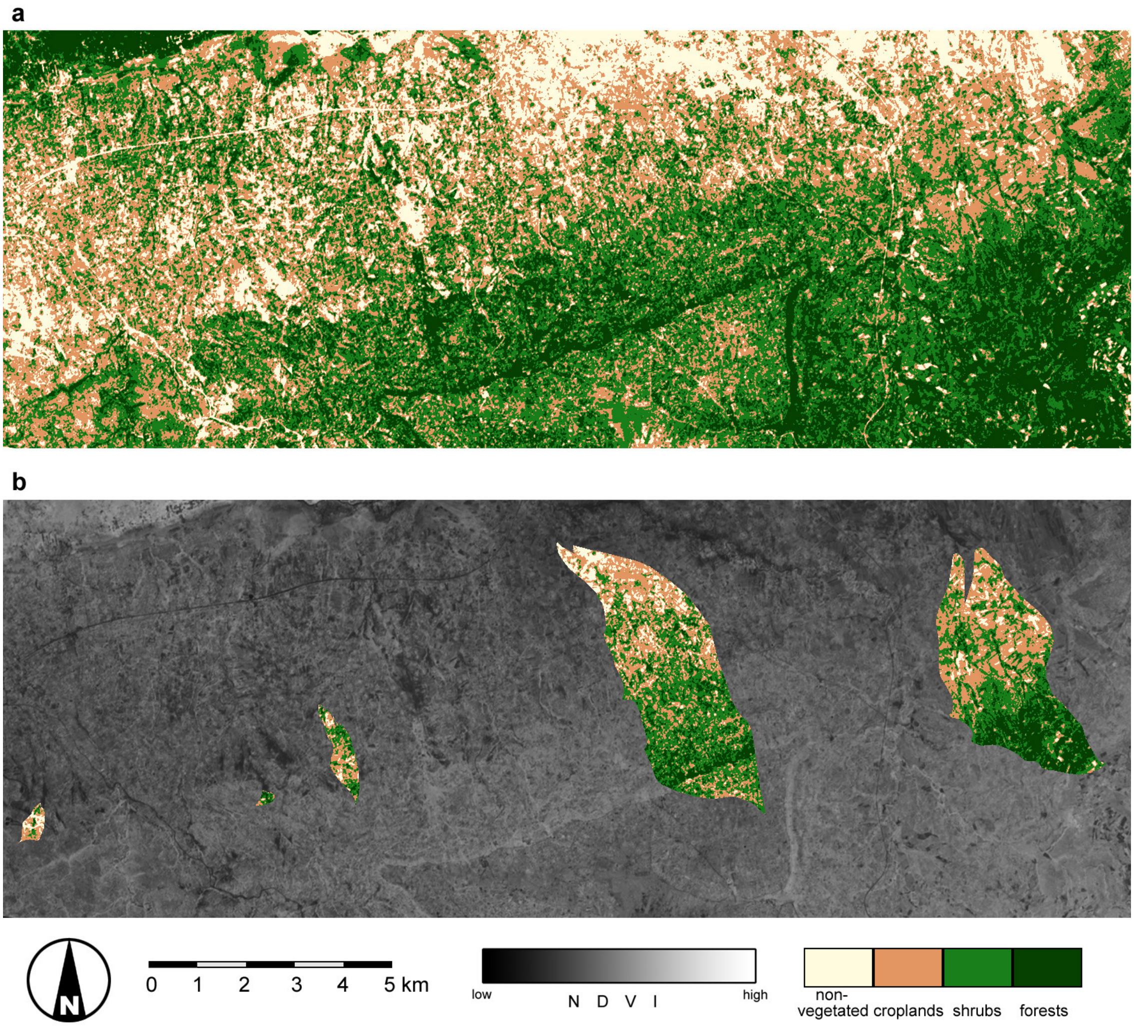

Fig. 6-10. Vegetation cover classification map obtained from clustering of NDVI data (a), and vegetation cover classes for 5 gully catchments. Four classes of vegetation coverage were defined as “forests”, “shrubs”, “croplands” and “nonvegetated” from dense vegetation.

6.2.2. Gullying Patterns

As we described in Chapter II, gullies were classified to two types from their patterns. Gullies in Awach-Kano and Paponditi study sites are characterized by comparatively deep single channel, perpendicular banks and distinct headcuts probably formed by streamflow and mass wasting, and they were classified as Awach type. Gullies in Ragen and Sondu-Miriu are characterized by their braided shallow channel beds, and they were classified as Sondu type. As an additional characteristics, plenty of earth pillars were observed in the field. The gullying pattern of the upstream part in Nyalunya study site was Sondu type, and downstream was Awach type (see plates II-1, II-2, II-3, II-4 and II-5 for typical Awach typed gullies, and plates II-11, II-12 and II-13 for Sondu typed).

Gullying patterns of the 5 locations were depicted as a result of interpretation of aerial photographs and field measurement (Figs. 3-2 and 3-3). Interpretation of the aerial photographs is to extract edges of gully head and sidewalls by viewing stereopairs. Although aerial photographs were not stereomatched, it is possible to introduce the gullying patterns into GIS by georeference operation because the GPS-based absolute positions of several points were recorded in the field. Characteristics of the gullying patterns are summarized in Table 6-1.

6.2.3. Upslope Catchment Areas

The upslope catchments of the 5 gullied locations were defined from DEMs and the topographical maps. The dividing ridges of the upslope catchment were depicted by interpreting the topographical map contours, and the flat parts which were hard to determine watersheds were depicted from DEMs (Fig. 6-4).

Slope gradient was calculated for each catchments from TIN. However, accuracy of representation of ridges is not reliable for slope calculations, because the TIN modelling truncate ridges as described in the section 6.1.1. To avoid the problems, angles of triangular shapes along the ridges were ignored and were replaced with surrounding gradients derived from TIN-based slope surfaces. Slope gradient was classified as zones of gentle, moderate and steep slopes, as shown in Fig. 6-11. Gentle slopes have a range of approximately 0–6°, and moderate and steep slopes have ranges of approximately 6–30° and >30°, respectively. Areas of these classified slopes (gentle, moderate and steep) were measured (Table 6-2).

NDVI values range between -1 and 1, but the values obtained by NDVI calculation for this escarpment zone from the ASTER VNIR data range between -0.07 and 0.83. The map of these classified land covers and data are shown in Fig. 6-10 and Table 6-3, respectively.

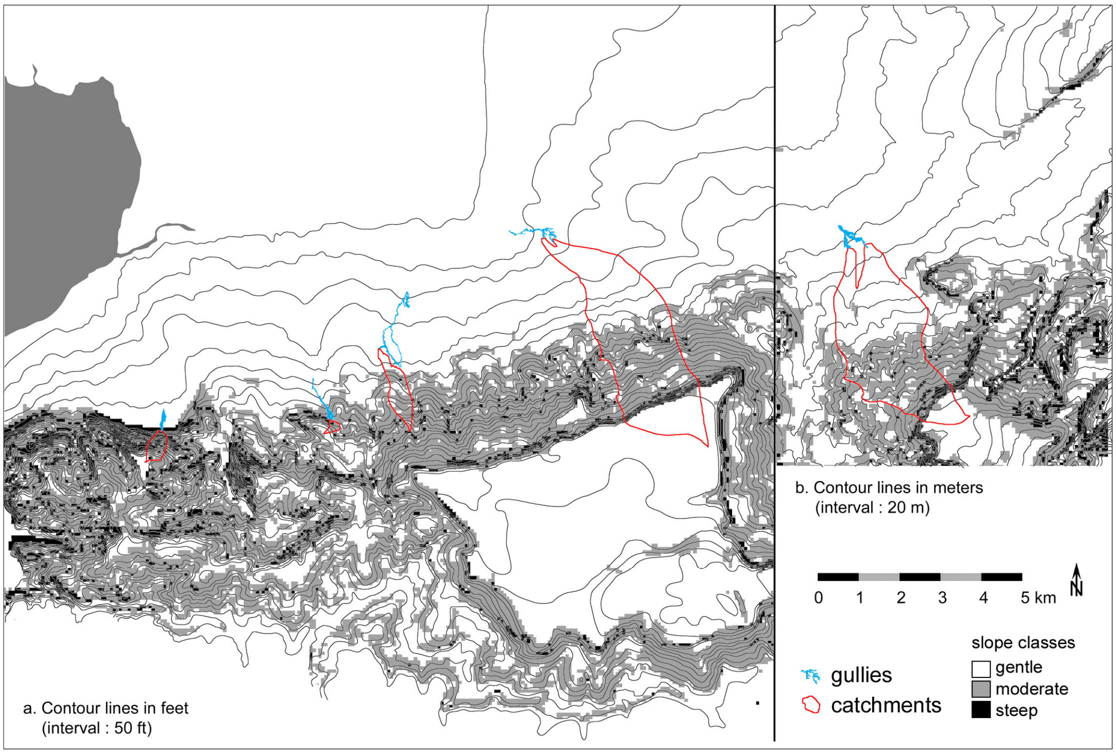

Fig. 6-11. Slope gradient of the study area.

Table 6-1. Characteristics of gullies.

	Sondu-Miriu	Ragen	Nyalunya	Paponditi	Awach-Kano
gullying type*	Sondu	Sondu	Sondu/Awach	Awach	Awach
headcut retreat	not active	not active	active (down)	active	very active
			not active (upper)		
soils	lateritic	lateritic	lateritic/alluvium	alluvium	alluvium
depth (m)	2 – 4	2 – 5	4 – 8	5 – 10	2 – 14

* Gullying type as described in Chapter II.

Table 6-2. Geomorphic information of catchments.

		Sondu-Miriu	Ragen	Nyalunya	Paponditi	Awach-Kano
	catchment area (ha)	30.3	8.3	75.2	954.5	884.4
	relative height (m)	260	30	160	350	380
slope	gentle	12.2 %	9.2 %	37.8 %	56.2 %	58.1 %
	moderate	38.2 %	78.5 %	61.1 %	39.2 %	38.7 %
	steep	49.6 %	12.3 %	1.1 %	4.6 %	3.2 %

Table 6-3. Land-cover dataset.

	Sondu-Miriu		Ragen		Nyalunya		Paponditi		Awach-Kano	
non-vegetated	11.1ha	37%	0.2ha	2%	6.6ha	9%	70.2ha	7%	31ha	4%
croplands	15.1ha	49%	1.8ha	22%	27.2ha	36%	324.5ha	34%	264.6ha	30%
shrubs	3.7ha	12%	4.2ha	51%	34.7ha	46%	456.7ha	48%	330.6ha	37%
forests	0.5ha	2%	2.1ha	25%	6.7ha	9%	103.2ha	11%	258.2ha	29%

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VII. CONCLUDING REMARKS

Field investigations and image analyses have been carried out from geological, geographical, hydrological, ecological and agricultural approaches as we described in the previous chapters. Our study aims at understanding of the gullying situations and proposing ideas of assessment for conservation. Gully erosion in the study area varies in its physiognomy such as eroding patterns and head cut retreat rate. These characteristics are the result of complex combinations of eroding forces like overland flow concentration and suspended load density, and lithological properties like porosity and cementing substances. These factors are also controlled by upslope catchment areas, vegetational coverage, land uses, precipitation and geological backgrounds. Our descriptive classification of gullies to Sondu and Awach types are based on their physiognomical characteristics but the results of sediment hardness tests and microscopy follow this classification.

In order to evaluate the erodibility of the land and to predict gully expansion, it is necessary to focus not only on the lands to be eroded but on the eroding factors from upslope catchments. We achieved assessment-suggestion map on the basis of the necessity considering the former to be as 'eroding zone' and the latter as 'contributing zone'.

7.1. Eroding Zone

According to the head cut retreat of the Awach-typed gullies, the most active gully head is treated as mainly formed by mass movements in conjunction with water flow (overland and subsurface flows). Poor-vegetated lands of unconsolidated sediments are very vulnerable to mass movement and causes Awach-typed gully erosion. This means that the soil hardness, geology and the land cover classes can be considered as mass movement-sensitive factors among the information we have collected —active gully erosion sensitivity in the eroding zone by combination of these factors. One of the best ways for visual detection of the erodibility is multi spectral display in RGB colours. The vulnerability map as tone gradation in alluvium towards the Lake Victoria was produced regarding the hardness distribution as gradation of the vulnerability. Blending this vulnerability map as Red with toned land cover classes as Green, erosion sensitive surfaces are displayed as Yellow (Fig. 7-1).

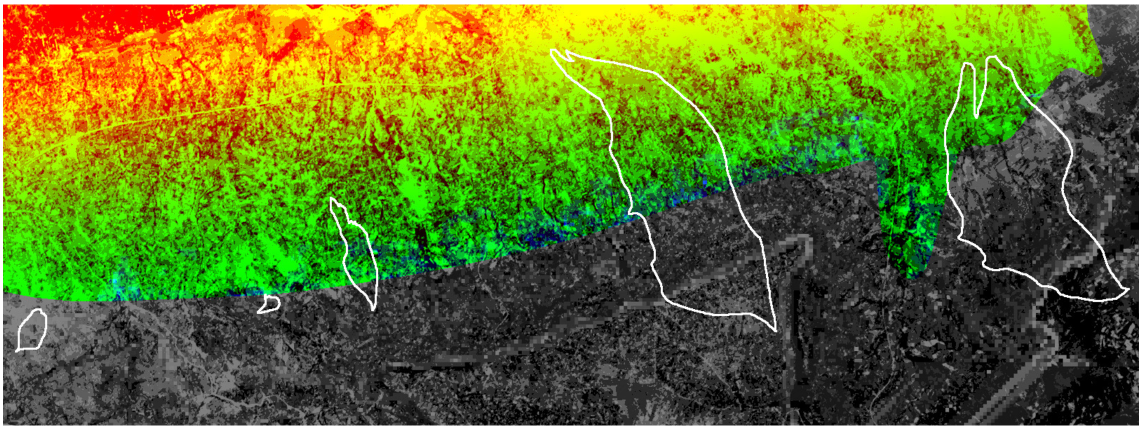

Fig. 7-1. Erosion sensitivity of the eroding zone along Kendu escarpment. Tonal soil vulnerability as Red channel and tonal land cover classes as Green channel were blended and highly erosion-sensitive surface is highlighted in Yellow.

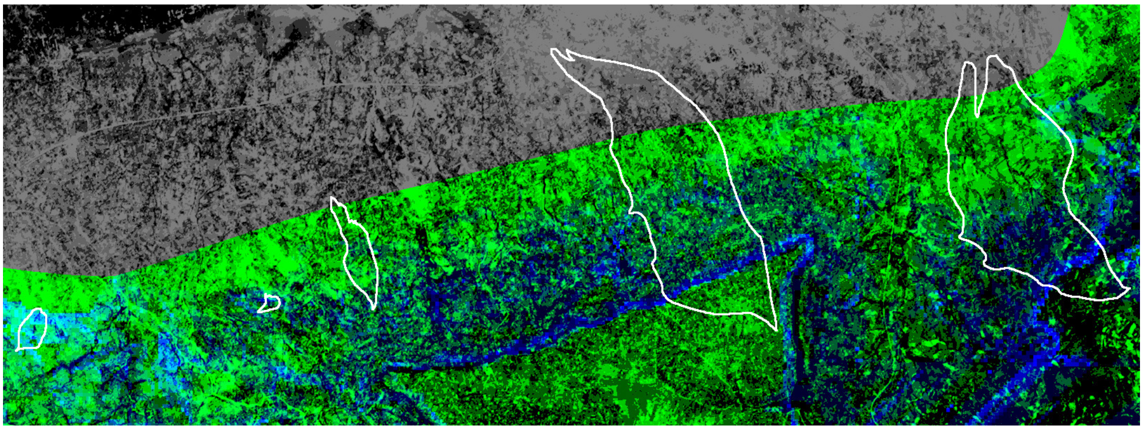

Fig. 7-2. Mass wasting/debris sensitivity of the contributing zone along Kendu escarpment. Tonal slope gradient as Blue channel and tonal land cover classes as Green channel were blended and highly mass wasting/debris-sensitive surface is highlighted in Cyan.

7.2. Contributing Zone

Rapid runoff occurrence in upslope catchment area may cause overland flow and bare soil surface causes suspended runoff which has more eroding energy. Excess runoff occurs on land surfaces of low permeability like bare rock surfaces or thin sediments on basement rocks. Together with the overland flow caused by runoff, not to mention of debris but even sands and pebbles in the flow can be strong eroding forces. These debris and sand-and-pebble suspended flow can occur on steep condition. Therefore, slope gradient and land cover classes can be eroding factors for contributing zone. Blending slope gradient map as Blue and land cover classes as Green just as the eroding zone, sensitivity spots are highlighted in brighter Cyan (Fig. 7-2).

7.3. Perspectives

As shown above, erosion-sensitive points and mass wasting/debris-sensitive points are highlighted in multi spectral display of overlay analysis of geo-referenced information. Combining the two assessment zones, this RGB multi-spectral expression can be an overview of the types of sensitivity to erosion in whole catchments (Fig. 7-3). Overview assessment of the both eroding and contributing zones in one gully catchment has advantages in rousing consciousness about the erosion risks and building effective countermeasures because of its graphically-oriented representation. However, there remain some problems to be overcome in order to obtain highly accurate assessment and/or prediction of gully erosion.

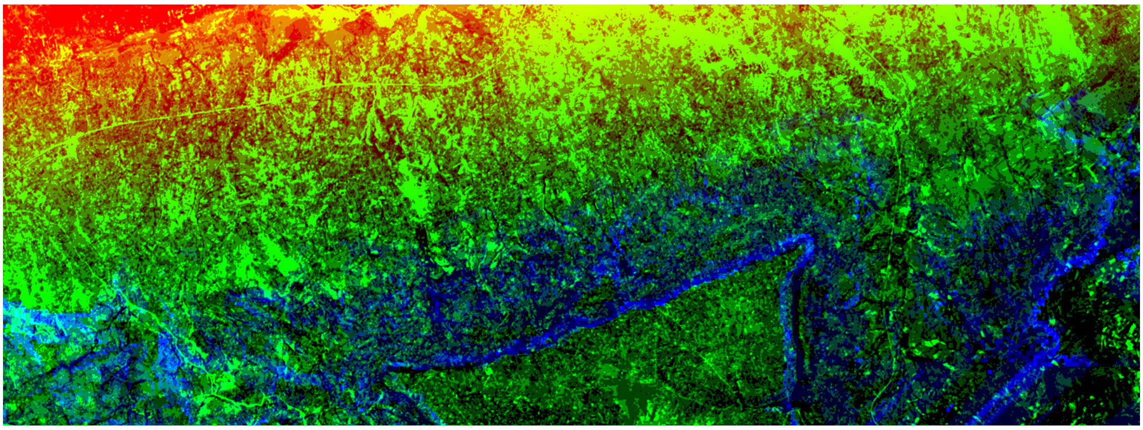

Fig. 7-3. Total erosion sensitivity assessment as an example of hazard warning map. Figures 7-1 and 7-2 were combined.

Land use was not fully reflected in this study because of the lack of geo-referenced data such as orthophotos or GIS shape files in spite that the background had been investigated and discussed in Chapter V. Land use classification should also be considered as a source of runoff and/or flow suspension. In order to specialize in land use classification for erosion assessment, long term monitoring is needed. Not only from agricultural aspect such as crop classification, infrastructure such as road network should be considered. Drainage of the surface flow on low-gradient flat topography is controlled by road or footpath network, and to make matters worse, most of the roads located on the upslope catchments of the gullies studied here are not tarmacked. Bare land surfaces like untarmacked road are suspension-producing factors. Since it is common that untarmacked road becomes muddy and forms channels in rainy seasons in Kenyan highlands, taking untarmacked road network into consideration merits further accurate assessment of the contributing zones. But this fact indicates the necessity of combination of bare surface network with micro-topography for drainage simulation. Without mentioning, high-resolution DEM is needed for micro-topography detection. The result of the soil hardness testing represents, although the data is not enough for discussion, that soil vulnerability marked by soil hardness may control the gullying types and is need to be mapped as a data layer for the erodibility assessment downslope. For identification of detailed sediment properties, geological discussion such as diagenetic variations and geochronology should be included.

On the basis of these positive and negative perspectives, we suggest following subjects to be considered by strategy planners for appropriate gully erosion assessment and land conservation.

- Assessment as catchment scale for each gully system
- High resolution DEM that is open to public
- Further geological survey focused on sediment properties
- Planting and damming strategies based on our assessment

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Plate II-1. Photograph of an upstream (c. 3 m in depth) of the Awach-Kano gully (A) in Fig 3-4. (July 2003)

Plate II-2. Photograph of an upstream (c. 5 m in depth) of the Awach-Kano gully (D) in Fig 3-4. (August 2004)

Plate II-3. Photograph of a gully head (below) at the Awach-Kano gully (D) in Fig.3-4. (August 2005)

Plate II-4. Photograph of a deep channel (10-15 m in depth) of the Awach-Kano gully. (August 2005)

Plate II-5. Photograph of a perpendicular bank (c.14 m in height) of the Awach-Kano gully. (July 2003)

Plate II-6. Photograph of an upstream (c. 8 m in depth) of the Paponditi gully. (August 2005)

Plate II-7. Photograph of an upstream part of the Nyalunya gully (5-8 m in depth), a panoramic view. (September 2004)

Plate II-8. Photograph of an upstream part of the Nyalunya gully. A broken line indicates unconformity between the Archaean granitoid (left) and the alluvium (right). The sidewall is 4 m high. (August 2005)

Plate II-9. Photograph of a downstream part of the Nyalunya gully. (August 2005)

Plate II-10. Photograph of the Ragen gully (2-5 m in depth), a panoramic view. (August 2005)

Plate II-11. Photograph of the Sondu-Miriu gully (3-6 m in depth), a panoramic view. (July 2005)

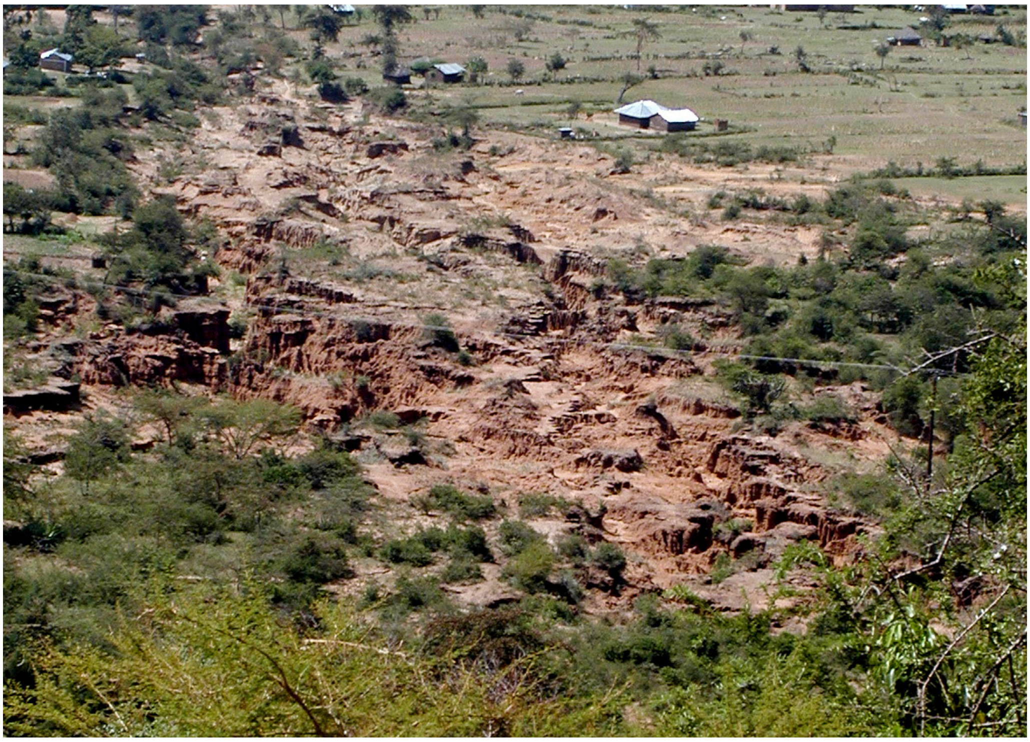

Plate II-12. Photograph of the Sondu-Miriu gully, an overhead view from the escarpment. (August 2004)

Plate II-13. Photograph of earth pillars (c. 3 m in height), the Sondu-Miriu gully. (July 2003)

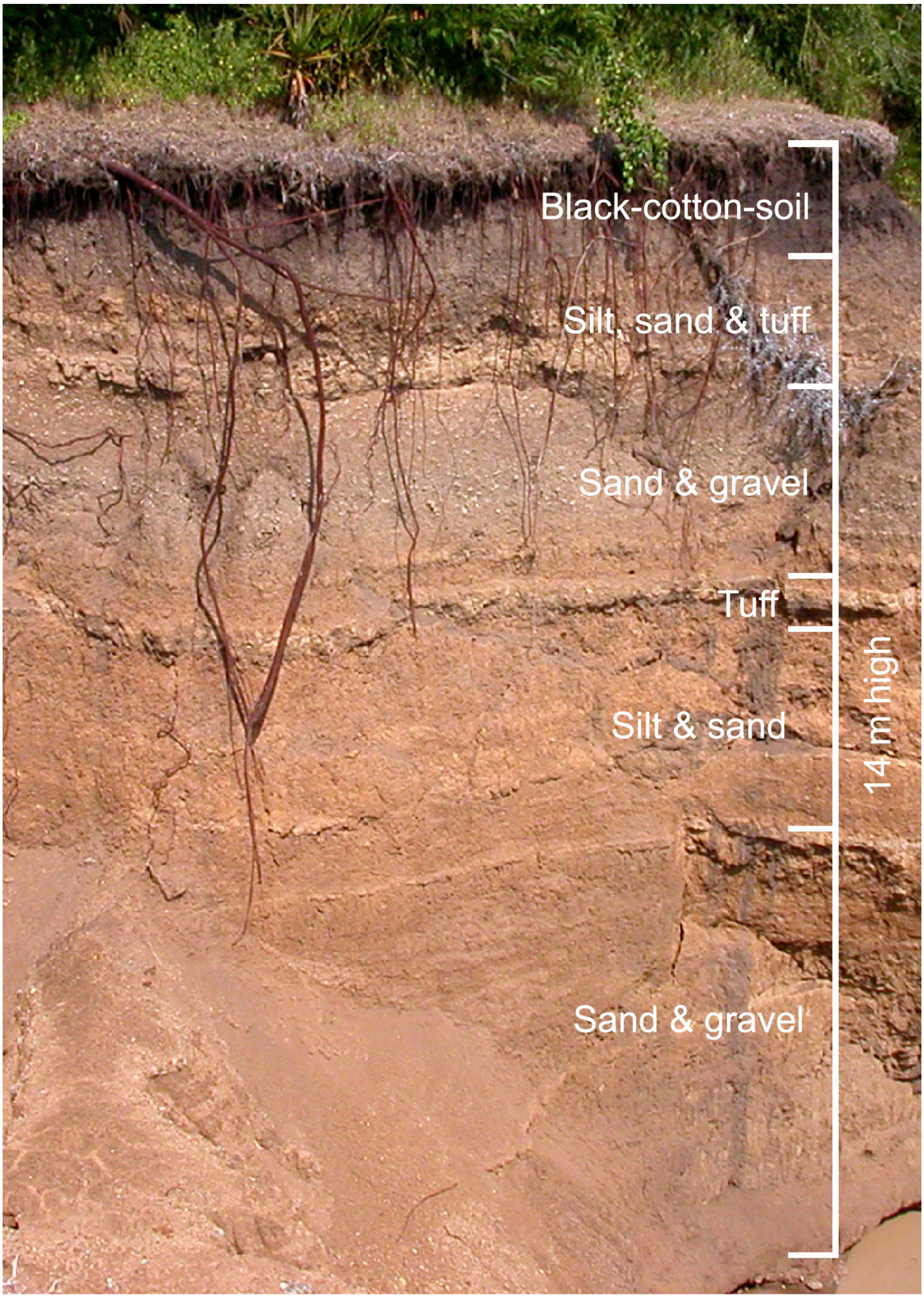

Plate II-14. Photograph of a typical stratigraphic section observed in the Awach-Kano gully sidewall. The height of this sidewall is approximately 14 m. (July 2003)

Plate IV-1. A newly installed rain gauge in the schoolyard, Kericho.
(August 2003)

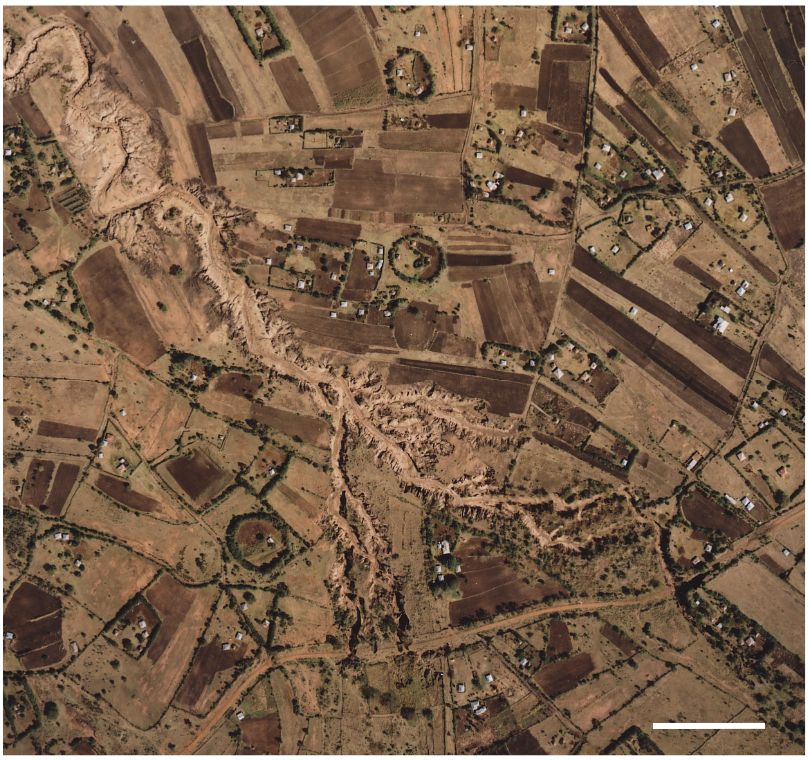

Plate VI-1. Aerial photograph of the Awach-Kano study area.
(Scale bar: 100 m)

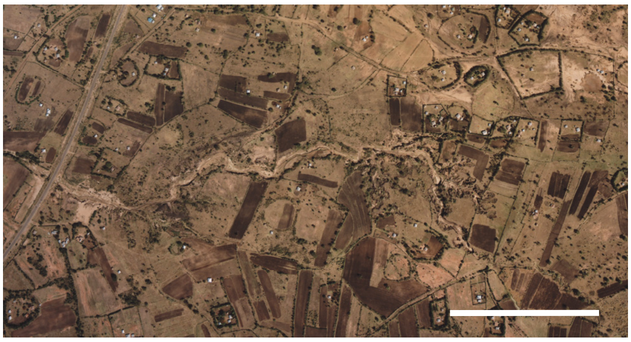

Plate VI-2. Aerial photograph of the Paponditi study area. (Scale bar: 500 m)

Plate VI-3. Aerial photograph of the Nyalunya study area. (Scale bar: 200 m)

Plate VI-4. Aerial photograph of the Ragen study area. (Scale bar: 200 m)

Plate VI-5. Aerial photograph of the Sondu-Miriu study area.
(Scale bar: 200 m)