Analysis of the Sediment Production Characteristics by the Satellite Image - Case Study in Tanzania -

Hiroshi OGAWA(1), Hiroyuki KATHURO(1),
Yoshihiro MOTOKI(1),Kiyotaka ONO(2)
Kazuo ISONO(2), Masahiro YAMAGUCHI(3) , Eisuke TACHIBANA(3)

(1) Nippon Koei Corporation, Japan, E-mail:a4257@n-koei.co.jp
(2) Remote Sensing Technology Center, Japan,
(3) Japan International Cooperation Agency, Japan

Abstract

The satellite image analysis is thought to be the effective measure for the topographical analysis in the area which cannot use the aerial photograph because of various conditions. This poster session is the case study for the sediment production analysis by satellite analysis and field investigation.

The Central Railway Line in the United Republic of Tanzania which main transportation in Tanzania has been repeatedly damaged by floods and the sediment discharge. Railway passes wide basins that belong to Great Rift Valley (eastern part). The flood-prone area is in this basin. The target area (approximately 6600km^2) is located in this basin. This area belongs to the savanna climate region which has the wet season and dry one. As for the geological feature, rock consists of Paleoproterozoic. Gabbro covers gneiss and metamorphic rock as bedrock widely. After the 1970s, cultivation campaign was launched in Tanzania for the production of food. Therefore, the cultivated lands expanded on the upper pediments. The result was increased surface erosion in the area. Furthermore, overgrazing assisted this condition.

This time, we tried to use the satellite optical image (Rapid-Eye, SPOT) for the analysis of the sediment production. The land cover could be classified into five colors which show the difference of the sediment production. Furthermore, we made the topographical and the slope classification maps using ALOS with DEM data. In addition, we could confirm the river channel changes using the Synthetic Aperture Radar (SAR) image. We could get the sediment producing characteristics effectively of the target area by a series of satellite image analysis. We are confirmed that the satellite image analysis is the effective on vast area without enough surface data.

Keywords: Satellite image analysis, Sediment production, Optical satellite image, SAR, River channel change

1. Introduction

The Japan International Cooperation Agency (JICA) has recognized the importance of rehabilitating the Central Railway Line based on the results of the JICA-funded "Comprehensive Transport and Trade System Development Master Plan in Tanzania" (2011–14). The Japanese Government subsequently conducted "The Study on the Central Corridor Railway Revitalization and Energy Efficiency Project" (2013–14), which identified that the flood prone area between Kilosa and Gulwe could be the biggest bottleneck of the entire Central Railway Line, and thus recommended that flood protection measures be a candidate for Japanese assistance.

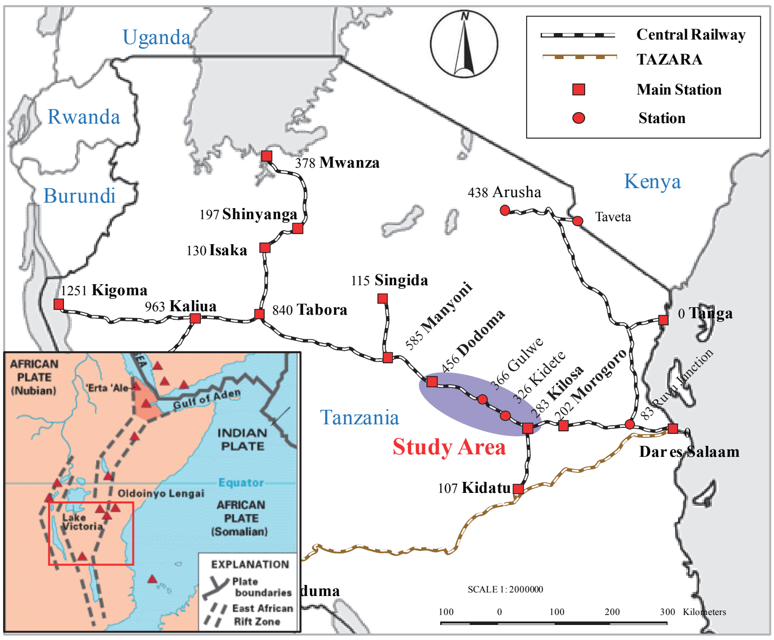


Fig.1.1. Study Area and railway

2. Field characteristic

2.1. Topography

The watershed spreads out from the southeast to the northwest direction. Mountains over 2,000 m above sea level are distributed throughout the watershed. However, aside from this, most of this watershed consists of vast plains.

According to Fig.2.3, Dodoma area is covered by a group of Cambisols. On the other hand, Mpwapwa, Kongwa, and the other areas are almost covered by Luvisols (as per the classification system of the Food and Agriculture Organization, or FAO). Cambisols and Luvisols are suitable soils for agriculture.

The topography of Tanzania is governed by the formation of the Rift Valley and the processes of the formation of topography. The formation of mountains is closely associated with the activity of magma, as previously mentioned. Next, the process of topographical change is associated with weathering and erosion.

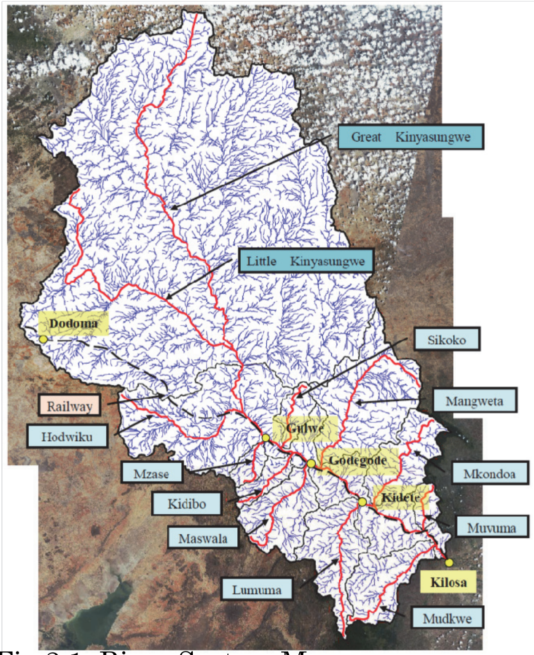


Fig.2.1. River System Map

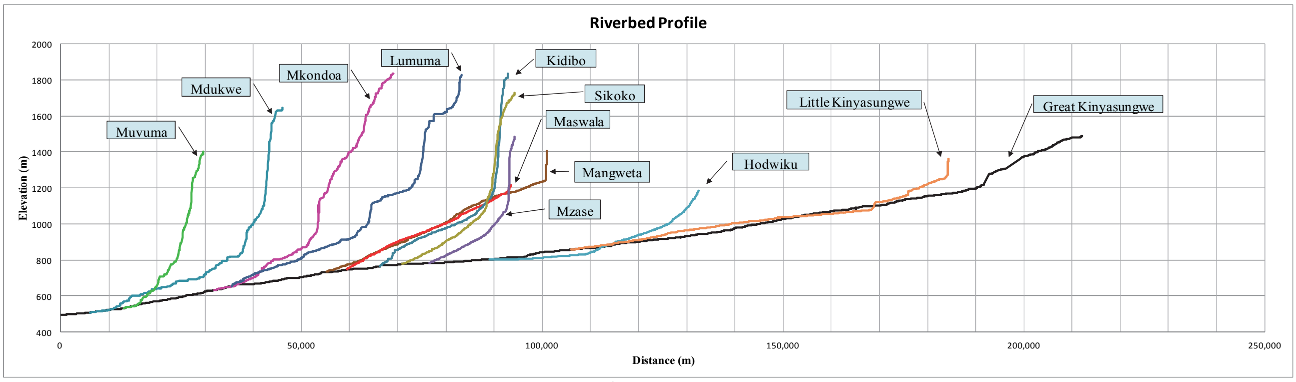


Fig.2.2. Riverbed Profile in the Target Area

The process of topographical change is divided into three stages.

i) Young age
The original topography

ii) Mature age
The mountain is formed, and erosion is actively taking place.

iii) Old age
Peneplain spreads, monadnocks are seen in places

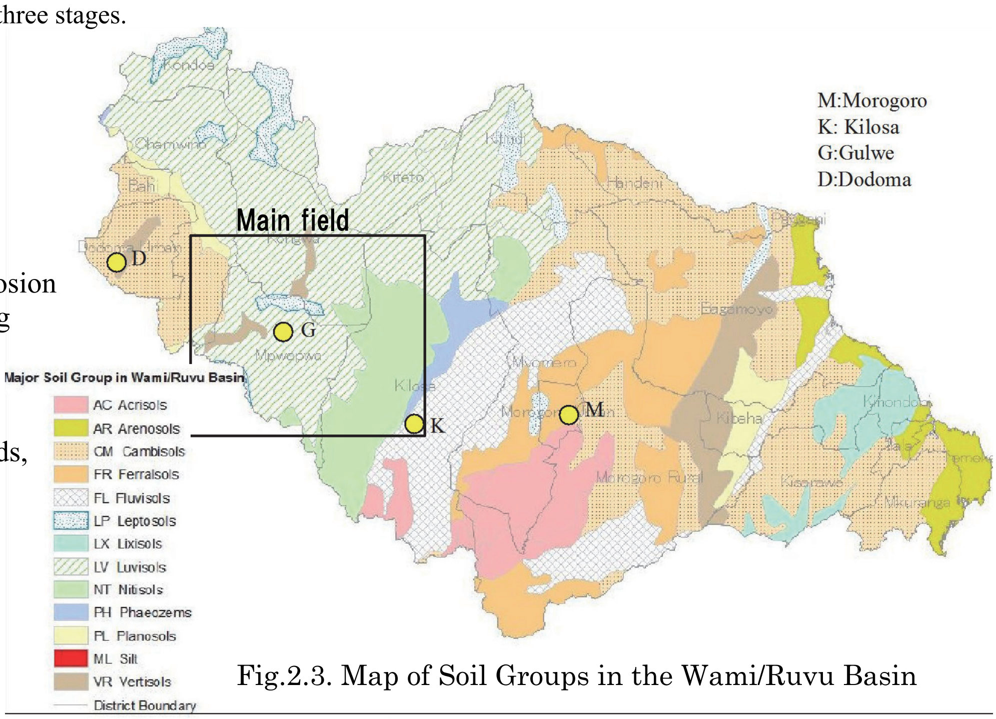


Fig.2.3. Map of Soil Groups in the Wami/Ruvu Basin

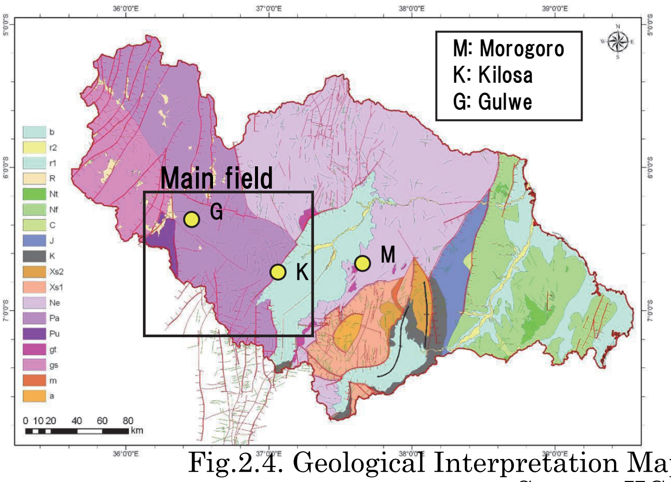
Source: JICA Wami/Ruvu Basin Study, 2013

2.2 Geology

Tanzania is underlain mainly by Archaean and Proterozoic rocks, mostly exhibiting ages of greater than two billion years (>2,000 Ma; 10^6 years). The Archaean rocks date from 2,500 Ma to 2,800 Ma and form the Tanzania Craton, a component of the African Plate, one of the world's largest slabs of continental crust.

The geological interpretation map is shown in Fig2.4. According to this map, as for the watershed on the upstream side of Kilosa,

Meta-igneous and sedimentary (Pa), Meta-sediments, orthogneiss, granulite (Pu), Migmatite, and granite (gs) are distributed.



Age		Name		Lithology	Remarks
Cenozoic	Quaternary	N	b	Beach sand, dune	
			r	Alluvial deposits(r2), Fluvial deposits(r1)	
		R		Lacustrine sediments	
	Tertiary	Nt		Terrace deposits	
		Nf		Fluvial marine sand	
Meso	Creta.	C		Continental and marine sandstone	
	Jura.	J		Mudstone and shale	Karoo series
Palaeozoic		K		Conglomerate and tillite	Karoo series
Proterozoic	Neo-	Xs	Xs2	Marble	Moozambique Belt (upper nappe)
			Xs1	Granulite, gneiss and migmatite	
		Ne		Composite metamorphic crust domain	Mozambique Belt sandstone
	Palaeo-	Pa		Meta-igneous and sedimentary rocks	Mozambique Belt
		Pu		Meta-sediments, orthogneiss, granulite, etc.	Usagaran belt
Archaean Basement		gt		Migmatite, granite and mafic dykes	Dodoman group
		gs		Migmatite and granite	Isangan group
Int.	Neo-P.	m		Meta-anorthosite complex(interlayered)	Plutonic rocks
		a		Meta-anorthosite complex	Plutonic rocks

Geologic boundarie Clear lineaments (faults) Unclear lineaments Anticlinal axis Synclinal axis

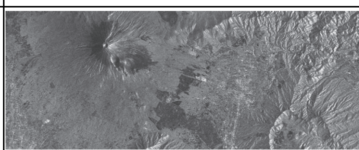
Fig.2.4. Geological Interpretation Map of the Wami/Ruvu Watershed
Source: JICA Wami/Ruvu Basin Study Report 2013

3. Study on Seasonal Changes of surfacelow using Satellite Photographs

3.1 Summary of the satellite analysis

The general characteristics of the satellite photographs are as shown in Fig3.1. Tab.3.1. shows advantage and disadvantage of the optical sensors and the radar. Synthetic Aperture Radar (SAR) has the advantage of being unaffected by weather conditions. Tab3.1. shows the differences in their resulting images.

Tab.3.1. Characteristics of Different Sensors

Sensor	Radar	Optical
Advantage	It can observe both day and night and under bad weather conditions.	It can acquire the images similar to the views from an airplane. Therefore, the results can be easily interpreted.
Disadvantage	The images are not easily interpreted.	It cannot observe under bad weather conditions, or at night, unless strong light sources are given.
Image	 Ortho-rectified (foreshortening) PALSAR imagery, 2006/12/30 (JST)	 Ortho-rectified AVNIR-2 imagery (true color), 2006/12/30 10:15 (JST)

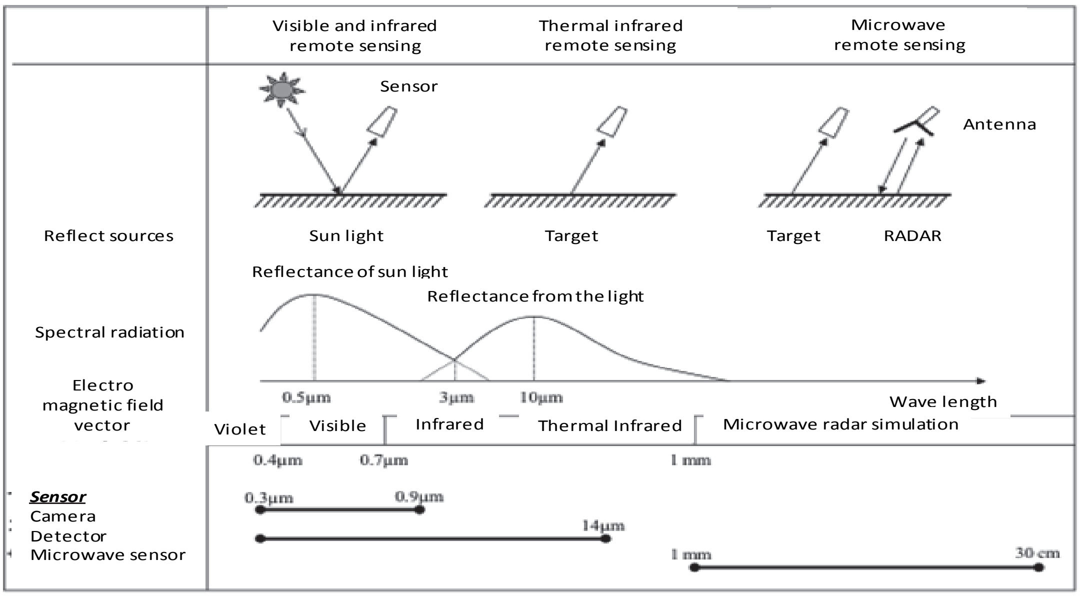


Fig.3.1.. Differences of Sensors

3.2 Land Cover Classification by Satellite Photo Analysis

According to the site investigation, the sediment discharge from the upstream areas of the Gulwe Bridge to the downstream areas is judged as not obvious, except for wash loads. Therefore, the sediment productivity between Kilosa and Gulwe is studied further below:

Generally, the type of land cover will indicate the tendency of sediment discharge (or lack thereof). For example, in forested areas, sediment does not flow out easily, because of the high-vegetation cover.

As previously mentioned, the stage of topography in this area is the old age. Because of this, slope failures are generally not observed in this area. On the other hand, the cultivated land allows sediment to flow out easily, as the ground lacks vegetation and is exposed to the rainfall. The Mzase, Kidibo and Maswala areas, which have expanding cultivated lands and overgrazing, exhibit this situation.

Fig.3.2. shows the optical image of the target area produced by RapidEYE, which was photographed in 2013. The optical image is the same tone as it is visible to the human eye. According to Fig.3.2, a dark tone corresponds to forest zones, a slightly less dark tone exists around the forest, and a reddish-brown tone corresponds to zones where the sediment productivity is high.

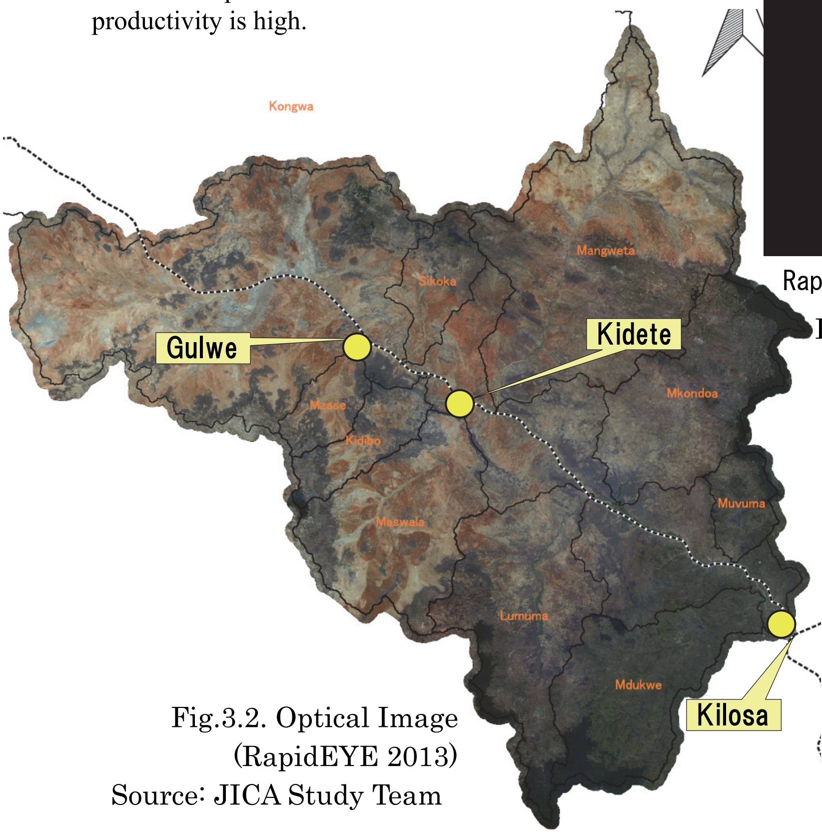
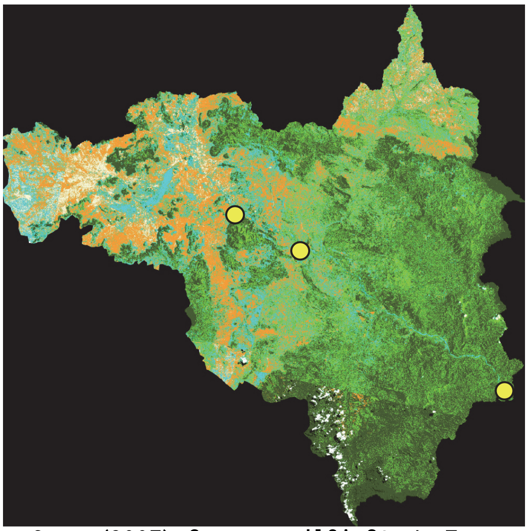
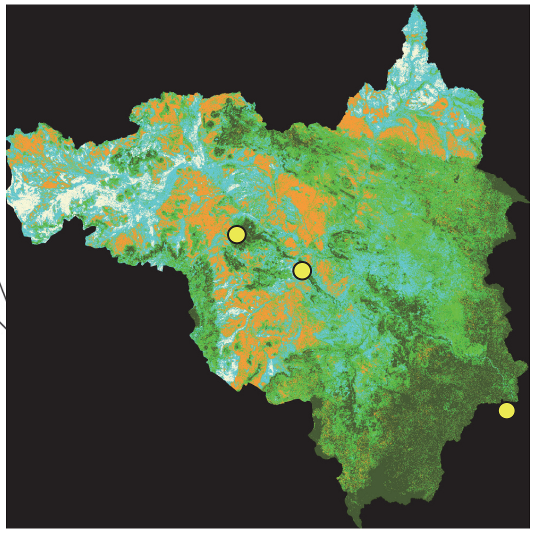


Fig.3.2. Optical Image (RapidEYE 2013)
Source: JICA Study Team

The tone classification of the target area was conducted based on the optical image. As a result, the image was classified into five color tones: Green, Yellow Green, Orange, Light Blue and White (Fig.3.3.).



Spot (2007) Source: JICA Study Team



Rapid-EYE (2013) Source: JICA Study Team

Fig.3.3. Photos by Image Analysis

The Spot image, whose resolution is 10 m, was photographed during 2007 (before the flood of December 2009). The Rapid image, whose resolution is 5 m, was photographed between 2013 and 2014 (after the flood of December 2011).

According to the site survey, areas corresponding to the orange color zone are often seen at the zone where gabbro has been weathered, and areas corresponding to the blue colored zone are often seen in areas in which the metamorphic rocks and gneiss have been weathered.

Considering the field reconnaissance, the color tones of the image are classified as shown in Tab.3.2. Fig.3.4. shows the condition of the typical sites of each color.

Tab.3.2. Tone Classification of the Image

Color	Characteristics of Distribution Area
Green	Dense Forest Area
Yellow Green	Bush or Cultivated Land Area
Orange	Mainly Weathered Lock Area of Mafic Igneous (main land use: Village, Cultivated Land)
Light Blue	Mainly Weathered Lock Area of Metamorphic Rock and Gneiss (main land use: Village, Cultivated Land and Swamp)
White	Mainly Sediment Deposition Area (main land use: Swamp, Cultivated Land)

Source: JICA Study Team

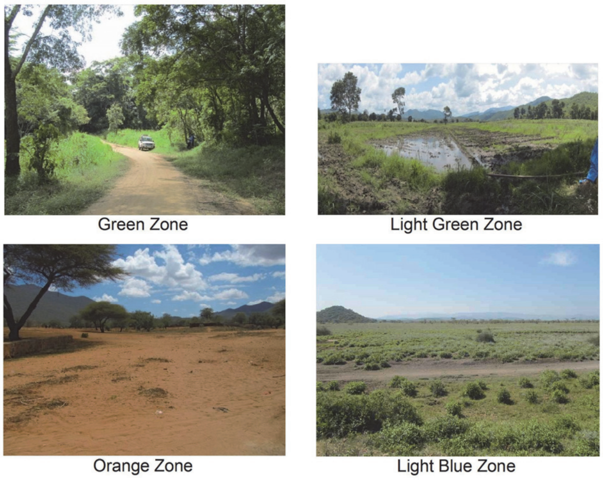


Fig.3.4. Condition of Typical Sites of Colored Areas

3.3 Study of Sediment Yield by Satellite Photo Analysis

(1) Reclassification based on the Characteristics of Land Cover

Orange color zones, in which the sediment productivity is high, are seen also in the forest zone, such as in the Mdkuwe watershed. However, the orange color of the forest zone is presumed to be fundamentally different from the orange color of cultivated land, such as the Maswala watershed. In other words, the sediment productivity of the orange color in the forest zone is judged to be lower than that of the cultivated land. Similarly, the light blue zones in the upstream of Maswala are assumed to be different from the other sites, such as swamp zones. Therefore, considering the characteristics of the sediment productivity based on the field reconnaissance, each color is classified as shown in Tab.3.3.

Tab.3.3. Classification of Tributaries by Sediment Productivity Source: JICA Study Team

category	Sediment Productivity			
	High		Low	
Branch / Classification	Mzase Kidib Maswala Sikoko	Mangweta	Lumuma Mdukwe Mkondoa Muvuma	Mangweta
Green	(all watersheds have low productivity)			
Yellow Green	○		○	○
Orange	○	○	○	
Light Blue	○		○	○
White	○		○	○

(2) Difference of the Productivity by Slope Gradient

The gradients of the slope and riverbed are important factors in sediment transportation ability. Tab.3.4. shows the general sediment movement pattern according to the gradients. According to this figure, the following things can be pointed out.

There are almost no slope failures in mountains of this target area. Therefore, the sediment production area is judged to be the pediment area. The sediment productivity of slopes of less than three degrees is low. The movement of material on these gentle slopes is of a material which is less than that of sand. The material in the sediment production zone of the target area is the same.

On the riverbed, there is bed load transport (as opposed to suspended load, transition).Fig.3.5.shows the distribution of the slopes less than three degrees. According to this figure, the following points can be made:

i) Vast plains are distributed in the Msagali, in the upstream area of Gulwe.

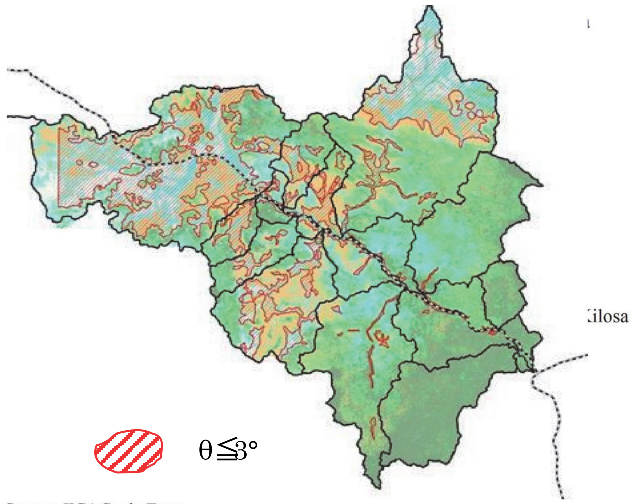
ii) Slopes less than three degrees are distributed in the Mzase, Kidibo, and Maswala.

iii) However, in the mountainous areas between the Kilosa and Kidete, slopes less than three degrees are basically not present.

Tab.3.4. Sediment Movement Form Productivity

Riverbed Gradient	θ<1/300-1/200	θ<2-3deg (1/30-1/20)	θ<5-10deg (1/7-1/6)	15deg(1/4)<=θ
Occurrence area	Plain / Swamp	Pediment	Foot of Mountain	Mountain Slope
Erosion Form	*(River Bank/ Riverbed Erosion)*	Sheet Erosion *(River Bank/ Riverbed Erosion)*	Sheet Erosion *(River Bank/ Riverbed Erosion)*	Landslide /Slope Failure
Zone of Flow /Deposition	Flow / Deposition Zone	Flow / Deposition Zone	Flow / Deposition Zone	Flow Zone
Flow Form in the River	Bed Load Transport *(Bed Load / Suspended Load /Wash Load)*	Bed Load Transport *(Bed Load / Suspended Load /Wash Load)*	Debris Flow	
Riverbed Material* (Except Wash Load)	Sand, Granule, (Pebble) *(Sorting Process)*	Silt, Sand, Granule, Pebble *(Sorting Process)*	Fine material, Sand, Gravel, Cobble, (Boulder) *(Sorting Process)*	Fine material, Sand, Gravel, Cobble, Boulder

*Refer to Riverbed Material Aanlysis



Source: JICA Study Team

Fig.3.5. Distribution of Slopes less than Three Degrees (3°)

(3) Try to calculate of Sediment Yield

Calculation of the sediment yield is calculated as follows:

i) The sediment yield is calculated based on the existing document about dam deposition (refer to Tab3.5.).
ii) However, annual erosion depth should be considered as characteristic of each watershed.
iii) The value based on the data of dam deposition is average. Practically, each value has a wide range, so erosion depth should be considered at about this range.

This erosion depth is included in river erosion.

Tab.3.5. Erosion Depth based on the Existing Document

Dam	Area (km^2)	Erosion Depth ($mm/km^2/y$)
Ikowa	3,807,000	0.17
Matumbulu	333,000	0.58
Msalatu	420,000	0.56
Imagi	169,500	0.60
Kisongo	129,500	0.48

Source: JICA Study Team

Tab.3.6. Annual Erosion Depth

Erosin Depth ($mm/km^2/y$)

Classification	Slope < 3°	Slope >=3°	
		Mzase, Kidibo, Maswala, Sikoko, R3, R4, R5, L4, L5, (Mangweta:Orange A)	**Lumuma, Mdukwe, Mangweta, Mkondoa, Muvuma, R1, R2, L1, L2, L3**
Green	0.001	0.01	0.01
Yellow Green (A)	0.001	0.05	
Yellow Green (B)			0.02
Orange(A)	0.01	0.80	
Orange(B)			0.05
Light Blue (A)	0.01	1.50	
Light Blue (B)			0.05
White	0.01	0.60	0.60

Source: JICA Study Team

The result of image analysis by RapidEYE is total sediment yield from the tributaries to the main river is about 680,000 m^3, and about 910,000 m^3 with the addition of the remaining watershed area. Additionally, the sediment discharge can be divided into upstream downstream areas, with Kidete as a boundary, considering the riverbed slope.

We guess the high value for specific sediment discharge ($m^3/km^2/year$) in the upstream in comparison with the downstream.

4. Conclusion and presence theme

This presentation is a interim report of countermeasure project. In the case of investigation area is wide, it's too difficult for analysis in the limited term of project. This presentation area has different colors by geological basement. In such area, we can classify subarea by optics image analysis. The calculation of Sediment Yield will have much improved. Now, we try to analyze correct volume more proper than this presentation. In the dry land, satellite analysis is effective on Quantitative interpretation of the sediment production characteristics.