7. Sediment Analysis

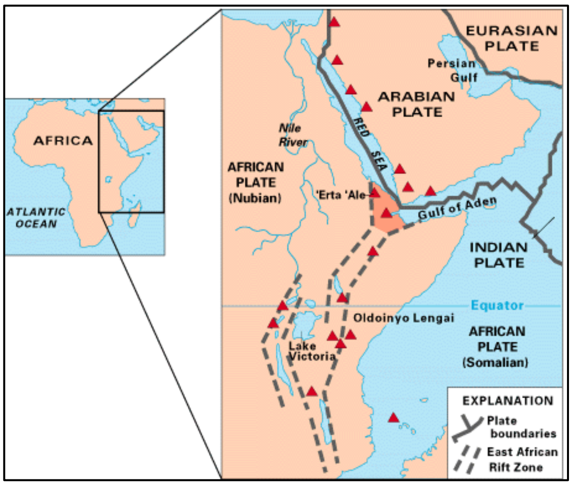
7.1 Natural Conditions

7.1.1 Geology

(1) East African Rift System (EARS)

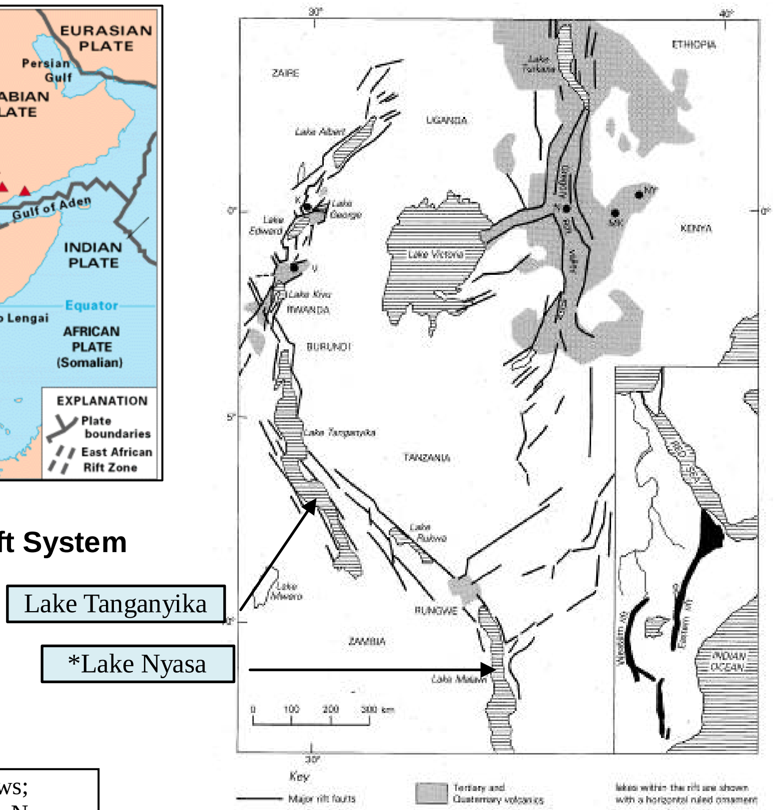
The geological structure of Tanzania is characterized by the Great Rift Valley, of which the African section is known as the East African Rift System (EARS). The East and West Rift Valleys pass across Lake Victoria in the north of Tanzania (Figure 7.1). The East Rift Valley is broken around Lake Turkana in Kenya, which contains an active volcano (Turkana Lake is a crater lake). The East Rift Valley in Tanzania can be clearly recognized on the east side of Lake Victoria, but is less clearly recognized on the south side.

On the other hand, the West Rift Valley can be clearly recognized on the west and south sides of Lake Victoria. Lake Tanganyika and Lake Nyasa are the lakes which are formed in the Rift Valley (Figure 7.2).



Source: USGS

Figure 7.1: East African Rift System

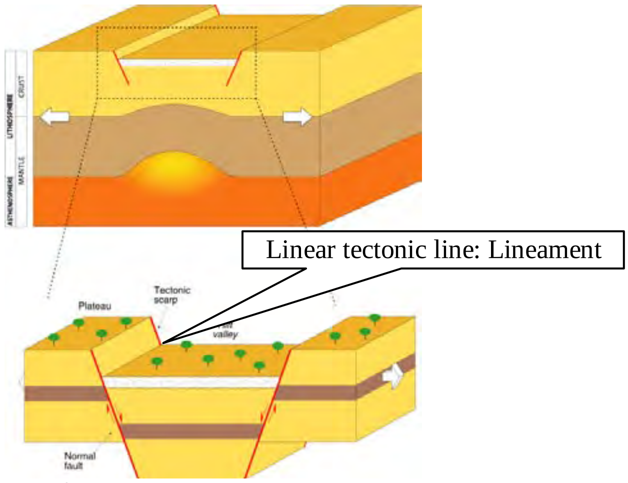


*Lake Nyasa has two names as follows;
In Tanzania and Mozambique: Lake Nyasa
In Malawi: Lake Malawi

Source: JICA Wami/Ruvu Basin Study Report 2013

Figure 7.2: Great Rift Valley in Tanzania

The Rift Valley has enormous fractures affecting the continental plates that progressively widen over elapsed. The process is related to the divergent movements of lithospheric plates above the underlying asthenosphere, in slow convective motion. Figure 7.3 shows schematic diagrams of the Rift Valley development. The Rift Valley represents the primary and most apparent/ manifested response to this divergence and to the consequent application of tensional forces to the plates, which is manifested through the development of normal faults.



Source: Rift Valley Development by Giacomo Corti; http://ethiopianrift.igg.cnr.it/index.htm

Figure 7.3: Formation of the Rift Valley

(2) Geology

A rift valley has been formed by the divergent (eastward and westward) spreading of two plates, the African Plate and Somalian Plate, by rising magma (Figure 7.3 above). According to a JICA report ("The Study on Water Resources Management and Development in Wami/Ruvu Basin in the United Republic of Tanzania" Final Report November 2013, Chapter 9, page 9-10 to page 9-18), the geology of Tanzania and Wami/Ruvu watershed is described as follows:

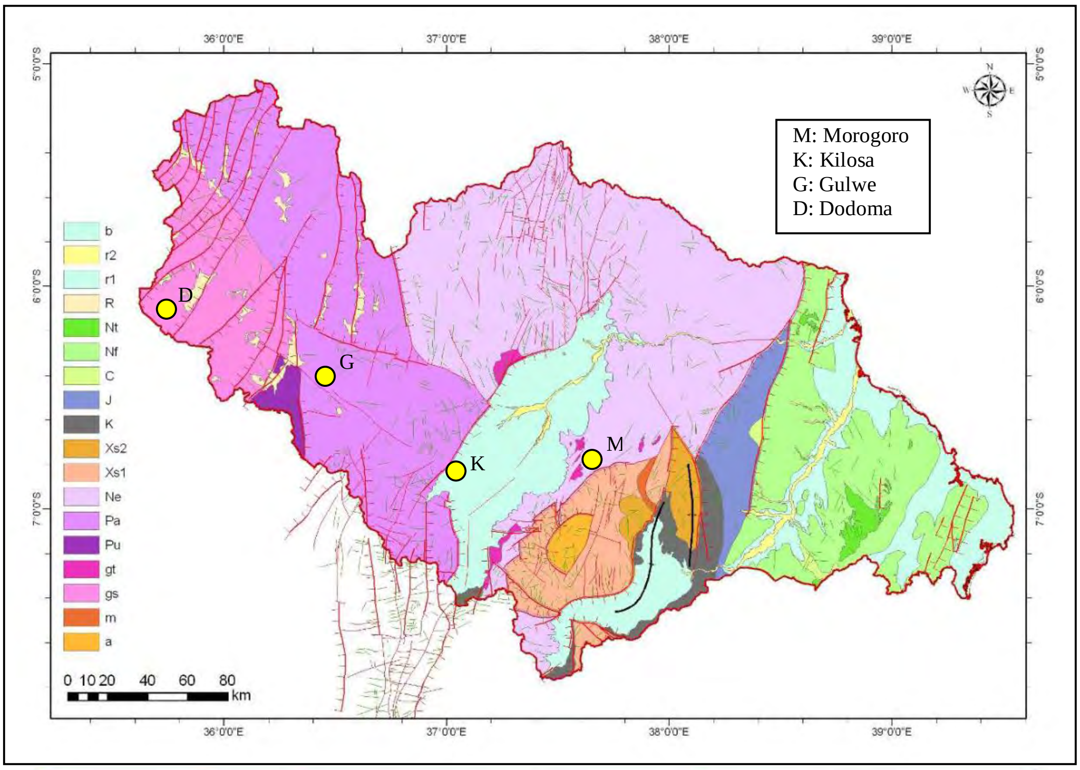
Tanzania is underlain mainly by Archaean and Proterozoic rocks, mostly exhibiting ages of greater than two billion years (>2,000 Ma; 10^6 years). The Archaean rocks date from 2,500 Ma to 2,800 Ma and form the Tanzania Craton, a component of the African Plate, one of the world's largest slabs of continental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

The Archaean of Tanzania can be divided into three units: (i) the Dodoman gneisses of central Tanzania, (ii) the Nyanzian granite-greenstone terrain of the north, and (iii) the overlying Kavirondian system of the Lake Victoria region. The Dodoman is regarded by some as equivalent to the Nyanzian, having been subjected to higher degrees of metamorphism, migmatization and digestion. Dodoman gneisses are distributed only in the western part of the Wami/Ruvu basin.

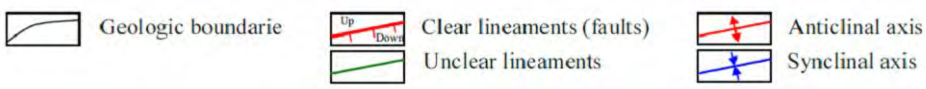
The southeastern part of Tanzania is underlain by the Late Permian to Jurassic Karoo series. This series is prevalent all over southern Africa, reaching its northern-most outcrop in Tanzania. The Upper Mesozoic is represented by limestones, sandstones and shales, with coal, gypsum and salt in the coastal regions, even if in the Wami/Ruvu basin. Cenozoic events saw the incipient dislocation of the African Plate, with rupturing occurring in the West and East African Rift Systems (Figure 7.3).

In Tanzania, the Western Rift is marked by Lakes Nyasa and Tanganyika, while the Eastern, or Gregory Rift, passes through Lake Natron before joining the Western Rift south of Lake Nyasa. Subsidiary rifts are found in the Selous Basin and at Lake Rukwa, where some Karoo rocks are preserved.

The geological interpretation map is shown in Figure 7.4. 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

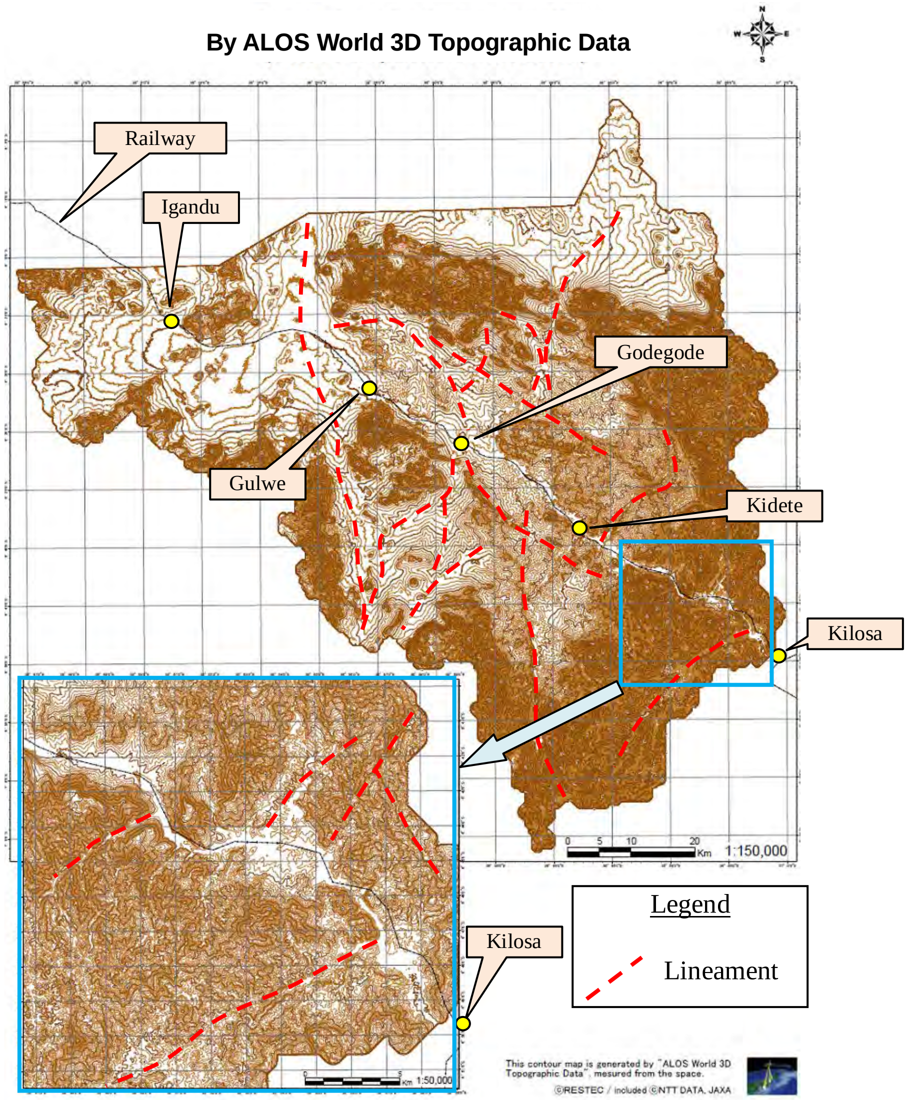


Source: JICA Wami/Ruvu Basin Study Report 2013

Figure 7.4: Geological Interpretation Map of the Wami/Ruvu Watershed

(3) Distribution of Lineament

Generally, a fault is recognized on the ground as a “lineament”, which is a visible linear pattern (refer to Figure 7.3). These lineaments can be observed by remote sensing images or topographical map made from those images. Figure 7.5 is the topographical map made by ALOS (Advanced Land Observing Satellite) showing the main lineaments in the target area. A great deal of lineaments are observed along the Rift Valley. Small lineaments can be observed near the large lineament. In the target area especially, a multitude of small lineaments are distributed throughout.



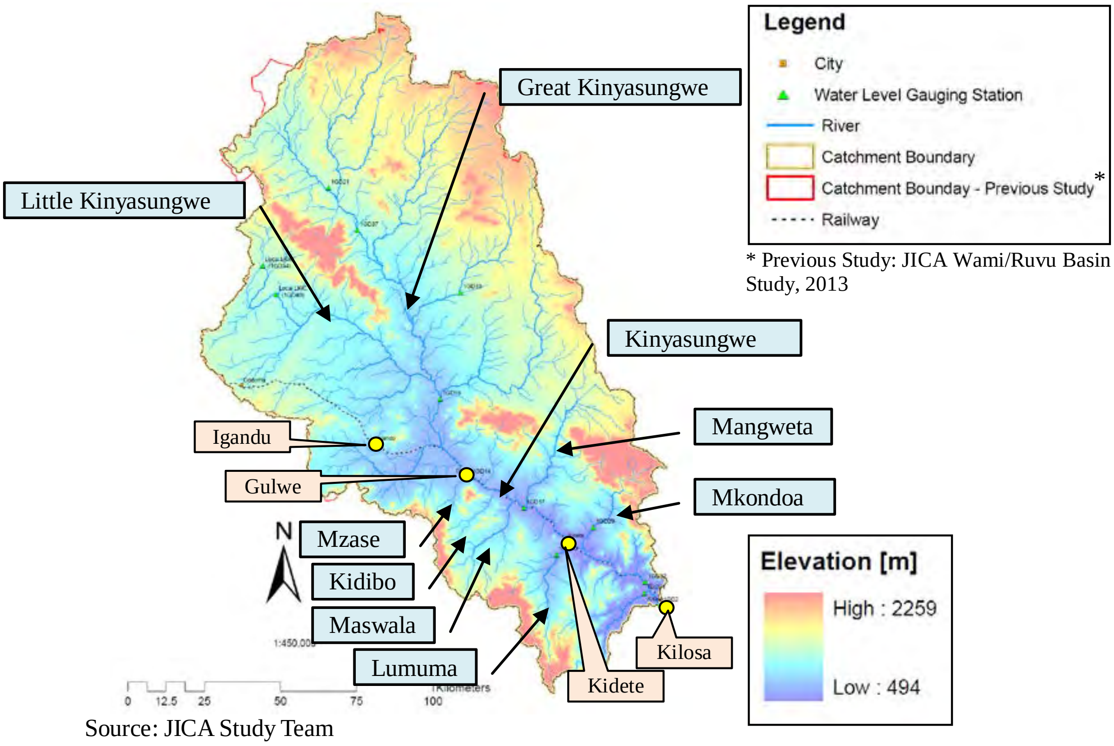
Source: JICA Study Team

Figure 7.5: Distribution of Lineaments in the Target Area

7.1.2 Topography

(1) Outline of General 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 (Figure 7.6). However, aside from this, most of this watershed consists of vast plains.

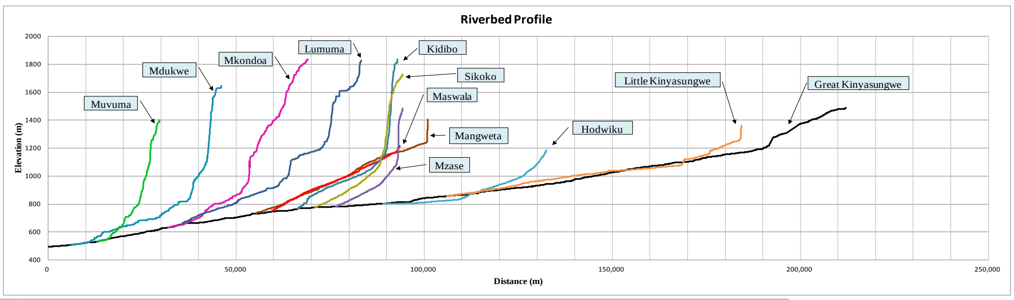


Source: JICA Study Team

Figure 7.6: Outline of Topography

(2) River Profile

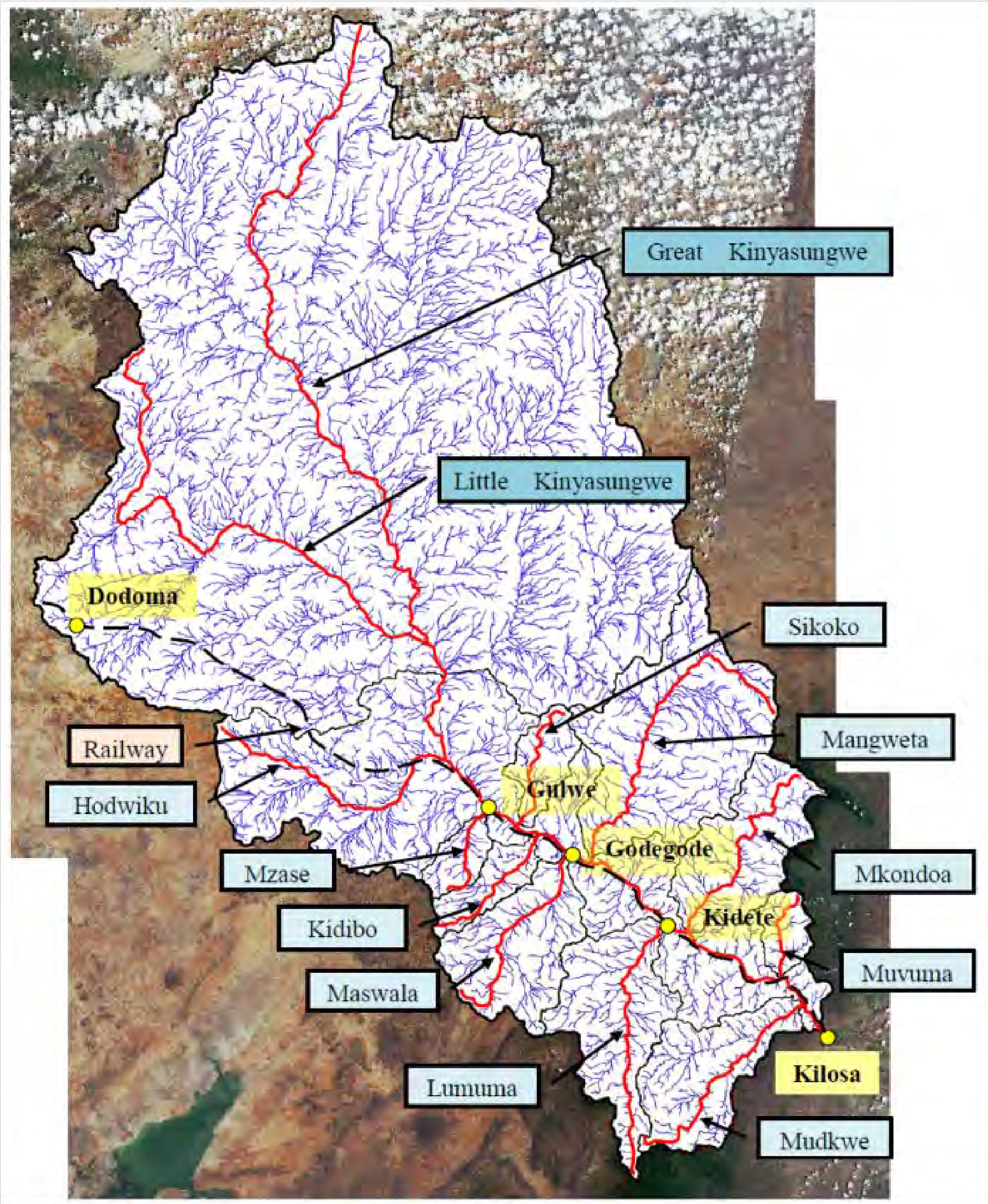
The target area, in particular in the upstream portion from Kilosa to Gulwe, is generally characterized by progressive bank erosion along the mainstream and abundant sediment discharge emptying into the mainstream from several tributaries. The sediment material has deposited and/or been transported to the middle and downstream reaches of the target area. In fact, this tendency can be seen in aggradations near the confluences of the Mzase to the Lumuma by examining the riverbed profile of the mainstream and main tributaries as shown in Figure 7.7.



G. Kinyasungwe	1/213 - 1/285 - 1/583 - 1/246 - 1/81
Mudkwe	1/215 - 1/138 - 1/492 - 1/3
Muvuma	1/126 - 1/34 - 1/10
Mkondoa	1/127 - 1/174 - 1/69 - 1/25
Lumuma	1/93 - 1/35 - 1/92 - 1/5 - 1/245
Mangweta	1/114 - 1/81 - 1/50 - 1/115
Maswala	1/70 - 1/94 - 1/71 - 1/19
Kidibo	1/54 - 1/84 -1/35 - 1/5
Sikoko	1/70 - 1/39 - 1/5 - 1/15
Mzase	1/74 - 1/31 - 1/2
Hodwiku	1/650 - 1/100 - 1/38 - 1/24
L. Kinyasungwe	1/240 - 1/475 - 1/136 - 1/89

Source: JICA Study Team

Figure 7.7: Riverbed Profile in the Target Area

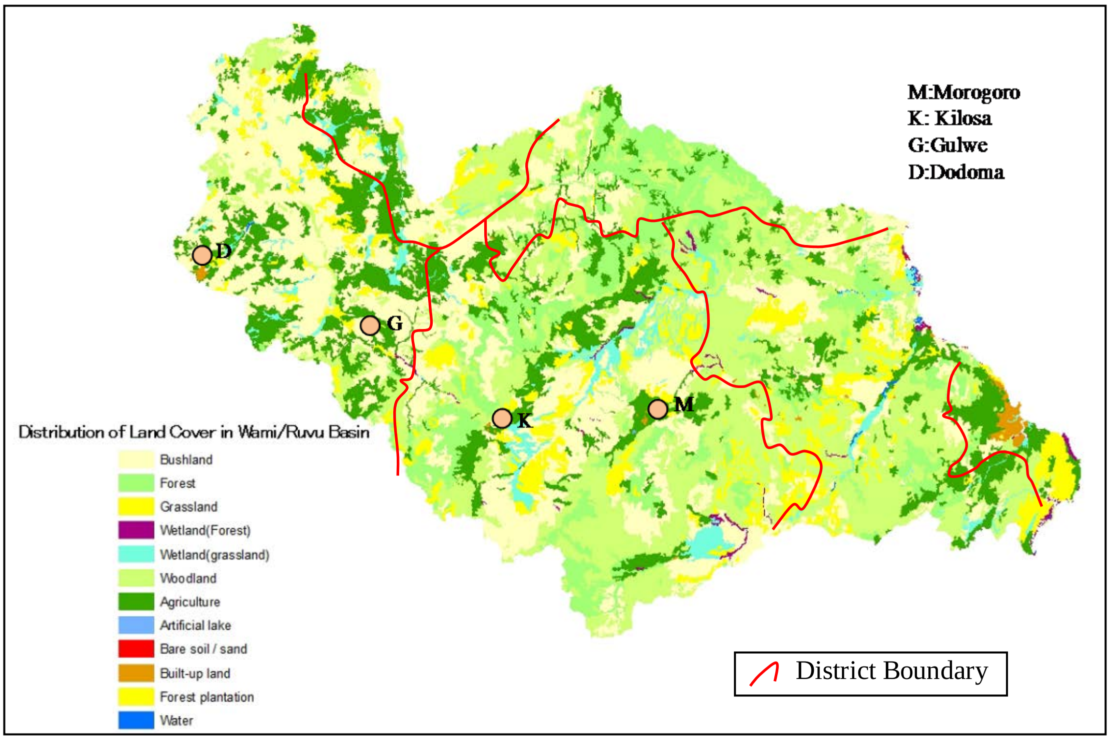


Source: JICA Study Team

Figure 7.8: River System Map

7.1.3 Land Cover

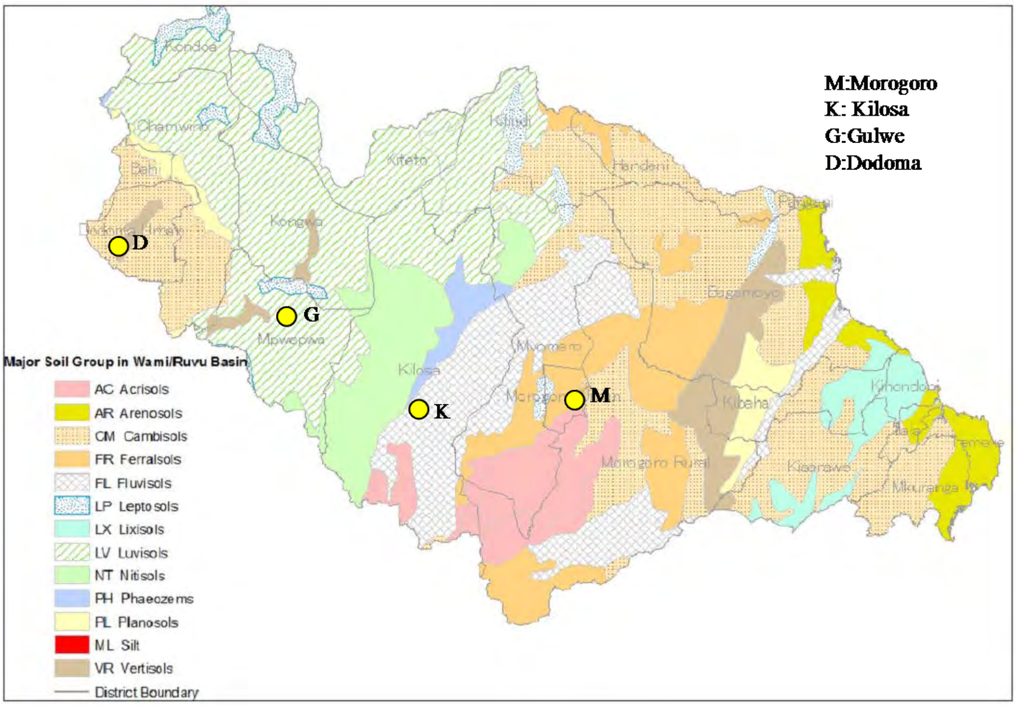
As per the JICA Wami/Ruvu Basin Study, the land cover, namely the land vegetation types in Wami/Ruvu Basin, are shown in Figure 7.9. The Mkondoa sub basin including Kilosa is covered by forested, agricultural and bush land, etc. On the other hand, the western area of Gulwe in the Kinyasungwe sub basion is mostly developed by agricultural land.



Source: JICA Wami/Ruvu Basin Study, 2013

Figure 7.9: Map of Land Cover in the Wami/Ruvu Basin (2002)

According to Figure 7.10, 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.



Source: JICA Wami/Ruvu Basin Study, 2013

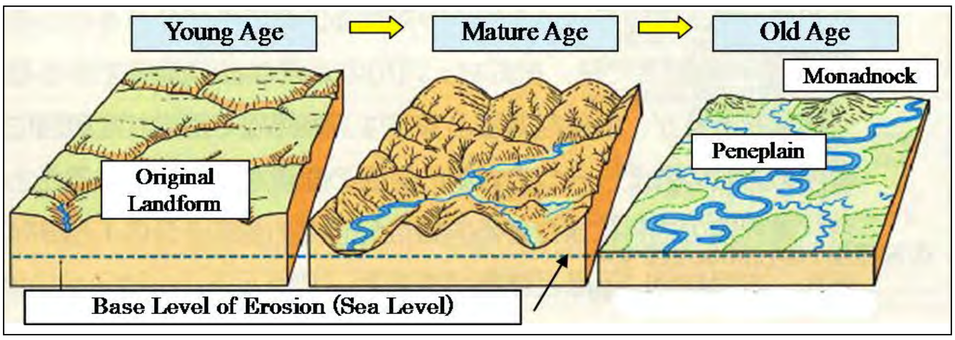
Figure 7.10: Map of Soil Groups in the Wami/Ruvu Basin

7.2 Outline of Historical Development of Landforms

7.2.1 Process of Topographical Change

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. The process of topographical change is divided into three stages (Figure 7.11).

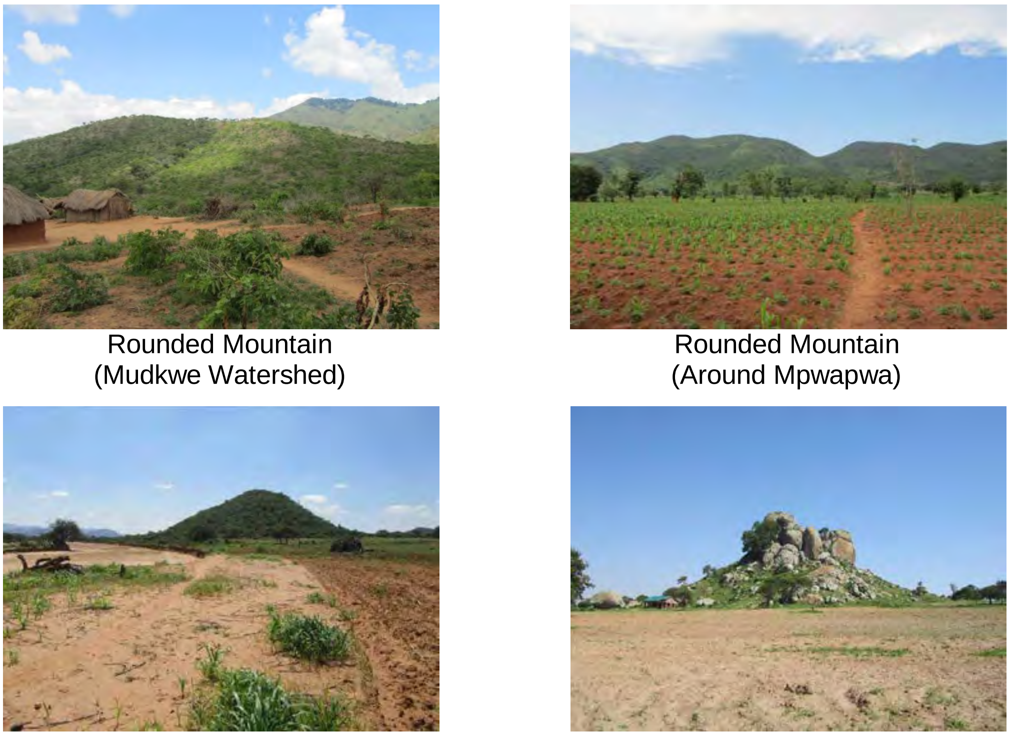
i) Young age: the original topography
ii) Mature age: the mountain is formed, and erosion is actively taking place.
iii) Old age: Peneplain spreads, monadnocks are seen in places



Source: http://blog.goo.ne.jp/morinoizumi33/e/d9662728fd1d07312545d362e62f2f1c

Figure 7.11: Process of Topographical Change

As for the Study Area, 2,000-meter mountains, which are presumed to have been formed by the previously mentioned geological tectonic movements, are distributed to the north and south between Kilosa and Kidete, and rounded mountain and monadnocks are seen in the plains between Kilosa and Dodoma (Figure 7.12). Therefore, the stage of topography between Kilosa and Dodoma is judged to be the old age.



Rounded Mountain
(Mudkwe Watershed)

Rounded Mountain
(Around Mpwapwa)

Monadnock
(Mzase Watershed)

Monadnock
(Mangweta Watershed)

Figure 7.12: Eroded Landforms

7.2.2 Historical Development of Landform

The target area is located in the East Rift Valley, as mentioned above. Therefore, the target area's development was affected by those of the greater rift valley system. Especially, this area is characterized by its plains, lakes and swamps. Figure 7.13 shows these characteristics.

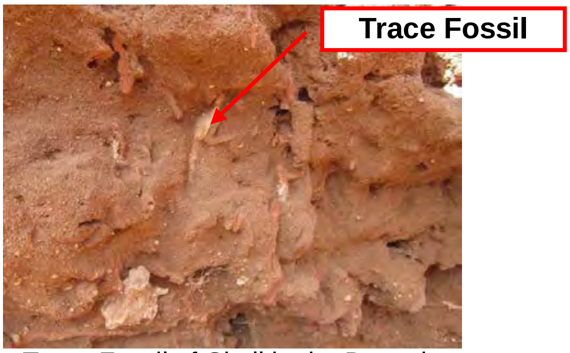
Plain (Swamp in Rainy Season)
(Msagali Area)

Plain (Swamp in Rainy Season)
(Mangweta Area)

Pediment Distributed in the Area
(In the Middle Reaches of Maswala)

Old Deposition observed in Pediment
(In the Middle Reaches of Maswala)

Lake Deposit
(Makutupu Area near Mangweta)

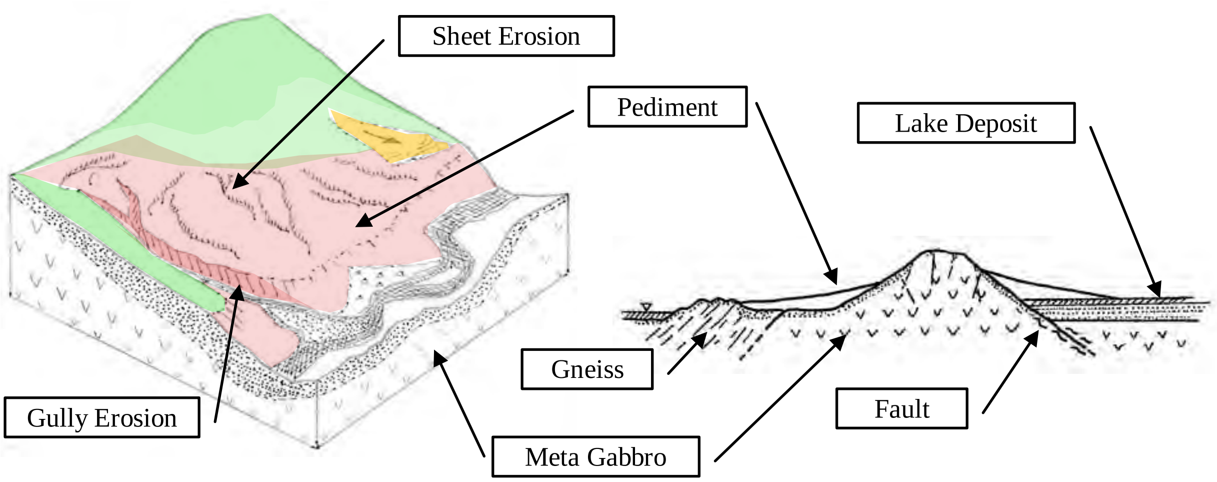


Trace Fossil of Shell in the Deposit
(Same as on the Left)

Figure 7.13: Characteristics of Lift Valley Floor

The historical development of landform in this area is summarized as below. Figure 7.14 shows a diagram of the historical development of landform in this area.

i) There were vast lakes in this area once.
ii) Sediment flowed into the lake and deposited.
iii) Pediment developed at the foot of the mountains at the same time.
iv) When the lakes were disappearing, rivers eroded the lake deposits simultaneously.
v) Traces of current landforms show fresh ones, therefore these phenomena are presumed to have occurred after the glacial period.



Source: JICA Study Team

Figure 7.14: Traces of Development of Landform

7.2.3 Trace of Catastrophic Phenomena

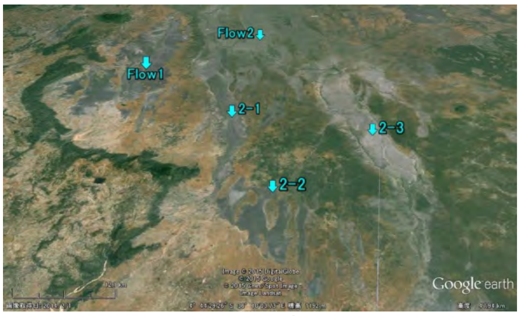
In satellite photos, traces of very unique topography are observed in the upper streams of the Kinyasungwe watershed; their characteristics are as follows:

- A clear gray deposition which is aggraded in the valley is observed in large areas (Figure 7.15A). Figure 7.15B shows the entire location.
- An unclear gray zone is also seen around these depositions.
- These depositions in the valley can be recognized as the traces of flow units.
- For example, in the rift valley in which Lake Natron is located, many streaks, which are presumed to have been eroded by liquid, are observed (Figure 7.15C: the red line in the figure is the presumed fault). The slope degree of this section is about 1/227 (0.25 degree).
- These streaks are not patterns which are formed by the sinking of the rift valley; rather, they are obviously traces which were eroded by hydrodynamic loads.
- Furthermore, in the downstream of these streaks, a plain, which has no vegetation around the foot of mountain, is observed (the area of ocher in Figure 7.15D). Generally, vegetation grows better in lowlands than highlands. But the condition of this zone is entirely opposite of this, in spite of the good environment for vegetation. This is thought to be the result of past vegetation having been deteriorated by huge destructive forces.
- In fact, a trace of the large landslide can be also seen at the Kenya side.
- The East Rift Valley is presumed to have suffered devastation around Lake Turkana in Kenya (in the lake, there is an active volcano).
- At that time, a large landslide (600 km long by 300 km wide) is presumed to have occurred around Lake Turkana in the Quaternary. Because of this, the trace remains a very clear geographical feature (Figure 7.15E).

Considering all these factors, the following hypotheses are able to be extracted:

- Volcanoes around Turkana Lake are presumed to have erupted with diastrophism. The old, large, lake is assumed to have been created by the eruption at the same time.

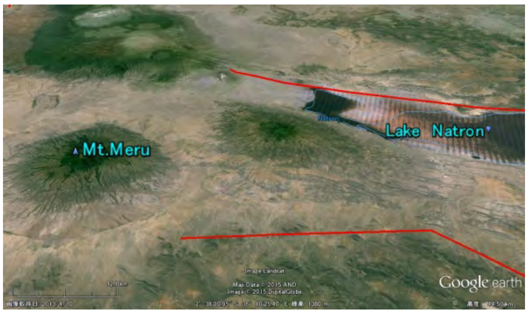
- At almost the same time, the huge landslide occurred, and immediately afterwards, a great deal of sediment flowed out toward the east, south and north sides.
- The sediment which flowed out toward the south side passed through the Rift Valley and reached present-day Tanzania. The traces of Flow Unit 1–5 are presumed to be the traces of this time (Figure 7.15F).
- Figure 7.16 is sediment which was observed in Kibakwe Village. Probably, there might have been a large lake at that time, as mentioned above. But the sediment which was observed in a disturbed condition at the foot of the mountains, which has no lake deposit, has the possibility of being formed by that trace.



A: Flow Unit 1–2

B: Flow Unit 1–5

C: Streaks in the Rift Valley



D: Trace of Outflow

E: Trace of Huge Landslide

F: Trace of Outflow of Large Landslide

Source: JICA Study Team

Figure 7.15: Traces of Catastrophic Phenomena

Deposition has No Structural
Lake Deposit

Unnatural Contact with Slope

Figure 7.16: Sediment Observed at the Kibakwe

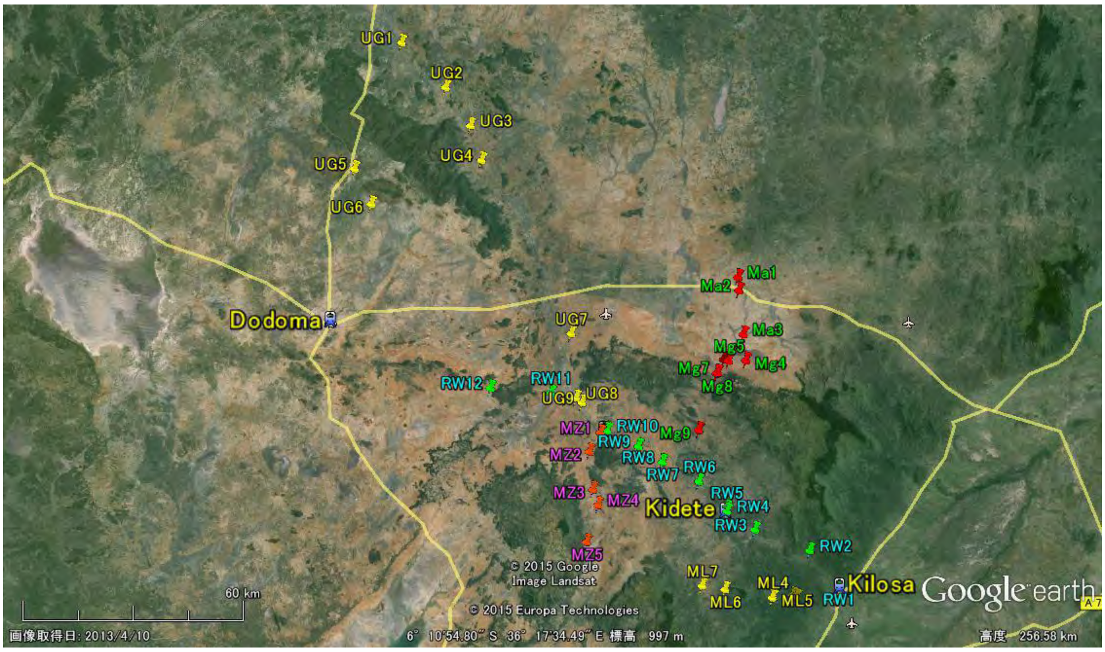
7.3 Reconnaissance Results for Sediment Analysis

7.3.1 Outline of Reconnaissance

The field reconnaissance was conducted in two mobilizations, first in December 2014 and again in February 2015, as follows:

i) Mudkwe–Lumuma watershed (15 December 2014)
ii) Mkondoa–Kinyasungwe River along the railway between Kilosa and Dodoma (16 December 2014, 5/11 February 2015)
iii) Mzase watershed (17 December 2014, 5 February 2015)
iv) Mangweta watershed and near Mpwapwa (18 December 2014, 1 February 2015)
v) Upper reaches of the Kinyasungwe River (3 February 2015)
vi) Dodoma–Gulwe along the railway, Kidibo and Maswala (22–23 May 2015)

A map of field reconnaissance points is shown in Figure 7.17.



Source: JICA Study Team

Figure 7.17: Map of Field Reconnaissance

Table 7.1: Coordinates of Reconnaissance Location

Site	Name	Latitude (S)	Longitude (E)	Site	Name	Latitude (S)	Longitude (E)
ML1	Mdukwe W*	6°51'19.10"	36°52'30.19"	UG1	G* Kinyasungwe	5°30'53.96"	35°55'5.88"
ML2	Mdukwe W*	6°51'9.29"	36°52'17.08"	UG2	Itiso	5°37'24.37"	36° 1'30.91"
ML3	Mdukwe W*	6°51'2.52"	36°51'59.45"	UG3	Ikombo	5°42'58.24"	36° 5'5.55"
ML4	Mdukwe W*	6°51'20.90"	36°49'2.98"	UG4	Dabalo Dam	5°47'58.03"	36° 6'41.55"
ML5	Mdukwe W*	6°51'24.09"	36°48'54.93"	UG5	Mayamaya	5°49'10.24"	35°48'14.58"
ML6	Lumuma W*	6°50'8.88"	36°41'59.87"	UG6	Chihanga	5°54'17.00"	35°50'38.28"
ML7	Lumuma W*	6°49'34.44"	36°38'38.34"	UG7	Kongwa	6°13'4.22"	36°19'37.92"
RW1	Kilosa B*	6°49'54.09"	36°58'41.64"	UG8	G* Kinyasungwe	6°22'23.04"	36°20'21.79"
RW2	Km 297.3	6°44'36.60"	36°54'26.01"	UG9	G* Kinyasungwe	6°23'5.24"	36°21'13.45"
RW3	Km 315.1	6°41'31.82"	36°46'26.09"	UG10	Near Gulwe	6°26'48.33"	36°24'37.77"
RW4	Km 325.2 (Kidete B*)	6°38'48.78"	36°42'20.01"	UG11	Near Gulwe	6°26'59.53"	36°24'48.27"
RW5	Kidete Dam	6°38'17.05"	36°42'11.62"	Ma1	Mangweta (Pundambili V*)	6° 4'57.38"	36°43'52.53"
RW6	Km 338.0	6°34'28.29"	36°38'12.25"	Ma2	Mangweta (Pundambili V*)	6° 6'50.82"	36°43'59.58"
RW7	Maswala	6°31'39.36"	36°32'52.46"	Ma3	Mangweta	6°13'11.55"	36°44'36.74"
RW8	Maswala	6°31'41.61"	36°32'55.18"	Ma4	Mangweta (Mali V*)	6°16'57.25"	36°44'57.58"
RW9	Kidibo River	6°29'23.60"	36°29'25.26"	Ma5	Mangweta	6°17'0.06"	36°42'26.94"
RW10	Mzase River	6°27'6.31"	36°24'49.76"	Ma6	Mangweta	6°16'48.32"	36°41'45.29"
RW11	Msagali	6°21'37.03"	36°16'41.89"	Ma7	Mangweta (Chamkolomo V*)	6°18'15.00"	36°40'57.69"
RW12	Igandu	6°20'54.93"	36° 7'56.76"	Ma8	Mangweta (Chamkolomo V*)	6°18'50.90"	36°40'42.96"
MZ1	Mzase River	6°27'25.37"	36°23'53.19"	Ma9	Mangweta	6°27'2.74"	36°38'9.72"
MZ2	Mzase River	6°30'9.16"	36°22'16.62"	W*: Watershed			
MZ3	Kidibo River	6°35'37.77"	36°22'46.78"	B*: Bridge			
MZ4	Lukole V*	6°37'52.32"	36°23'31.97"	G*: Great			
MZ5	Kibakwe V*	6°43'13.09"	36°21'50.97"	V*: Village			

Source: JICA Study Team

7.3.2 Mdukwe–Lumuma Watershed

(1) Site ML1

The Mdukwe watershed consists of dense forests (Figure 7.18).

Figure 7.18: Condition of Dense Forest

(2) Site ML2, ML3

Site ML2

Although swidden cultivation (shifting agriculture) is conducted in places, obvious surface erosion is not observed (Figure 7.19A).

Site ML3

Streams in the mountain are mostly small and a slight sediment deposition is observed in the riverbed (Figure 7.19B).


A: Swidden Cultivation (No Erosion)


B: Slight Sediment Deposition

Figure 7.19: Condition in Mountain Areas

(3) Site ML4, ML5

Outcrops of bedrock are observed in the riverbed and on the road cutting slopes of the Mdukwe watershed (Figure 7.20). The surface soil (topsoil) of slopes is very thin, or basically non-existent.


A: Outcrop of Bedrock (No Sediment)


B: Outcrop of Sandstone

Figure 7.20: Condition of Outcrops

(4) Site ML6

This site is located in the Lumuma watershed. The mountain shape of the watershed boundary is rounded by long-term erosion through the Quaternary. Although most of the trees in the mountains have been cut, the land surface is covered by vegetation. No slope failures are observed (Figure 7.21).

Figure 7.21: Rounded Mountain Shape of the Watershed Boundary

(5) Site ML7

The river condition of the Lumuma River is almost gentle, without riverbank erosion and sediment deposition (Figure 7.22A). The Lumuma River watershed has a valley plain. A small stream, which is the Lumuma River itself, runs through this plain. Traces of sediment transportation are generally not observed in this riverbed.

However, remarkable river erosion starts from the point near the confluence with the Kinyasungwe River (Figure 7.22B: yellow arrow). This is presumed to be largely influenced by base-level erosion in the Kinyasungwe River.

A: Small River in the Upper Stream

B: Remarkable Erosion
Near River Confluence

Figure 7.22: Condition of the Lumuma River

7.3.3 Mkondoa–Kinyasungwe River along the Railway between Kilosa and Dodoma

(1) Site RW1

Surface water can be seen at the Kilosa Bridge. However, the water depth is very shallow and a great deal of sediment deposition is observed from the bridge (Figure 7.23A). The material of sediment mostly consists of sand (Figure 7.23B).

A: Marked Sediment Deposition

B: Material of Deposition (Sand)

Figure 7.23: Condition of Sediment Deposition

(2) Site RW2

This site is located at the right bank of the Mkondoa River (Km 297.3). The river width at this point is about 350 m. A great deal of sediment deposition is observed (Figure 7.24A), and gabion works are provided as bank protection (Figure 7.24B).

A: Condition of Sediment Deposition

B: Bank Protection by Gabion

Figure 7.24: Condition of Site Km 297.3

(3) Site RW3

This site is located at the right bank of the Mkondoa River (Km 315.1). The Mkondoa River meets the Kinyasungwe River 4.5 km upstream from this site. Riverbank erosion has been proceeding at this site (Figure 7.25A). The rate of erosion is approximately 180 meters over two years. Sediment discharge by riverbank erosion is presumed to be a supply source of sediment production in downstream areas. Bank protection works have been completed in February 2015 (Figure 7.25B).

A: Bank Protection Work

B: Gabion Works

Figure 7.25: Condition of Site Km 315.1

(4) Site RW4

This site is located downstream of the Lumuma River and near the confluence with the Kinyasungwe River (Km 325.2). The Lumuma River is a gentle river which does not have serious sediment deposition. However, remarkable riverbank erosion and sediment deposition are observed near the confluence with the Kinyasungwe River (Figure 7.26A). Sinking of revetments is observed at the downstream areas of the river channel works (Figure 7.26B).

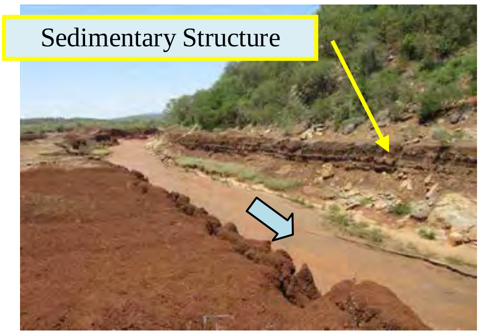
A: A Large Amount of Sediment Deposit

B: Gabion and Channel Works

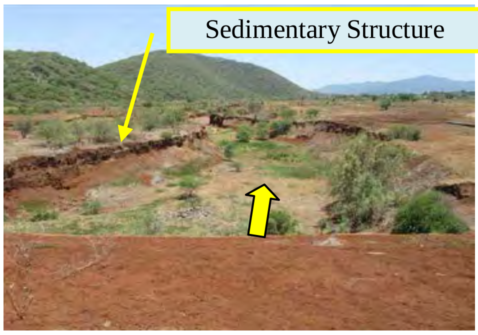
Figure 7.26: Condition of Site Km 325.2

(5) Site RW5

This site is the Kidete Dam site, the construction of which is presently halted. Sediment deposition is not observed on the current riverbed (Figure 7.27A). An outcropping of bedrock is observed on the left bank. On the other hand, the old river channel remains downstream of the dam (Figure 7.27B). Additionally, the deposition of reddish soil is observed characteristically in both the upstream and downstream areas of the dam (Figure 7.27C). The deposition, which has a sedimentary structure, is observed on top of the existing reddish soil deposition (Figure 7.27D). The reddish soil deposition has a solid formation, but is not layered, indicating that the reddish soil deposition was transported all at once (a single flood event).



A: Current River Channel



B: Old River Channel

C: Traces of Excavation

D: Solid Reddish Soil

Figure 7.27: Condition of the Kidete Dam Site

(6) Site RW6

This site is located at the right bank of the Kinyasungwe River (Km 337.4) A wide river, forming a floodplain, expands in this section (Figure 7.28A). Lower terrace deposits by floods are observed along the riverbank. The material consists of sands, which are easily eroded (Figure 7.28B).

A: Sediment Deposition
on the Wide Riverbed

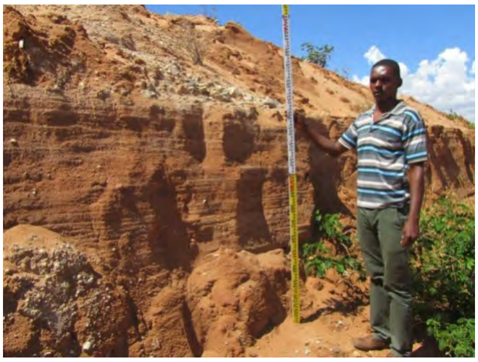
B: Lower Terrace Deposits
along the Riverbank

Figure 7.28: Condition of Site Km 337.4

(7) Site RW7, RW8

The adjacent areas of these sites are located about 1.5 km from Godegode Station. This section is located in the floodplain of the Maswala River. A great deal of sediment discharge is observed in the riverbed (Figure 7.29A). A thick deposition is spread over this area (Figure 7.29B). The box culvert of Site RW8 was open at the time of reconnaissance on 16 December 2014, but had been clogged by sediment at the reconnaissance time of 11 February 2015 (Figure 7.30A, B).

A: Condition of Remarkable Deposition
(RW7)



B: Deposition with Sedimentary
Structure

Figure 7.29: Condition of Maswala River near Godegode Station

A: Box Culvert (RW8)
(16 Dec. 2014)

B: Culverts Clogged by Sediment
(RW8: 11 Feb. 2015)

Figure 7.30: Condition of Maswala River near Godegode Station

(8) Site RW9

This site is located in the Kidibo River (Km 355.3), which is a right tributary of the Kinyasungwe River. Large areas of cultivated land exist in the upstream areas of the Kidibo River. Therefore, a great deal of sediment is presumed to have been flashed out from there. In this site, channel works were constructed (Figure 7.31A). A large floodplain is observed in the immediate upstream section of Site RW9, and remarkable riverbank erosion is observed along the right bank (Figure 7.31B). On the other hand, the left bank was protected by revetment works (Figure 7.31C, D).

A: Existing Channel Works
(Condition of Confluence)

B: Remarkable Riverbank Erosion

C: Revetment Works along Left Bank

D: Revetment Works along Left Bank

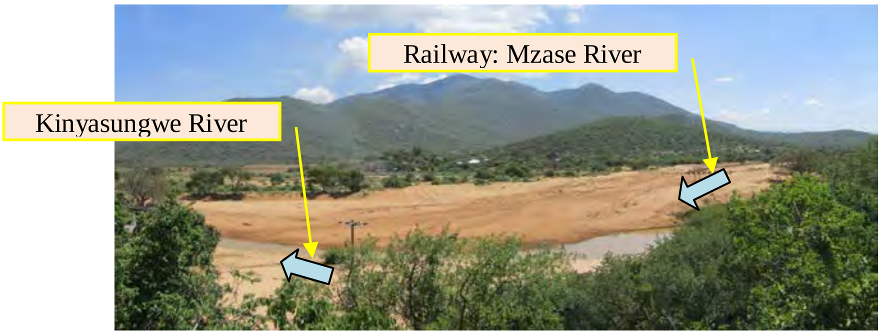
Figure 7.31: Site Condition (Kidibo River)

(9) Site RW10

This site is located in the Mzase River, which is stretching out from the southeast side of Gulwe station. A great deal of sediment discharge has been continuing (Figure 7.32A). Riverbed aggradations are the crucial issue for the railway at this site (Figure 7.32B). A great deal of sediment from the Mzase flows into the Kinyasungwe River (Figure 7.32C).

A: Sediment Deposition

B: Risky Bridge against Flood



C: Sediment Deposition at the Confluence

Figure 7.32: Condition of the Mzase River near Gulwe Station

(10) Site RW11

A large plain spreads along the Hodowiku River through the west side of Msagali Village. The railway runs through this plain. This large plain changes to a swamp in the rainy season (Figure 7.33A). Site RW11 is located in this area. The vast plain emerges at the end of rainy season (Figure 7.33B). Sediment which consists of grayish material is observed along the railway (Figure 7.33C). However, the trace, which has a sedimentary structure formed by flooding, is not observed on the outcrop of the deposition. Probably, this deposition is presumed to have been formed in the old age. Similar depositions are confirmed in the upstream areas of the Kinyasungwe and Mzase Rivers.

A: A Large Plain along the Railway (February 2015)

B: Condition in May 2015

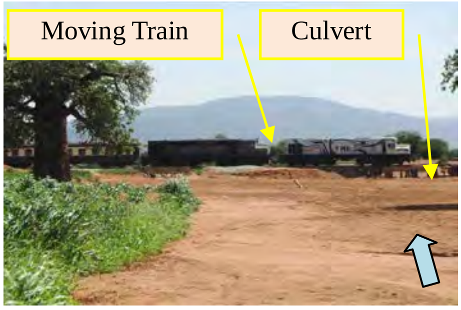
C: Old Sediment Deposition

Figure 7.33: A Large Plain Spreading through Msagali Village

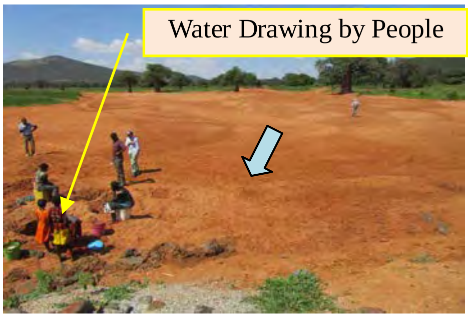
(11) Site RW12

This site is located near Igandu Station. This small watershed area has a very gentle slope. The height of the railway banking is low against the riverbed. Therefore, the bottoms of culverts should have been excavated lower than the riverbed height (Figure 7.34A, B). The opening of the culvert is too small for floodwaters to pass through. The floodwaters spread to the cultivated land due to the indistinct river channel shape and small bank height (Figure 7.34C, D). Construction of additional culverts to expand the opening underneath the railway was completed by TRL before December 2014.

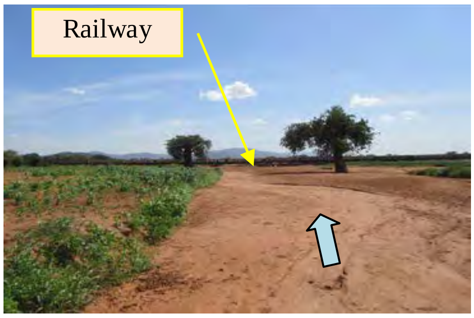
A: Restored Railway



B: Low Banking and Culvert



C: Spreading Sediment



D: Erosion and Deposition
on Cultivated Land

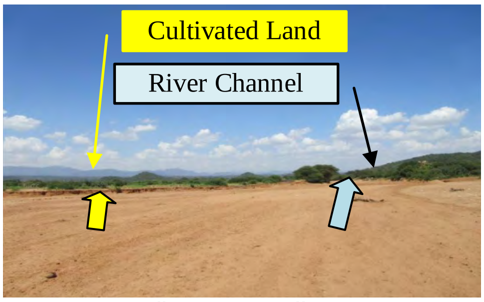
Figure 7.34: Condition at Igandu Area

7.3.4 Mzase–Kidibo–Maswala Watershed

(1) Site MZ1

This site is located about 1.8 km from Gulwe Station. At this site, remarkable riverbank erosion and a great deal of sediment deposition are observed (Figure 7.35A). A large sediment flooding area is observed in this area (Figure 7.35B). An artificial river channel was constructed between this site and confluence (Figure 7.35C). The river length is approximately 2.0 km. On the other hand, the riverbed of the artificial river channel has already covered by a great deal of sediment (Figure 7.35D). Therefore, this site is assumed to have become a floodplain (Figure 7.35E). In fact, the sediment discharge intruded into the cultivated lands of the adjacent village (Gulwe) during the flood on 28 March 2014 (Figure 7.35F).

A: A Great Deal of
Sediment Deposition



B: Sediment Flooding Area

C: Sediment Flooding and
Narrow River Channel
(Artificial River Channel)

D: Artificial River Channel Covered
by a Great Deal of Sediment

E: Condition of Sediment Flooding

F: Cultivated Land Covered
by the Sediment

Figure 7.35: Condition of the Mzase River near Gulwe Station

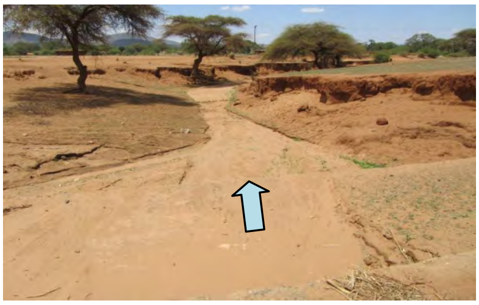
(2) Site MZ2

Upstream of the Mzase River, there are widespread large cultivated areas. Figure 7.36A shows the photo during the dry season, and Figure 7.36B shows the condition (covered by grasses) in the wet season. On the other hand, sediment deposition is observed on the upstream side of the road, which has a similar function to the consolidation dam (Figure 7.36C). This sediment was likely transported and deposited by flood discharges from the cultivated lands. The riverbanks of the downstream side are eroded (Figure 7.36D).

A: Cultivated Land of Upstream Side
(17 Dec. 2014)

B: Same as (A)
(5 Feb. 2015)

C: Road having Consolidation
Dam Function



D: Condition of Riverbank Erosion
at Downstream Side

Figure 7.36: Condition of Upstream Area of the Mzase River

(3) Site MZ3

This site is located upstream of the Lukole River, which is the left tributary of the Kidibo River. Sediment deposition is observed on the upstream and downstream side of the bridge across the river. However, the deposition is not so significant. Although riverbank erosion is also observed, it is not so serious (Figure 7.37).

A: Sediment Deposition and Riverbank
Erosion (17 Dec. 2014)

B: Same as on the Left
(5 Feb. 2015)

Figure 7.37: Condition of Upstream Area of the Kidibo River

(4) Site MZ4

This site is called the “Monadnock”, which as previously mentioned, is a final stage of the historical development of landform (Figure 7.38A). Namely, the current landform shows that this stage of the erosion process has finished. Therefore, the surface soil has been mostly washed away, and an outcrop of the bedrock is observed in places (Figure 7.38B).

A: Monadnock

B: Exposed Bedrock and Lack of Surface Soil

Figure 7.38: Monadnock, located near Kibakwe Village

(5) Site MZ5

This site is located upstream of the Maswala River in Kibakwe Village. The sediment discharge in the riverbed is not marked (Figure 7.39A, B). But a great deal of sediment deposition, whose color is grayish brown, is observed at the foot of the mountain (Figure 7.39C). The height of the accumulated deposition of this site is about 10 m. The surface of this deposition forms a very gentle slope. And an outcrop of the bedrock is observed on the river channel at the foot of the mountain (Figure 7.39D). Actually, this landform is unnatural, considering the normal formation process of landforms, because the gentle topographical continuity, which was formed by long-term erosion, is not observed on the boundary between the mountain slope and the deposition. Additionally, the thickness of the deposition is too thick when compared to the height of mountain. In satellite photography, the sediment covering the foot of mountain is clearly observed (Figure 7.39E). Furthermore, according to the satellite photos, it should be noted that this site is located at the end of the small rift valley (Figure 7.39F).


A: River Condition


B: Little Sediment Deposition


C: Thick Deposition


D: River Channel at the Foot of Mountain (Outcrop of Bedrock)

E: The Foot of Mountain Covered by Sediment Deposition (Red Line: Presumed Fault)

F: Site MZ5 Located in the Small Rift Valley (Red Line: Presumed Fault)

Figure 7.39: Condition of Upstream Area of the Maswala River

7.3.5 Upstream Area from Gulwe

(1) Site UG1

This site is located in the most upstream reaches of the Great Kinyasungwe River. The landform is almost flat (Figure 7.40A). Sediment deposition with gray color is observed on the river channel during rainfall (Figure 7.40B). The supply source of this deposition is presumed to be lake deposits or sediment transported by a huge landslide (refer to Sections 7.2.2–7.2.3). On the other hand, this river channel does not have an obvious river channel formation. This plain changes to a floodplain during rainy seasons. It is possible to verify the existence of clayey compounds in the sediment deposition by forming a “string” with the deposition by hand (Figure 7.40B). This procedure was successful at this site, and therefore, the sediment contains clayey compounds.

A: River Channel during Rainfall

B: Sediment and String (Clay)

Figure 7.40: Condition of the Most Upstream Reaches of the Kinyasungwe River

(2) Site UG2

This site (Itiso) is located downstream of Site UG1, and is a water level gauging station (Figure 7.41A) managed by the Wami/Ruvu Basin Water Office. A small amount of surface flow was observed at the time of reconnaissance. The landform is almost flat, as in Site UG1. Some river channels are observed in the plain (Figure 7.41B). The sediment is colored gray, as in Site UG1.

A: A Small Amount of Sediment Deposition

B: River Channel during Rainfall

Figure 7.41: Condition of Itiso Site

(3) Site UG3

This site (Ikombo) is located downstream of Site UG2, and is a water level gauging station. The river channel shows a stable river channel. A small amount of sediment deposition is observed (Figure 7.42A, B).

A: A Small Amount of Sediment Deposition

B: Stable River Channel

Figure 7.42: Condition of Ikombo Site

(4) Site UG4

Dabalo Dam is located in the upstream area of the Great Kinyasungwe River. Several tributaries flow into the dam reservoir (Figure 7.43A). Since the landform of the Upper Great Kinyasungwe is flat, the sediment discharge is presumed to be minor, as mentioned above. Even if sediment discharges occur, most of the sediment material will deposit in this reservoir (Figure 7.43B).

A: Dabalo Dam B: Dam Reservoir

Figure 7.43: Condition of Dabalo Dam

(5) Site UG5

This site (Mayamaya) is located upstream of the Little Kinyasungwe River. This site is a water level gauging station (Figure 7.44A). The surrounding landform is flat, and traces of the sediment discharge from the upstream areas are not observed (Figure 7.44B).

A: Water Level Gauging Station B: Flat Surrounding Landform

Figure 7.44: Condition of Mayamaya Site

(6) Site UG6

This site (Chihanga) is located downstream of Site UG5, and is a water level gauging station. The surrounding landform is flat, and traces of the sediment discharge from the upstream area are not observed, as in Site UG5. The river channel is not obviously formed (Figure 7.45A, B).


A: Water Level Gauging Station


B: Obscure River Channel

Figure 7.45: Condition of Chihanga Site

(7) Site UG7

This site (Kongwa) is located in the middle reaches of Kinyasungwe River, and is a water level gauging station (Figure 7.46A, B). The surrounding landform is almost flat. Obvious sediment deposition transported by floods is not observed in the riverbed (Figure 7.46C). Instead, deposition which does not have an obvious sedimentary structure is observed on the riverbank (Figure 7.46D). Since the surrounding land is formed and composed of this deposition, this channel was formed in a relatively old era.


A: Full View of Site UG7


B: Water Level Gauging Station


C: Riverbed Condition


D: Old Deposition

Figure 7.46: Condition of Kongwa Site

(8) Site UG8

This river is the Hodwiku River. This site is located between Gulwe and Msagali. Sediment deposition is not observed in the riverbed (Figure 7.47A). An outcrop of the bedrock is observed in the riverbed (Figure 7.47B).

A: River Condition B: Outcrop of Bedrock

Figure 7.47: Condition of the Hodwiku River

(9) Site UG9

This site is located downstream of Site UG8. Sediment deposition is almost not observed in the riverbed (Figure 7.48A). But a small amount of gravel deposition is observed on the left bank. An outcrop of the bedrock is observed in the riverbed (Figure 7.48B).

A: River Condition B: Outcrop of Bedrock

Figure 7.48: Condition of the Hodwiku River

(10) Site UG10, UG11

Site UG10 and Site UG11 are adjacent to each other, and are located upstream of Gulwe Station. At Site UG10, a new road with a road embankment has been constructed across the river (Figure 7.49A). Due to the dam effect, the road embankment creates a large swamp on the upstream side (Figure 7.49B). According to satellite photography, cultivated lands are distributed along the small streams of the Kinyasungwe River (Figure 7.49C). On the other hand, at the downstream location of Site UG11, a great deal of sediment, which flowed into the Kinyasungwe River from the Mzase River, is observed (Figure 7.49D).

A: Banking of New Road

B: Swamp of Upstream Area

C: Before Road Construction

D: Confluence of Mzase River

Figure 7.49: Condition of Gulwe Site

7.3.6 Mangweta Watershed

The Mangweta watershed can be divided into the northern and southern areas. The northern area shows the plain land and the southern area is surrounded by mountains. The boundary of these two areas is located in the middle reaches of the Mangweta River. The sediment discharge conditions are observed as follows:

(1) Site Ma1, Ma2

Site Ma1 and Site Ma2 are located near the watershed boundary of the northern part of Mangweta. Site Ma1 is Monadnock, which shows the stage of the old age (refer to Section 7.2.1), and is in the process of topographical change (Figure 7.50A). Site Ma2 reflects the typical landform of the northern area (Figure 7.50B).

A: Monadnock

B: Cultivated Land

Figure 7.50: Landform of the Northern Part of Mangweta

(2) Site Ma3

This site is located at the northern part of Mangweta. The northern area is covered by reddish and gray soils. The gray soil is observed along the small rivers (Figure 7.51A). Since this gray layer does not have a sedimentary structure, this deposition is presumed not to have been the deposition which was formed by floods (Figure 7.51B).


A: Gray Soil along the River Channel

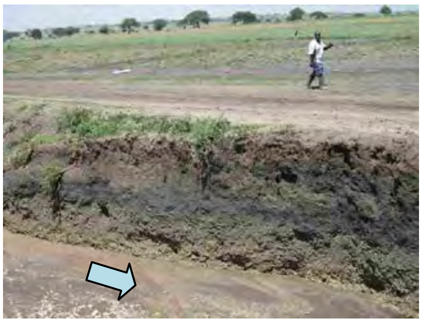
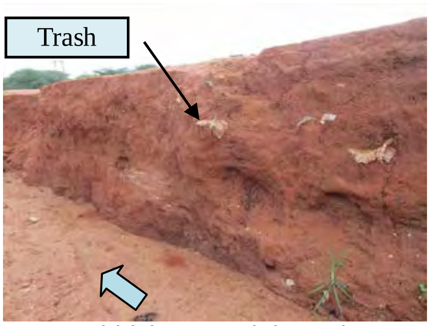

B: Layer Structure in Deposition

Figure 7.51: Condition of the Northern Part of Mangweta

(3) Site Ma4

This site is located at the northern part of Mangweta. The reddish soil spreads over this northern area, as shown in Figure 7.52A. However, rubbish, which has been caught between soils, is observed here (Figure 7.52B). Surface erosion seems to be active in this area.


A: Land Covered by Reddish Soil



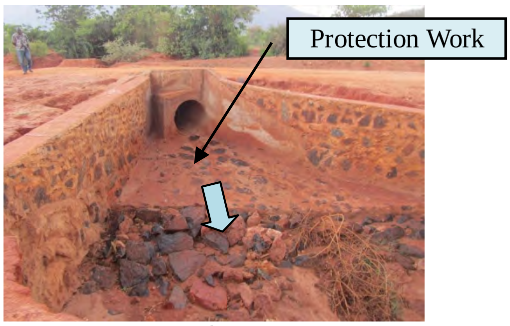
B: Rubbish Spread throughout the Reddish Soil

Figure 7.52: Condition of the Northern Part of Mangweta

(4) Site Ma5

Reddish soil has the characteristic of being susceptible against erosion (Figure 7.53A). The road gutter has been eroded by running waters, which flowed out from the culvert during rainfall. The apron protection works seem effective against erosion (Figure 7.53B).


A: Eroded Road Gutter

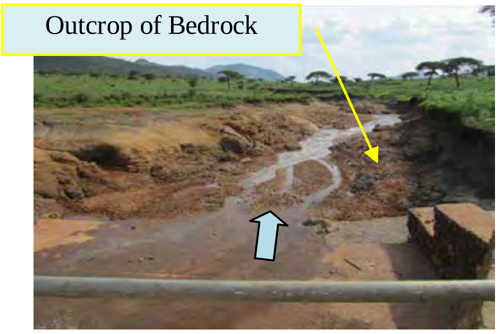


B: Road Culvert

Figure 7.53: Condition of the Northern Part of Mangweta

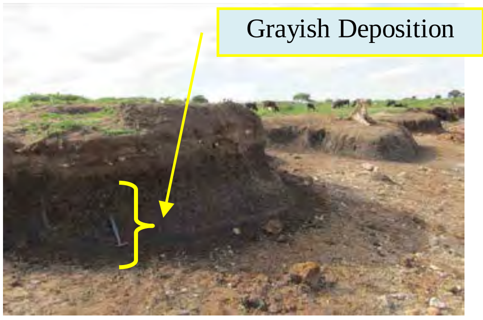
(5) Site Ma6

This site is located at the south end of the northern area. An outcrop of bedrock is observed in the riverbed (Figure 7.54A). The layer thickness of the surface soil is relatively thin. Marked deposition, which was transported by floods, is not observed in the riverbed (Figure 7.54B). However, the bedrock around this site is covered by grayish sediment (Figure 7.54C). Because the deposition does not have sedimentary structure formed by successive floods, this deposition is presumed to have been deposited in the old age (Figure 7.54D).

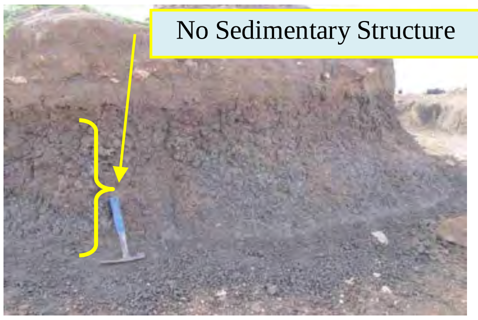


A: Thin Surface Soil


B: River in the Plain



C: Trace of Old Deposition



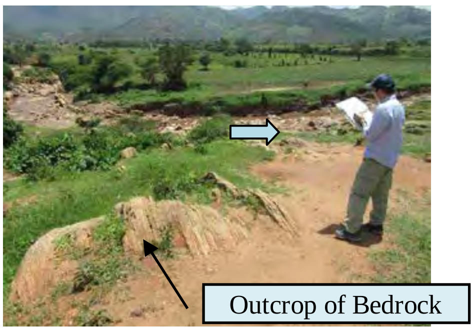
D: Near View of the Left

Figure 7.54: Condition of the Northern Part of Mangweta

(6) Site Ma7

This site is located at the boundary of the northern area and the southern area. Obvious riverbed erosion starts from this site (Figure 7.55A). Additionally, an outcrop of bedrock is distributed around this site (Figure 7.55B).


A: Obvious Riverbed Erosion



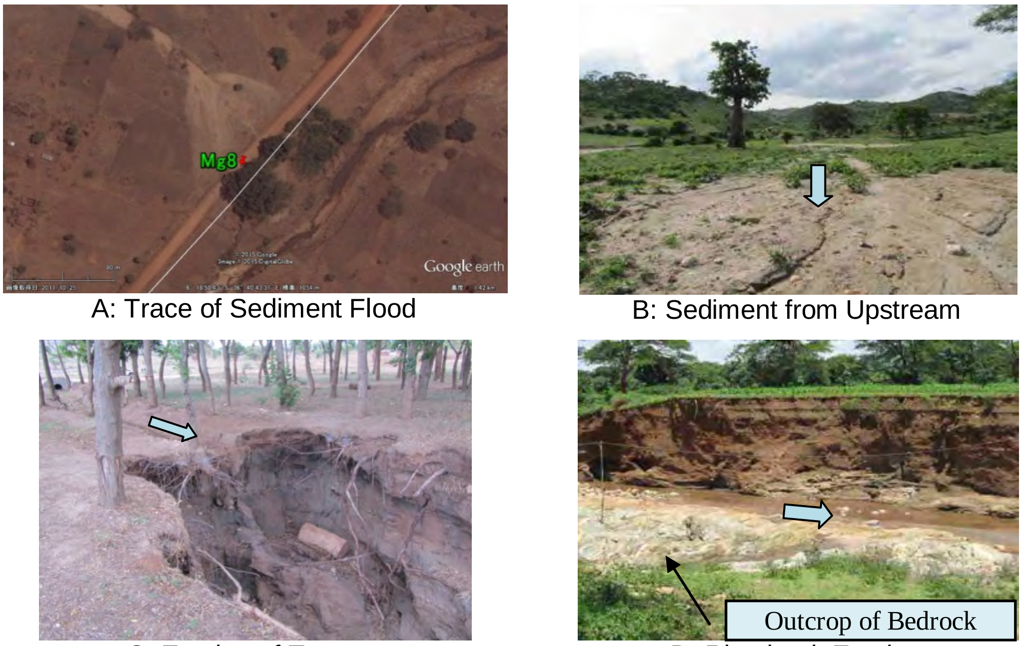
B: Shallow Bedrock

Figure 7.55: Condition of the Middle Reaches of Mangweta

(7) Site Ma8

This site is located at the north end of the southern area. The sediment discharge from the mountain side is the characteristic phenomenon (Figure 7.56A). However, evidence of slope failure is not observed on the mountain slope. Therefore, the discharged sediment is presumed to have been supplied from adjacent cultivated lands (Figure 7.56B). Additionally, a great deal of flood flow from the mountain causes the remarkable erosion on the right bank side (Figure 7.56C).

Steep cliffs which were formed by floods are observed along both riverbanks along the mainstream (Figure 7.56D). Additionally, thick sediment deposition is observed at both sides of the riverbank on the bedrock. This thick deposition is assumed to be the deposition which had been formed in the old age.



A: Trace of Sediment Flood
B: Sediment from Upstream
C: Erosion of Terrace
D: Riverbank Erosion

Figure 7.56: Condition of the Middle Reaches of Mangweta

(8) Site Ma9

This site is located in the middle reaches of the southern area. Remarkable river erosion is observed on both riverbanks, as in Site Ma8 (Figure 7.57A, B). An outcrop is observed in the riverbed (Figure 7.57C). Additionally, a thin deposition is observed partly in the riverbed. According to satellite photography, obvious deposition is distributed in the section from the downstream of site Ma9 up to the confluence (Figure 7.57D). The deposition in this section is presumed to be a source of supply to the Kinyasungwe River.

A: Remarkable River Erosion

B: Remarkable River Erosion

C: Outcrop of Bedrock

D: Deposition in Mangweta River
(in the Southern Area)

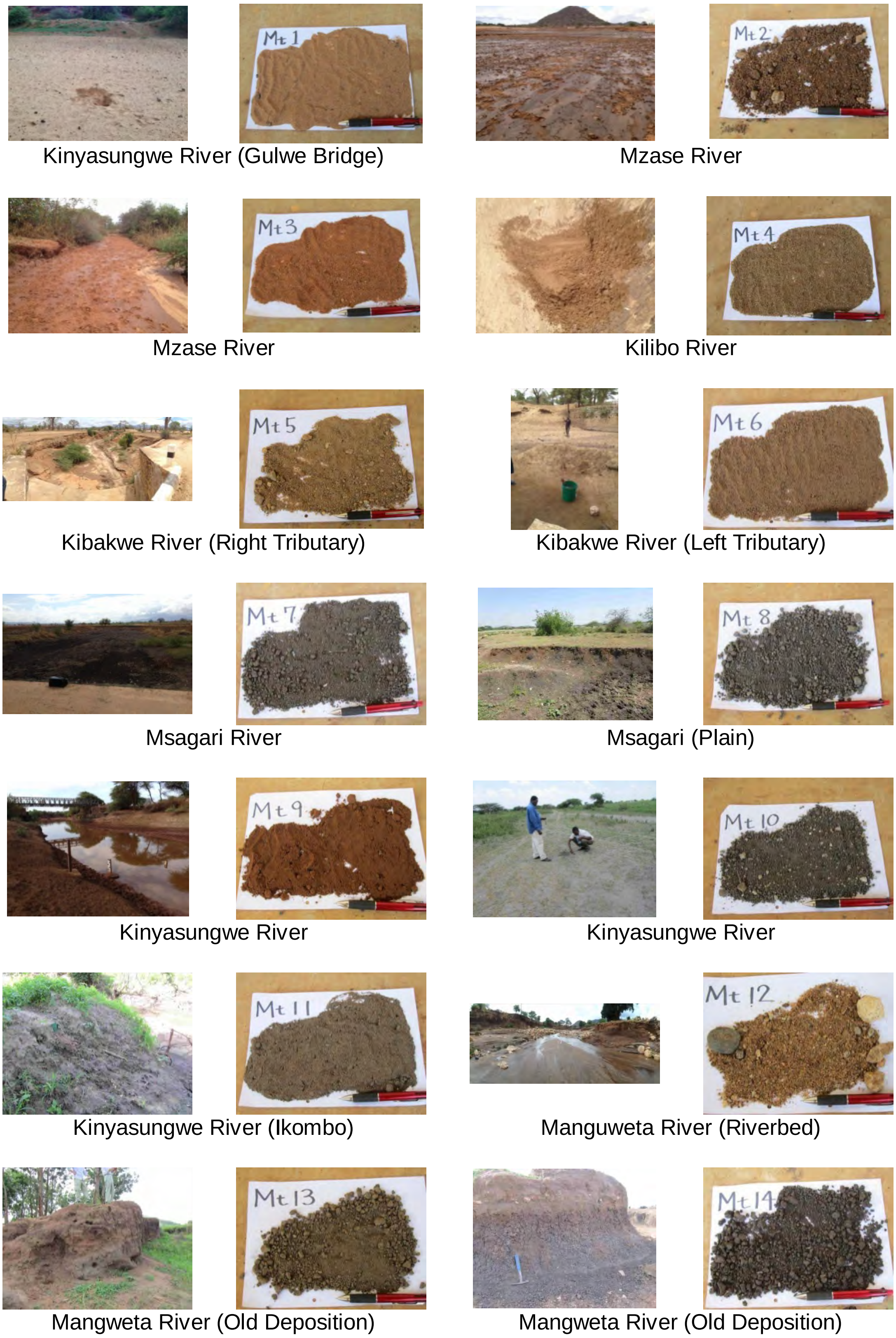
Figure 7.57: Condition of the Middle Reaches of Mangweta

7.3.7 Material of Sediment Deposition

The sediment deposition of the riverbed is characteristic of both the geology and the soils of the watershed. Especially, the color is an indicator of the source(s) of supply. As previously mentioned, the sediment deposition of each site has a distinct color (or colors). Figure 7.58 shows the location of the sampling sites of riverbed materials, and Figure 7.59 shows a list of deposition.

Source: JICA Study Team

Figure 7.58: Map of Sampling Sites of Riverbed Materials



Source: JICA Study Team

Figure 7.59: Comparison of Deposition Materials

7.3.8 Characteristics of Sediment Discharge Based on Reconnaissance

(1) Sediment Production from the Perspective of Geology and Topography

Geology and Geological Structure: Meta-igneous, Meta-sediments, gneiss, granulite, Migmatite and granite in Precambrian, which are greater than two billion years old (>2,000 Ma), are distributed in this watershed. The geological structure of Tanzania is characterized by the Great Rift Valley. Therefore, a lot of lineaments which express faults are observed along the Rift Valley.

Historical Development of Landform: The current landform has been formed over a long period of erosion. According to the process of topographical change, the current stage is "the old age". Therefore, the eroded ground has formed a gentle landform. An outcrop of bedrock is observed on the mountain slope, the surface land, the riverbed, etc. Sediment deposition with reddish or gray color is observed in the upstream areas of the Kinyasungwe, Mzase, and Kibakwe watersheds. The deposition is presumed to have been deposited in the old age. As mentioned above, this deposition is presumed to be the lake deposit or the sediment transported from Kenya, which was produced by a huge landslide.

(2) Sediment Deposition in the River

Kilosa–Kidete: Dense forests are distributed in the Mdukwe–Lumuma and Mkondoa watersheds. The surface soil of the mountain slopes is thin, and an outcrop of bedrock is observed on the slope, the riverbed, and the road surface. A small amount of sediment deposition is observed in the riverbed of the small streams.

The Upstream Area from Gulwe: The upstream area from Gulwe of the Kinyasungwe River forms a vast plain. Swamps are formed in the wet season in the lower areas of the vast plain. In this area, sediment deposition which has been obviously transported by floods was mostly not observed. Additionally, a vast plain spreads in the upstream area of the Gulwe Bridge, and traces of sediment discharge are not observed. Therefore, the sediment discharge from the upstream areas of the Gulwe Bridge to the downstream areas is judged as not obvious, except for wash loads.

(3) Source of Sediment Production

The Remarkable Sediment Production Area: The area which has the most remarkable sediment discharge is observed in the section between Kidete and Gulwe. Especially, the Maswala, the Kidibo, and the Mzase Rivers are the ones in which the sediment discharge is quite significant.

The Sediment Discharge Characteristics of Three Tributaries: The bedrock was observed at the channel works of the Mzase River and the channel river of the Maswala River near the railway. The relative height of the confluence of the Maswala and the Kidibo Rivers is a few meters. Basically, these areas consist of the old alluvial fan, of which end parts (tongue shaped by deposited fan) have a steep slope. Currently, the aggradations of bed slope of the mainstream does not affect to those in the tributaries, in other words, the bed slope seems stable in those tributaries. That proves still active inflow of sediment material produced in the tributaries toward the mainstream.

The Source of Sediment Production: The source of sediment production is judged to be the expanded cultivated lands in the upstream areas of the tributaries. Because the surface soil was disturbed by cultivation and overgrazing, they flow out easily during rainfall. The disturbance of surface soil is assumed to weaken the resistance to the raindrop erosion and surface flow. Floods are presumed to accelerate the bank erosion process.

(4) Sediment Transportation Capacity

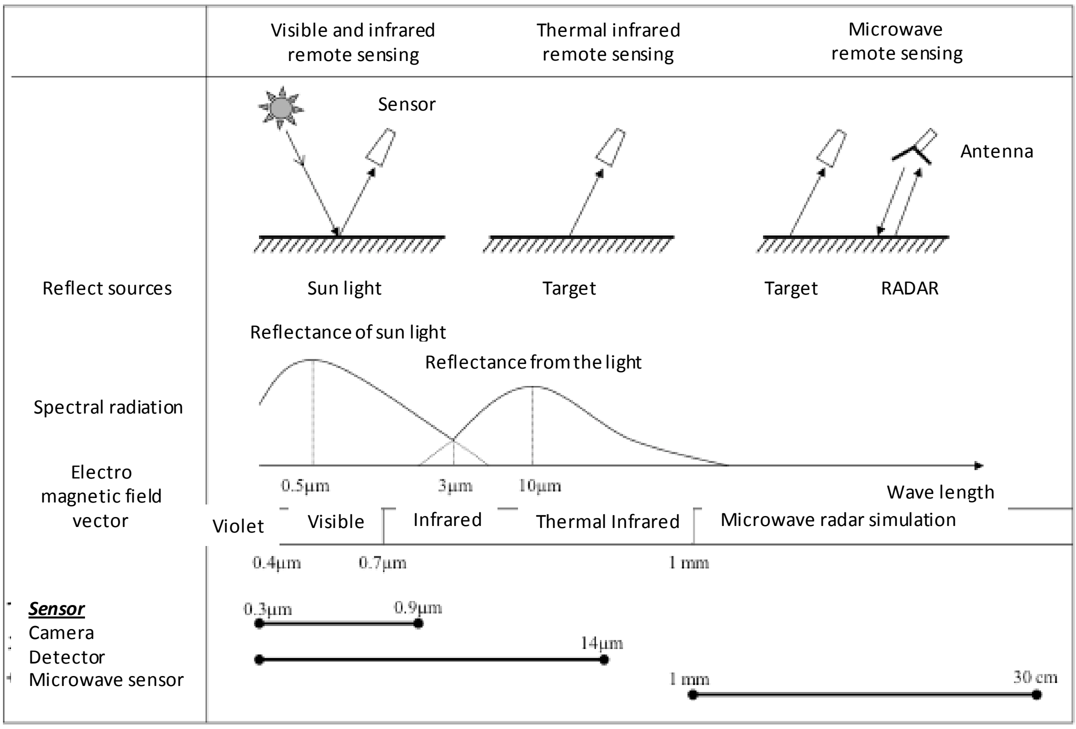
Sediment Transportation Capacity of the Kinyasungwe River: The Kinyasungwe River does not have the required volume of river water to flow continuously and move deposition in the riverbed. Therefore, the riverbed of the Kinyasungwe River has been rising.

Sediment Transportation Capacity of Tributaries: The aggradation of the Kinyasungwe River influences the aggradation of its tributaries.

7.4 Study on Seasonal Changes of Surface Flow Using Satellite Photographs

7.4.1 About Synthetic Aperture Radar (SAR)

The general characteristics of the satellite photographs are as shown in Figure 7.60. Table 7.2 shows advantage and disadvantage of the optical sensors and the radar. Synthetic Aperture Radar (SAR) has the advantage of being unaffected by weather conditions. Figure 7.61 shows the differences in their resulting images.



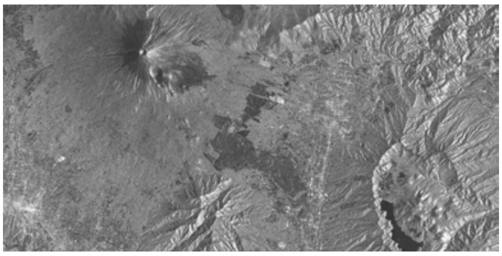
Source: Illustration Remote Sensing, 1992, Japan Association of Surveyors

Figure 7.60: Differences of Sensors

Table 7.2: Characteristics of Different Sensors

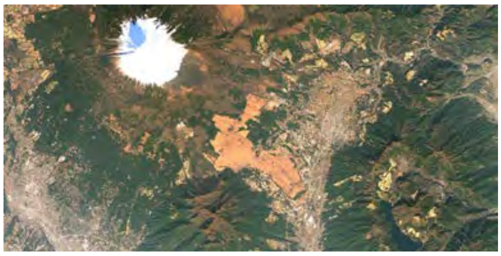
Sensor	**Radar**	**Optical**
Advantage	It can observe both day and night and under bad weather conditions.	It can acquire the images similar to the views from an airplane. Therefore, the results can be easily interpreted.
Disadvantage	The images are not easily interpreted.	It cannot observe under bad weather conditions, or at night, unless strong light sources are given.

Source: JICA Study Team



Ortho-rectified (foreshortening) PALSAR imagery, 2006/12/30 10:15 (JST)

Radar Image



Ortho-rectified AVNIR-2 imagery (true color), 2006/12/30 10:15 (JST)

Optical Image

Source: JICA Study Team

Figure 7.61: Differences of Resulting Images: Radar vs. Optical

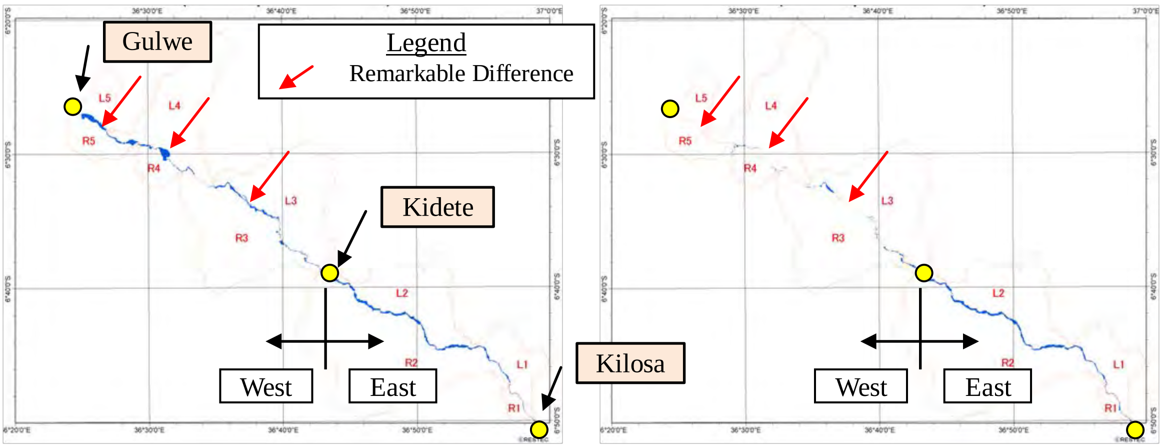
7.4.2 Result of the Analysis by Radar

The seasonal changes of surface flow were studied using satellite photographs from both the dry season and the wet season. The sensor used for this analysis was PALSAR installed on the Japanese satellite ALOS ("Daichi", in Japanese). The orbit cycle of ALOS is 46 days. Therefore, a proper photographing date has to be selected depending on this cycle. The resolution of the images is 10 m. The selection of the photograph date used for the analysis was done in consideration of the December 2009 flood (Figure 7.62).

Year	2009				2010							
Month	9	10	11	12	1	2	3	4	5	6	7	8
Season	Dry			Wet				Dry				
Flood				■								
Orbiting Pass No RSP569 (West Pass)				14 Dec. ←			→	1 May				
Orbiting Pass No RSP568 (East Pass)					12 Jan. ←		→	14 Apr.				

Figure 7.62: Season and Photographing Date

Figure 7.63 shows the results of analysis. Obvious difference between the rainy and dry seasons is confirmed. The river channel, which is not observed in the dry season between Gulwe and Kidete, is observed in the wet season.



A: Result of Wet Season B: Result of Dry Season

Figure 7.63: Difference between the Dry Season and the Wet Season

7.5 Sediment Analysis based on Satellite Photo Analysis

7.5.1 Past Studies Related to Sediment Yield

This section refers to the following document: "Soil Erosion and Sedimentation in Semi-arid Tanzania; Studies of Environmental Change and Ecological Imbalance", by Carl Christiansson, Scandinavian Institute of African Studies, Uppsala and Department of Physical Geography, University of Stockholm (hereinafter called "Document Ch").

This report is written about sediment yield in almost the same area as this Study Area, namely, between Dodoma and Mpwapwa. Especially, this historical information of sediment deposition in the irrigation dams is important data for the Study Team. The investigation spanned from 1968–1974.

(1) Background of Sediment Yield

The following list quotes from various sections of Document Ch:

i) During the latter half of the 1930s and 1940s, the Agricultural Department carried out an intense propaganda program for soil conservation, including contour banking, and restrictions were introduced against cultivation and grazing on the upper pediments.

ii) At the same time, people were taught to use cattle manure, during the 1940s manuring became more and more widespread. A semi-permanent type of cultivation could be maintained in the valleys.

iii) Many of the fields on the upper pediments, which at that time were already badly eroded and most probably gave poor returns, were abandoned. The upper pediments then served mainly as grazing areas and land for fuel wood production.

iv) By 1960 the bush-vegetation had got denser, but grass seemed to be scarce. In the early 1970s, the bush was still denser and partly impenetrable.

v) In 1974 general cultivation campaign was launched in Tanzania. The aim was to increase the production of food crops in order to make the country less dependent on imports.

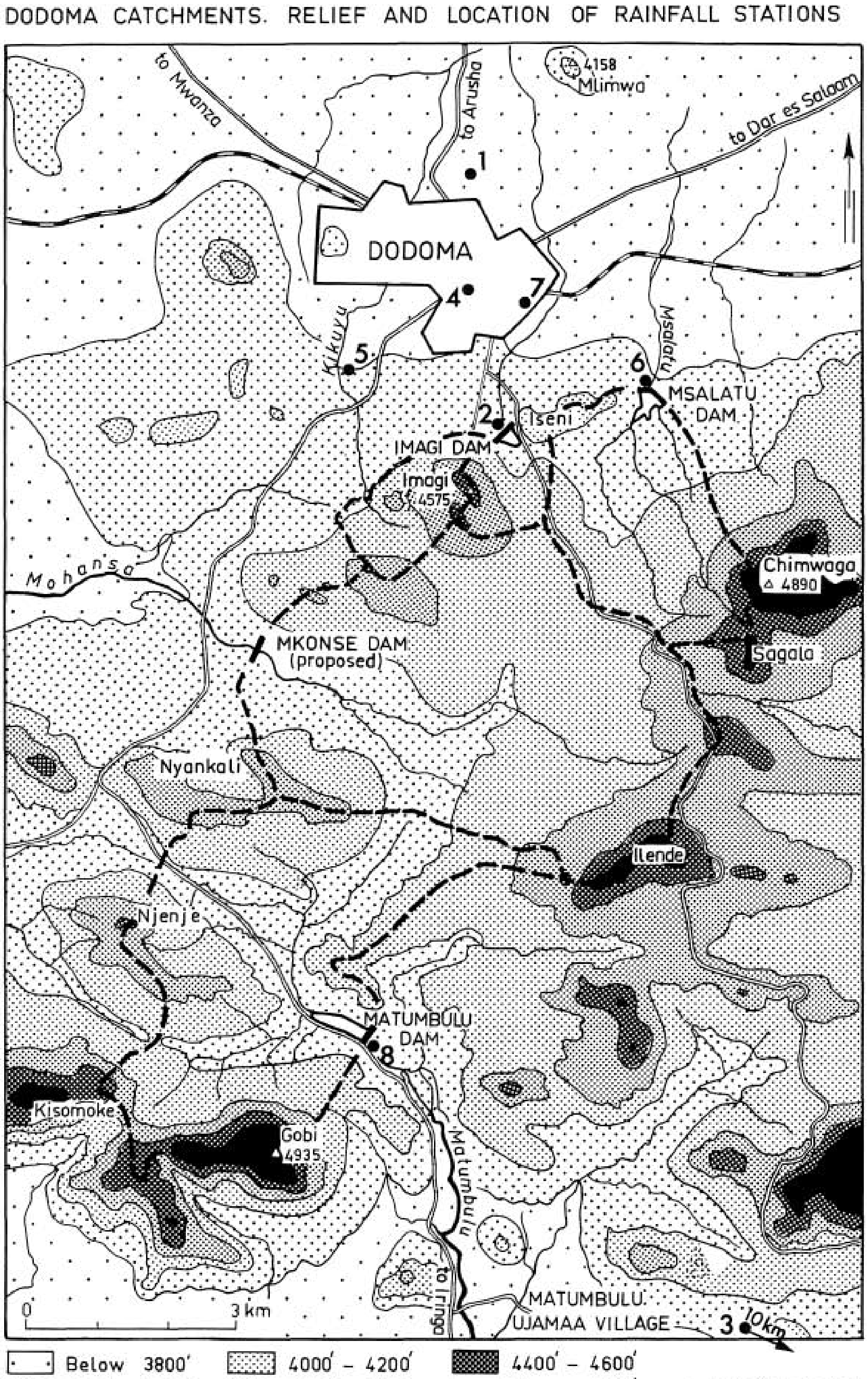
vi) Around Dodoma, many fields were again cleared on the upper pediments.

vii) The result was increased erosion and in some cases new gullies were formed.

viii) After all, the conservation program failed. The banks were not strong enough to keep the runoff water back. On occasion with intense rain the water broke through one contour bank after the other. The reason for the collapses may have been seepage underneath the ridges or defects in the design.

The investigation area of the report is shown in Figure 7.64.

The conditions at that time are shown in Figure 7.65 (quoted from "Document Ch").



Source: Document Ch, p. 19

Figure 7.64: Dodoma Catchments

Kongwa Plain (October 1974)

Msalatu River (March 1970)

Imagi Dam Full View (December 1970)

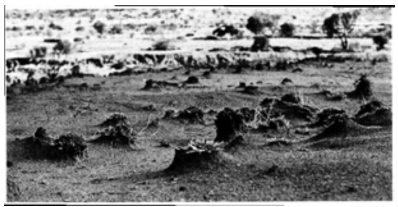
Deciduous bush in Mpwapwa
(November 1974)

Tor Topography and Cattle Track (December 1971)

Thicket in Ugogo
(Early 20th Century)

Overgrazing
(October 1974)

Erosion in Kondoa
(December 1971)



Sheet Erosion
(December 1971)

Tree-less Land
(September 1971)

Active Gully Erosion
in Kondoa (December 1971)

Wooded Grassland in the
Kongwa (early 20th Century)

Source: Document Ch

Figure 7.65: Condition of This Area in the 20th Century

(2) Real Condition of Dam Deposition

At that time, five irrigation dams were constructed in Dodoma and its surrounding areas. The original function of these dams has declined due to sediment deposition. The condition of the five dams' deposition is reported in "Document Ch". The result is shown in Table 7.3 (edited by the JICA Study Team). The locations of four out of the five dams are shown in Figure 7.66.

Table 7.3: Condition of Dam Deposition

Dam Name	Construction	Catchment Area (km2)	Capacity (m3) (a)	Note
Ikowa	1956-57	612.0	3,807,000	
Matumbulu	1960	15.0	333,000	
Msalatu	1944	8.5	420,000	Excavation: 8,000m3(1953)
Imagi	1929	2.2	169,500	Excavation: 9,000m3(1952)
Kisongo	1960	9.3	129,500	

Dam Name	Deposition Term	Total Sediment Yield (m3) (b)	Sediment Ratio (b/a %)	Annual sediment yield			
				m^3/yr	$m^3/km^2/yr$	$t/km^2/yr$ 1)	$mm/km^2/yr$
Ikowa	1957-60	696,000	18.3	231,700	379	570	0.38
	1960-63	371,000	9.7	123,700	202	300	0.20
	1963-69	425,000	11.2	70,800	116	170	0.12
	1969-74	315,000	8.3	63,000	103	150	0.10
	1957-74	**1,807,000**	**47.5**	**106,300**	**174**	**260**	**0.17**
Matumbulu	1962-71	84500	25.4	9389	626	940	0.63
	1971-74	20000	6.0	6667	445	670	0.45
	1962-74	**104500**	**31.4**	**8708**	**581**	**870**	**0.58**
Msalatu	1944-50	31,000	7.4	5,167	607	910	0.61
	1950-60	39,000	9.3	3,900	458	690	0.46
	1960-71	60,000	14.3	5,455	641	960	0.64
	1971-74	14,000	3.3	4,667	548	820	0.55
	1944-74	**144,000**	**34.3**	**4,800**	**564**	**850**	**0.56**
Imagi 2)	1934-50	17,500	10.3	1,094	497	750	0.50
	1950-60	16,500	9.7	1,650	750	1,130	0.75
	1960-71	15,000	8.8	1,364	620	930	0.62
	1934-71	**49,000**	**28.9**	**1,324**	**602**	**900**	**0.60**
Kisongo 2) 3)	1960-69	37,400	28.9	4,156	447	670	0.45
	1969-71	11,900	9.2	5,950	640	960	0.64
	1960-71	**49,200**	**38.0**	**4,473**	**481**	**720**	**0.48**

1) γ: 1.5g/cm^3 2) edited by JICA study team 3) The other watershed (3° 20' S,36° 35'E)

Source: Document Ch, edited by JICA Study Team

Source: JICA Study Team

Figure 7.66: Map of Existing Four Dams in the Upstream Area of Kinyasungwe

7.5.2 Land Cover Classification by Satellite Photo Analysis

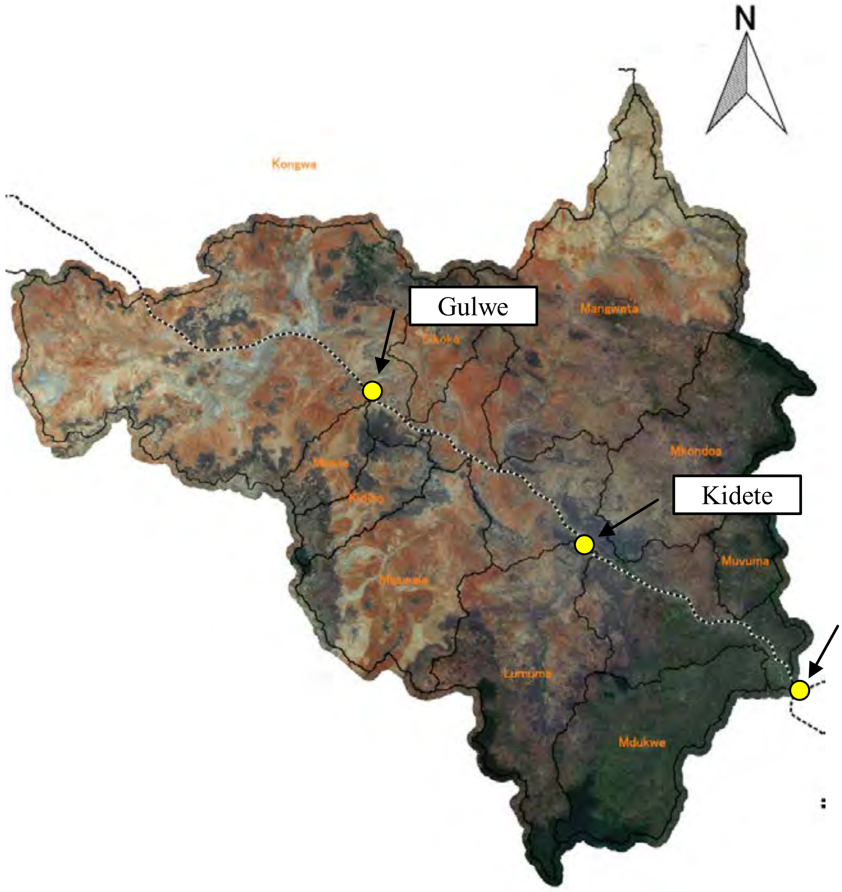
According to the site investigation, the sediment discharge from the upstream areas of the Gulwe Bridge to the downstream areas is judged as not obvious, except for wash loads. Therefore, the sediment productivity between Kilosa and Gulwe is studied further below:

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.

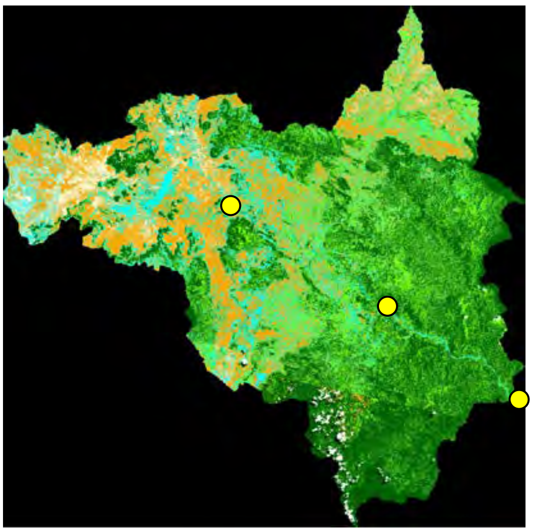
Figure 7.67 shows the optical image of the target area produced by RapidEYE, which was photographed in 2013. The optical image is the same tone as it is visible to the human eye. According to Figure 7.67, a dark tone corresponds to forest zones, a slightly less dark tone exists around the forest, and a reddish-brown tone corresponds to zones where the sediment productivity is high.

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 (Figure 7.68).

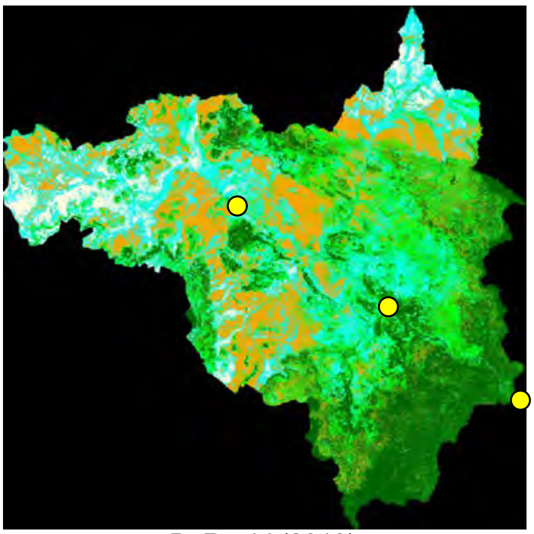


Source: JICA Study Team

Figure 7.67: Optical Image (RapidEYE 2013)



A: Spot (2007)



B: Rapid (2013)

Source: JICA Study Team

Figure 7.68: 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 Table 7.4. Figure 7.69 shows the condition of the typical sites of each color.

Table 7.4: Tone Classification of the Image

Color	Characteristics of Distribution Area
Green	Dense Forest Area
Yellow Green	Bush or Cultivated Land Area
Orange	Mainly Weathered Rock Area of Mafic Igneous (main land use: Village, Cultivated Land)
Light Blue	Mainly Weathered Rock 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

Green Zone Light Green Zone

Orange Zone Light Blue Zone

Figure 7.69: Condition of Typical Sites of Colored Areas

7.5.3 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 Table 7.5.

Table 7.5: Classification of Tributaries by Sediment Productivity

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

Source: JICA Study Team

(2) Difference of the Productivity by Slope Gradient

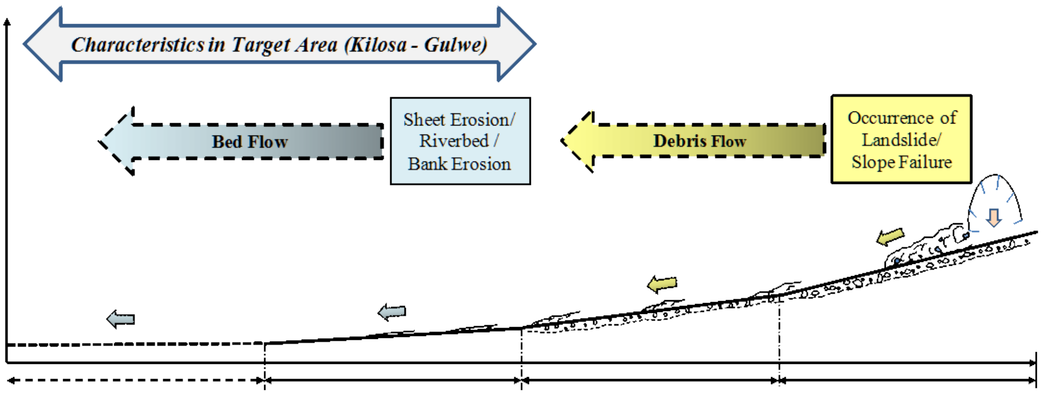
The gradients of the slope and riverbed are important factors in sediment transportation ability. Figure 7.70 shows the general sediment movement pattern according to the gradients. According to this figure, the following things can be pointed out.

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).

Figure 7.71 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.

General Characteristics of Sediment Discharege

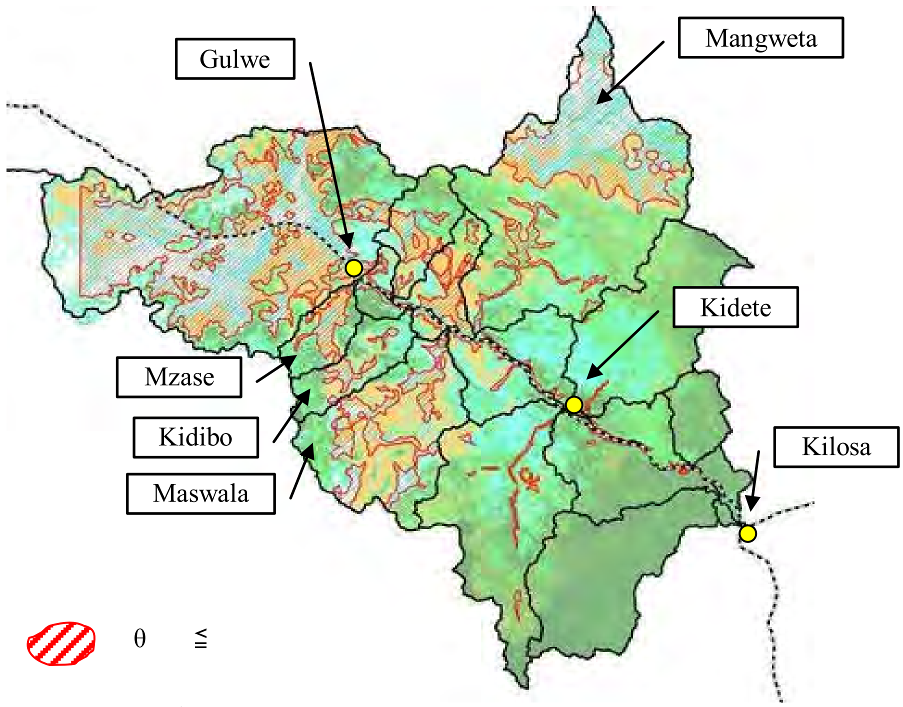


Riverbed Gradient	θ<1/300-1/200	θ<2-3deg (1/30-1/20)	θ<5-10deg (1/7-1/6)	15deg(1/4)<=θ
Occurrence area	Plain / Swamp	Pediment	Foot of Mountain	Mountain Slope
Erosion Form	*(River Bank/ Riverbed Erosion)*	Sheet Erosion *(River Bank/ Riverbed Erosion)*	Sheet Erosion *(River Bank/ Riverbed Erosion)*	Landslide /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

Figure 7.70: Sediment Movement Form



Source: JICA Study Team

Figure 7.71: Distribution of Slopes less than Three Degrees (3°)

(3) Calculation 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 Section 7.5.1 and Table 7.6).
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.
iv) This erosion depth includes riverbed and bank erosion.

Table 7.6: 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

Table 7.7 shows the determined annual erosion depth of the respective colored zones.

Table 7.7: 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 as shown in Table 7.8. The 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. Figure 7.72 shows the enlarged view of the land cover by RapidEYE.

Table 7.8 shows the high value for specific sediment discharge ($m^3/km^2/year$) in the upstream in comparison with the downstream. The sediment inflow map into the main river is shown in Figure 7.73.

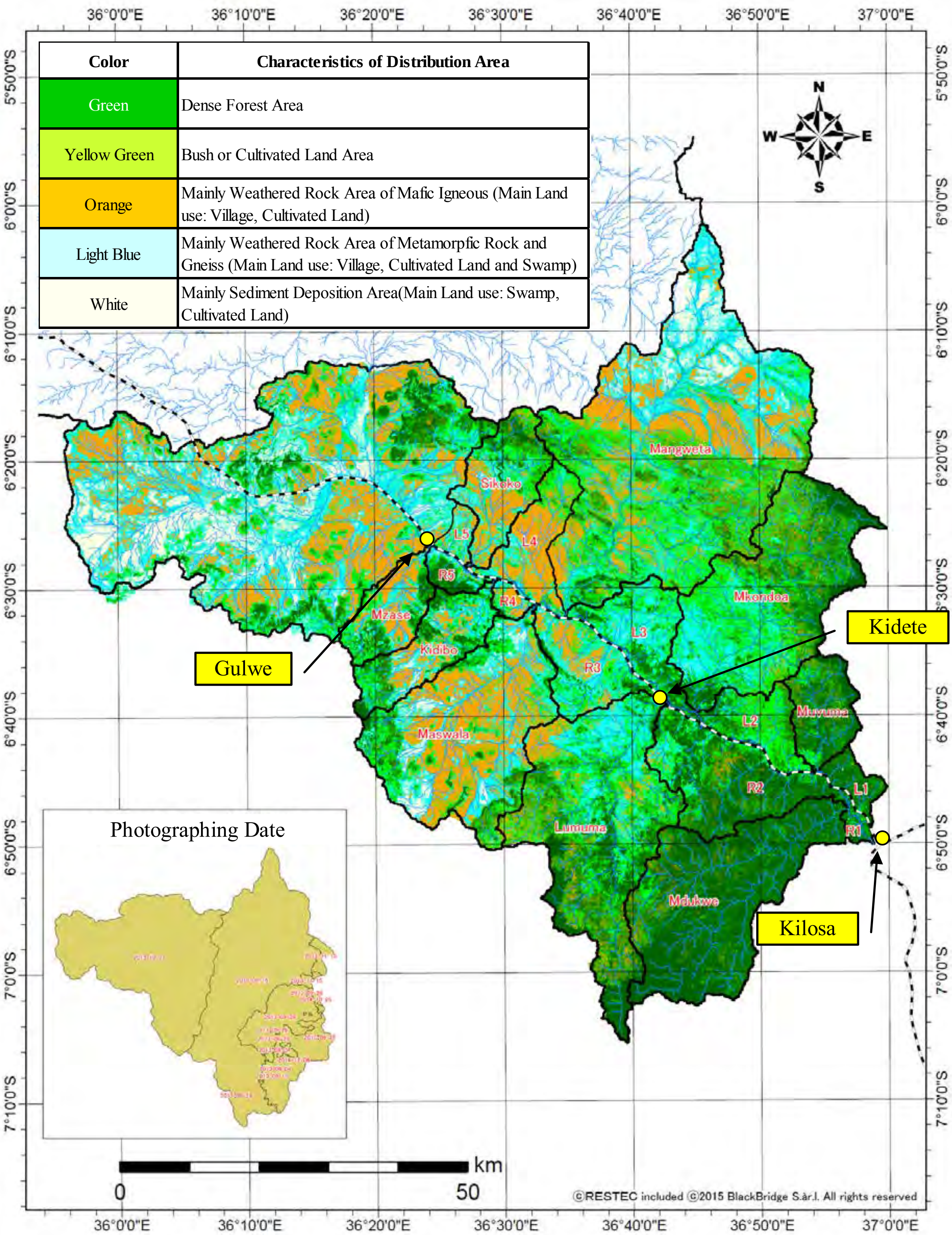
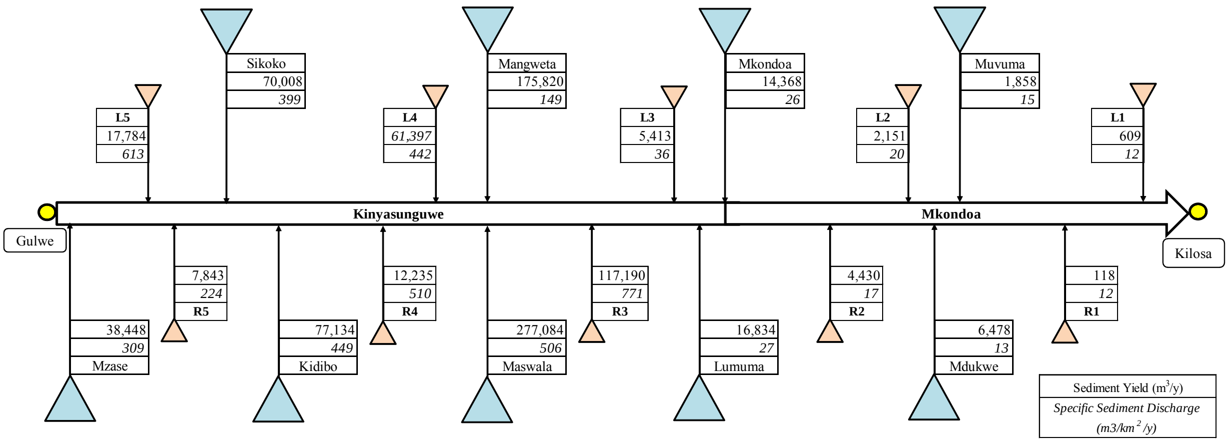


Figure 7.72: Land Cover Map by RapidEYE

Table 7.8: Sediment Yield from Tributaries

Tributary Watershed	Area (km^2)	RapidEYE (2012) Slope Classification	
		Total Sediment Yield (m^3/yr)	Specific Sediment Discharge (m^3/km^2/yr)
Mzase	124	38,448	309
Sikoko	175	70,008	399
Kidibo	171	77,134	449
Maswala	548	277,084	506
Mangweta	1,180	175,820	149
Sub-total (U/S)	2,198	638,494	290
Lumuma	629	16,834	27
Mkondoa	550	14,368	26
Muvuma	123	1,858	15
Mdukwe	512	6,478	13
Sub-total (D/S)	1,814	39,538	22
Tributaries Subtotal	4,012	678,032	169
L1	50	609	12
R1	10	118	12
L2	109	2,151	20
R2	266	4,430	17
Sub-total (D/S)	435	7,308	17
L3	149	5,413	36
R3	152	117,190	771
L4	139	61,397	442
R4	24	12,235	510
L5	29	17,784	613
R5	35	7,843	224
Sub-total (U/S)	528	221,862	420
Remaining Areas Subtotal (Gluwe～Kilosa)	963	229,170	238
Total (U/S)	2,726	860,355	316
Total (D/S)	2,249	46,847	21
Grand Total	4,975	907,202	182

Note: U/S: Upstream, D/S: Downstream
Source: JICA Study Team



Source: JICA Study Team

Figure 7.73: Sediment Inflow Map into the Mainstream

7.6 Study of Countermeasures for Sediment Disaster

7.6.1 Basic Policy

i) To control surface erosion in the cultivated lands.
ii) To control transport for sediment that has already deposited in the tributaries and in the Kinyasungwe River.
iii) To mitigate riverbank erosion.
iv) To stabilize the river channel.
v) To control flooding in the areas where sediment starts to move.
vi) To set up the proper river training works in the appropriate locations.
vii) To set up the criteria for handling of deposition in the controlled areas, to protect the original function of the countermeasures.
viii) To use in-situ materials as much as possible (following the INSEM, or In-situ Stabilized Excavation Materials, construction method).
ix) To prioritize the tributaries and areas/sections to be protected against sediment disaster by countermeasures.
x) To set the planning scale of the countermeasures in consideration of the conditions in the Kinyasungwe/Mkondoa mainstream.

7.6.2 Selection of Countermeasures

Generally, there are following countermeasures exist to control sediment discharge. Table 7.9 briefly explains the function of these countermeasures.

Table 7.9: Functions of Sediment Disaster Countermeasures

Construction Methods	Functions
A: Sand Pocket with Consolidation Dam	• A great deal of sediment, such as volcanic mud flow, can be trapped and stored temporarily. • The sediment in the sand pocket should be removed regularly to maintain the functionality.
B: Check Dam	• To catch the sediment. • To make the riverbed gradient gentle and mititage the potential flood energy.
C: River Channel Works	• To stabilize the river channel. • To prevent riverbed and bank erosion.
D: Riverbed Stabilization by Groundsills	• To fix the river channel. • To prevent riverbed and bank erosion. • Revetments should be constructed with groundsills.
E: INSEM Works	• To use in-situ materials.

Source: JICA Study Team

Figure 7.74 shows examples of applied countermeasures for sediment disasters in Japan and Indonesia.

Source: JICA Study Team and http://www.hkd.mlit.go.jp/sosiki/photo/01/15.html

Figure 7.74: Example of Sediment Disaster Countermeasures in Japan and Indonesia

7.6.3 Selection of Object Tributaries

The following three tributaries are selected based on the sediment discharge characteristics.

(1) First Priority

The Mzase and Maswara Rivers are judged to be of the highest priority, because these rivers have the active sediment discharge and affect the railway operation remarkably. Countermeasures for sediment disasters are required to be conducted immediately for these rivers.

(2) Second Priority

The Kidibo River does not affect the railway operation with remarkable sediment deposition. However, riverbank erosion is proceeding along the right bank in the immediate upstream area of the railway. Therefore, the right bank erosion is presumed to start proceeding after construction of a series of countermeasures. The present cross-section area of the channel works without clearance is judged to be too narrow in consideration of the upstream river width.

7.6.4 Planning Scale

The planning scale of flood protection measures for the railway structures along the Kinyasungwe/Mkondoa mainstream was set to cope with the experienced maximum flood discharge in all stretches of the mainstream. The design high water levels were duly decided based on the design flood discharge distribution as described in Subsection 8.2.1.

In case of the three tributaries of the Mzase, Kidibo and Maswala, appropriate countermeasures with certain scale of structures together with the flood protection along the mainstream are prerequisite to sustain stable railway operations in the future. These three tributaries have significant influence on the sediment discharge of the mainstream, as previously described. On the other hand, 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 Mzase and Maswala Rivers can be considered as part of the mainstream of the Kinyasungwe in terms of continuity of sediment transport along the river channels. In consideration of this, it is recommended that the required clearance and channel width of the tributaries is to be determined by the same planning scale of the mainstream.

7.6.5 Mzase River

(1) Current Conditions of Sediment Discharge

Current conditions of sediment disaster in the Mzase River are summarized as follows:

i) A great deal of sediment deposition is observed in between the upstream of the railway culvert and the confluence of the Kinyasungwe River. The reason is presumed to be that the tractive force of the Kinyasungwe River is not high enough to move it downstream.
ii) Expanding of the erosion area, which is remarkable on the left bank, is progressive in the upstream area of the channel works.
iii) Sediment deposition in the upstream area of the channel works is observed to be not so significant. In fact, an outcrop of the bedrock is observed on the riverbed. The channel works is presumed to be the section in which the sediment flows out without deposition.
iv) The flow section of the culvert which crosses the river is so narrow (40 m) that it interrupts the sediment discharge. Therefore, this culvert is thought to have a function like a check dam.

(2) Current Countermeasures

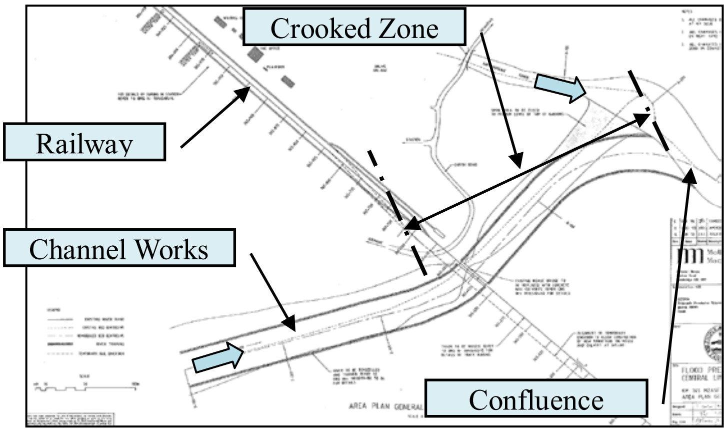
Channel works are constructed across the railway from the confluence of the Kinyasungwe River to the upstream flood area (Figure 7.75). The length is about 1,400 m. The general arrangement and longitudinal profile of river training at that time are shown in Figure 7.76 (Source: *Flood Prevention Works on TRC Central Line Contract Nr 3806 Volume III Drawings February 1994: Mott MacDonald in association GETINSA and Inter-Consult Ltd; hereinafter called as "Document M"*). The width of the river channel is a little narrower than that of the original river. The riverbed level was remodeled from 7.5 m/1000 m to 10.2 m/1000 m (Table 7.10 and Figure 7.77). However, the riverbed slope of the Kinyasungwe River is about 1/10 as compared with that of the Mzase River.

Almost Straight Channel Works

Crooked Zone near the Railway

Outcrop in the Channel Works

Figure 7.75: Existing Channel Works (Mzase)



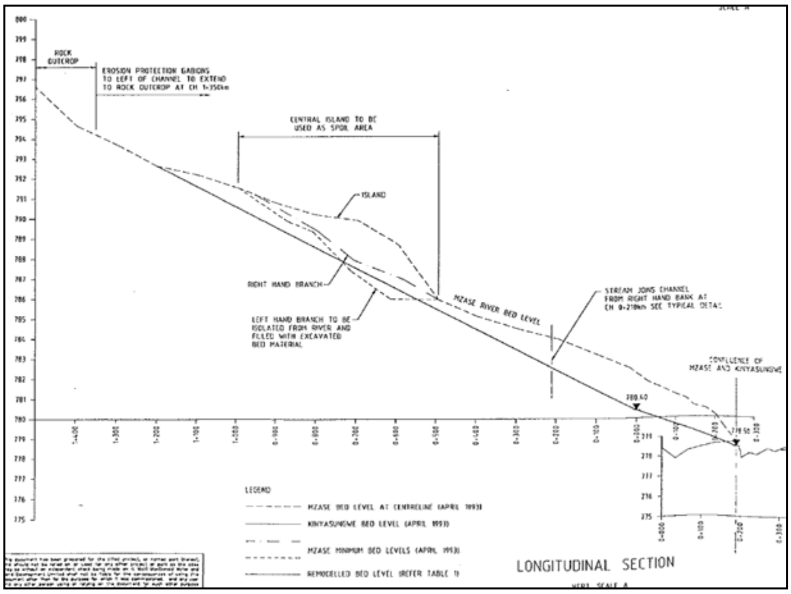
Source: Document M

Figure 7.76: Alignment of the Channel Works near Confluence (Mzase)

Table 7.10: Remodeled Bed Levels and Slopes (Mzase)

River	Chainage (m)	Bed Level at Centerline (m)	Slope Downstream of Chainage (m per 1000 m)
Mzase River	0-255	778.50	N/A
	0-200	778.90	7.5
	0-100	779.65	7.5
	0+000	780.40	7.5
	0+100	781.42	10.2
	0+200	782.44	10.2
	0+300	783.46	10.2
	0+400	784.48	10.2
	0+500	785.50	10.2
	0+600	786.52	10.2
	0+700	787.54	10.2
	0+800	788.56	10.2
	0+900	789.58	10.2
	1+000	790.60	10.2
	1+100	791.62	10.2
	1+200	792.64	10.2
Kinyasungwe River	0+190	778.50	1.2
	0+200	778.49	1.2
	0+400	778.25	1.2
	0+600	778.01	1.2
	0+800	777.77	1.2
	0+1000	-	1.2

Source: Document M



Source: Document M

Figure 7.77: Longitudinal Section of Channel Works (Mzase)

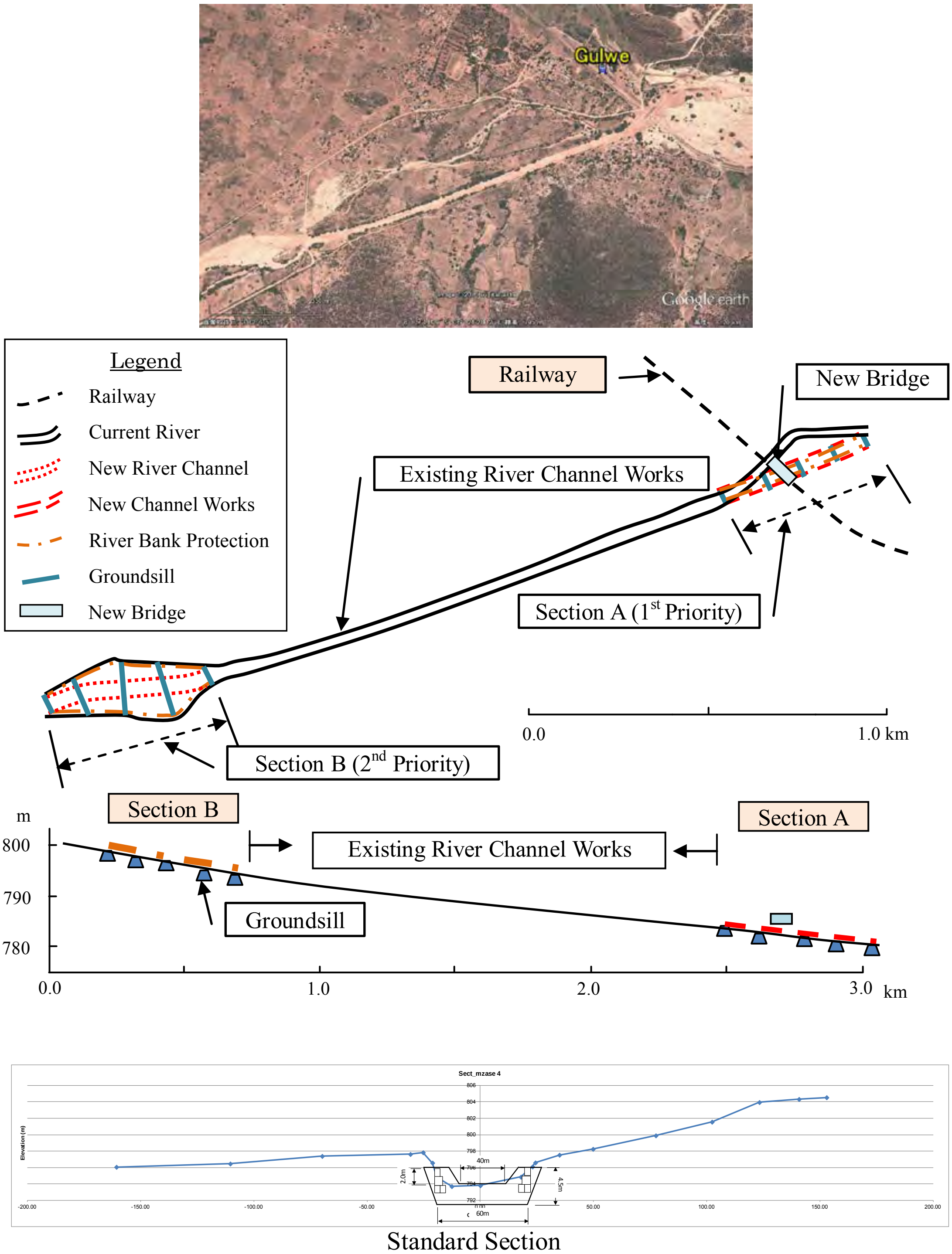
(3) Policy and Target Area of Countermeasures

The policy and target area of countermeasures for the Mzase River are as follows (Figure 7.78):

i) To straighten the curved channel works near the confluence. The curved channel interferes with the smooth flow and causes the sediment deposition (Section A).
ii) To stabilize the river channel and to prevent riverbank erosion in the upstream areas of the channel works by means of construction of ground sills, because riverbank erosion would be a major source of sediment (Section B).
iii) To remain the existing river channel between sections A and B as it is, because the portion works effectively.
iv) The construction area can be prioritized considering the direct effects to the safety of the railway.

(4) Proposed Countermeasures

Figure 7.78 shows the proposed plan of the countermeasure for the sediment disaster.



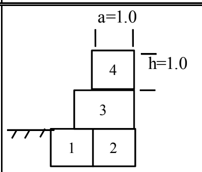
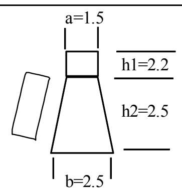
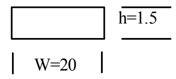
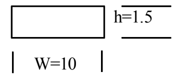
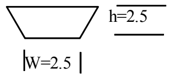
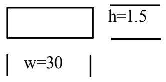
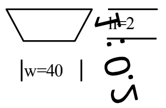
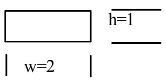
Source: JICA Study Team

Figure 7.78: Proposed Countermeasures (Mzase)

(5) Priority of Construction, Approximate Work Quantity and Cost

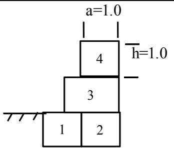
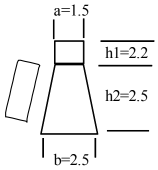
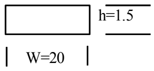
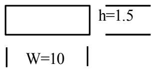
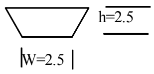
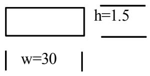
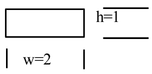
The first priority area is the downstream side near the railway, and the second is the upstream side. Table 7.11 shows the approximate work quantity and cost of the countermeasures for the first priority area of the Mzase River, and Table 7.12 shows that of the second priority area.

Table 7.11: Approximate Work Quantity and Cost of the Mzase River (First Priority)

Type of Consruction	Structure	Cross section (m2)	Ave Length (m)	Volume (m3)	No	ΣV (m3)	Unit price (Tsh)	cost (Tsh)	Note
Bank Protection of Upstream Area (Gabion)		4.5	500	2,250	2	4,500	306,952	1,381,284,000	Protection of river bank
Grandsill (Concrete)		8.3	40	200	5	1,000	487,512	487,512,000	Width of Overflow section : 40m With Apron
Apron (Concrete)		30	40	1,200	5	6,000	487,512	2,925,072,000	Width of Overflow section
Apron (Gabion)		15	40	600	5	3,000	306,952	920,856,000	Width of Overflow section
Excuvation for Groundsill		10	40	400	5	2,000	14,444	28,888,000	
Excuvation for Apron (Concrete and Gabion)		45	40	1,800	5	9,000	14,444	129,996,000	
Excuvation for Channel Works		84	500	42,000	1	42,000	14,444	606,648,000	
Excuvation for Depth of Embedment		2	500	1,000	2	2,000	14,444	28,888,000	For Bank Protection
Total								6,509,144,000	

Source: JICA Study Team

Table 7.12: Approximate Work Quantity and Cost of the Mzase River (Second Priority)

Type of Consruction	Structure	Cross section (m2)	Ave Length (m)	Volume (m3)	No	ΣV (m3)	Unit price (Tsh)	cost (Tsh)	Note
Bank Protection of Upstream Area (Gabion)		4.5	500	2,250	2	4,500	306,952	1,381,284,000	Protection of river bank
Grandsill (Concrete)		8.3	80	532	5	2,660	487,512	1,296,781,920	Width of Overflow section : 40m With Apron
Apron (Concrete)		30	44	1,320	5	6,600	487,512	3,217,579,200	Width of Overflow section +4m(2+2)
Apron (Gabion)		15	44	660	5	3,300	306,952	1,012,941,600	Width of Overflow section +4m(2+2)
Excuvation for Groundsill		10	80	800	5	4,000	14,444	57,776,000	
Excuvation for Apron (Concrete and Gabion)		45	44	1,980	5	9,900	14,444	142,995,600	
Excuvation for Depth of Embedment		2	500	1,000	2	2,000	14,444	28,888,000	For Bank Protection
Total								7,138,246,320	

Source: JICA Study Team

7.6.6 Maswala River

(1) Current Conditions of Sediment Discharge

The current conditions of sediment disaster in the Maswala River are summarized as follows:

i) A large alluvial fan deposit, which is an old one, is distributed at the confluence of the Kinyasungwe River. The reason for this is presumed to be that the Kinyasungwe River has a tractive force.
ii) This old fan deposit has been developed with recently-discharged sediment.
iii) In the upstream areas of this fan, remarkable bank erosion is observed. The bank-to-bank width at the eroded section is more than 150 m.
iv) The flow sections of the bridge and the road which cross the river are so narrow that these facilities interrupt sediment discharge. Therefore, these facilities are thought to have a function like a check dam.

(2) Current Countermeasures

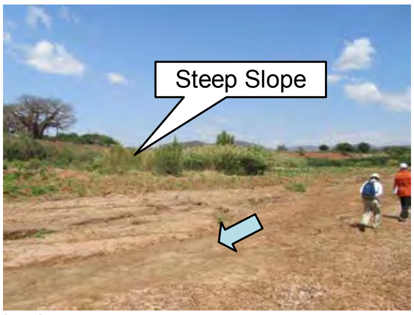
To date no major channel works, such as in the Mzase and the Kidibo River, has been done in the Maswala River. Flood countermeasures currently consist of small-scale channel works, but these river channels are not currently the main ones, and therefore, almost all the sediment discharge flows into the downstream river channels.

Figure 7.79 shows the current river channels, and Figure 7.79A and B show minor upstream ones. Figure 7.79C and D show the steep slope formed at the end parts of the alluvial fan. Figure 7.79E and F show the downstream river channels which are obstructed by discharged sediment. This condition shows that minor works cannot rectify this situation.

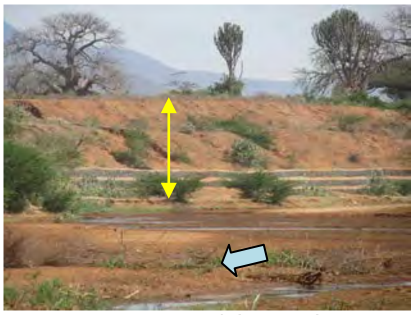
On the other hand, Figure 7.79G and H show current condition of the upstream reaches of the river, where the riverbank erosion is remarkable. Figure 7.79I and J show the flood traces on the right bank side. The depth of flood discharge at this site is about 2.5 m.

A: Channel Works
at the Upstream Side

B: Old River Channel



C: Old Alluvial Fan and Mainstream



D: Near View of Steep Slope

E: Obstructed the Culvert
in the Current River Channel

F: Same as on the Left
(Next to C)

G: River Conditon
of the Upstream Area

H: River Conditon
of the Upstream Area

I: Flood Trace of the Right Bank

J: Near View of G
Height of Flood; H≈2.5m

Figure 7.79: Current River Condition (Maswala)

(3) Policy and Target Area of Countermeasures

The policy and target area of countermeasures for the Maswala River is as follows (Figure 7.80):

i) To fix the river channel and to prevent riverbank erosion in the upstream side, because the riverbank erosion is presumed to be a supply source of a great deal of sediment (Target area A).

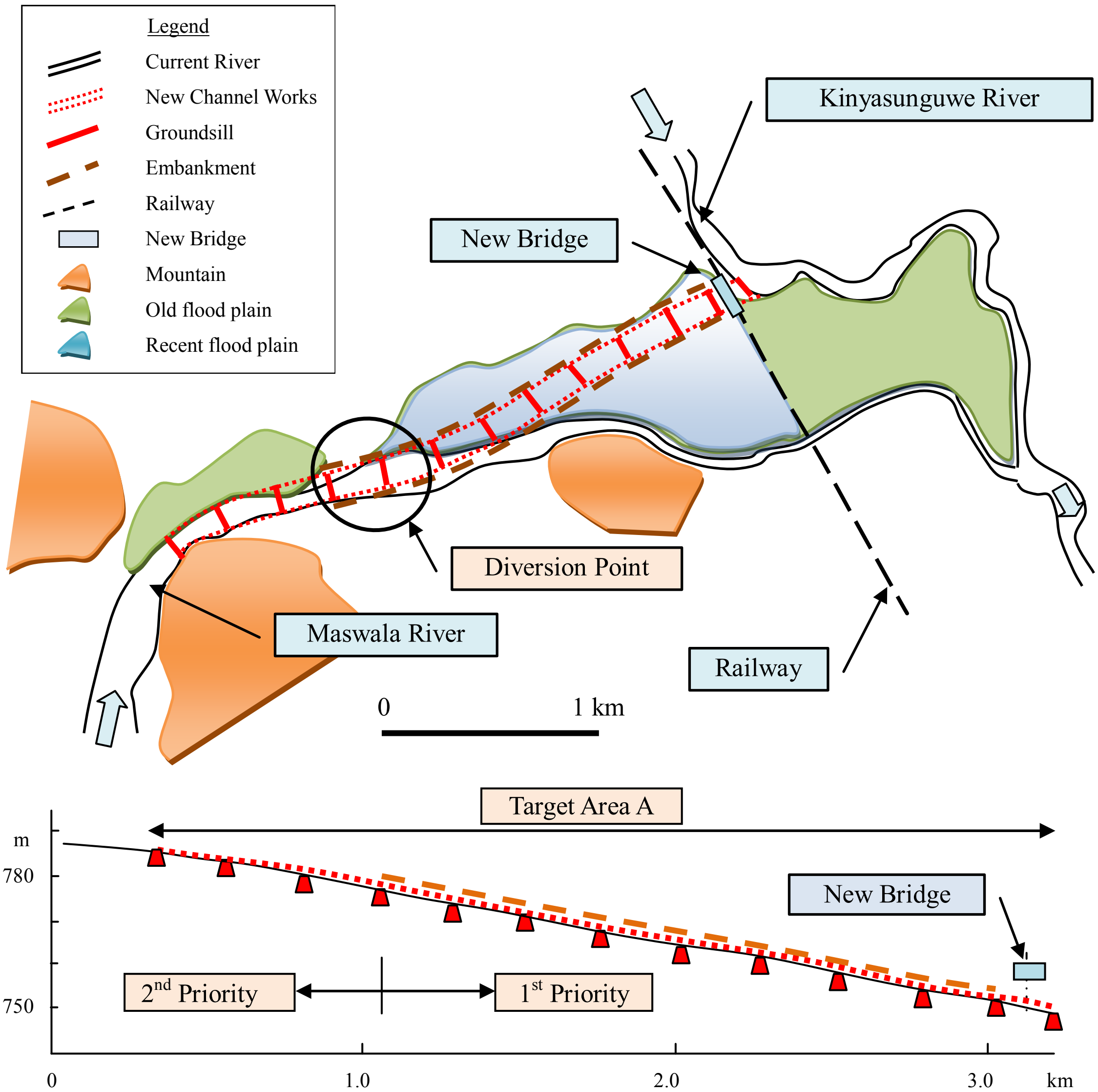
ii) To make the main river channel have enough cross-section area from the upstream to the downstream side. This is because at present, the current river channels do not have enough cross-section area as a whole. Therefore, the flow cross-section of the river channel works is required to be reexamined.

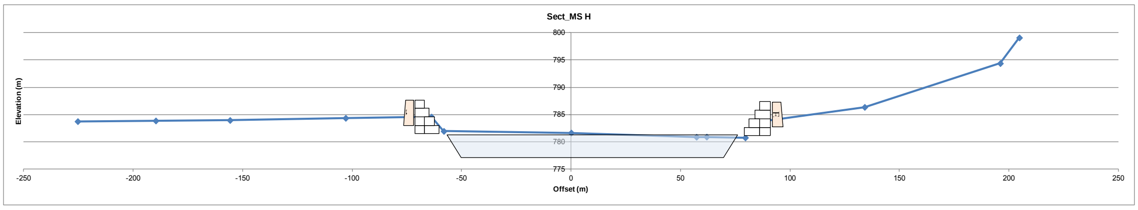
iii) The construction area can be prioritized considering the direct effects on the railway.

(4) Proposed Countermeasures

Figure 7.80 shows the proposed plan of the sediment disaster countermeasures. At this site, a set of comprehensive sediment countermeasures is required, consisting of channelization and construction of groundsills. In this area, the first priority is the downstream section from the diversion point, considering the connection to the current river channel.


Google earth


Legend
Current River
New Channel Works
Groundsill
Embankment
Railway
New Bridge
Mountain
Old flood plain
Recent flood plain
Kinyasunguwe River
New Bridge
Diversion Point
Maswala River
Railway
0
1 km
Target Area A
m
780
750
New Bridge
2nd Priority
1st Priority
0
1.0
2.0
3.0
km



Standard Section

Source: JICA Study Team

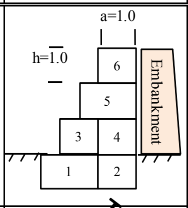
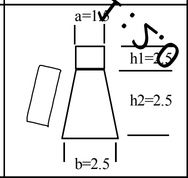
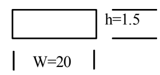
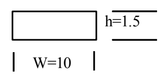
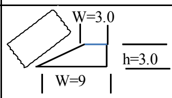
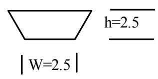
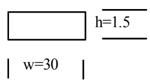
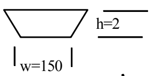
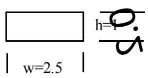
Figure 7.80: Proposed Countermeasures (Maswala)

(5) Priority of Construction, Approximate Work Quantity and Cost

The first priority area is the downstream side, between the connection with the river and the railway, and the second priority area is the remaining upstream side. Table 7.13 shows the approximate work quantity for first priority countermeasures for the Maswala River, and Table 7.14 shows that of the second priority ones.

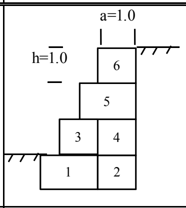
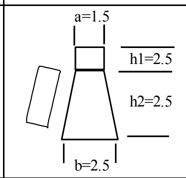
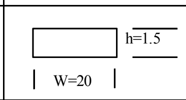
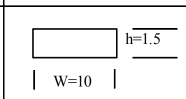
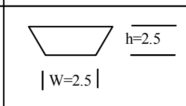
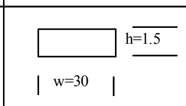
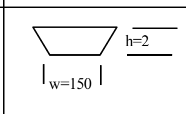
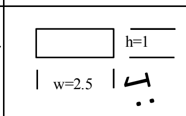
The upstream stretches of the new channel works has to be connected with the current river channel, as shown in Figure 7.80, to smoothly connect with the mainstream of the Kinysungwe. Therefore, the end of the upstream stretches is located at approximately 2 km from the railway, as marked in the figure above (diversion point).

Table 7.13: Approximate Work Quantity and Cost for the Maswala River (First Priority)

Type of Consruction	Structure	Cross section (m2)	Ave Length (m)	Volume (m3)	No	ΣV (m3)	Unit price (Tsh)	cost (Tsh)	Note
Bank Protection (Gabion)		7	1,800	12,600	2	25,200	306,952	7,735,190,400	Protection of river bank
Grandsill (Concrete)		8.75	150	825	10	8,250	487,512	4,021,974,000	Width of Overflow section : 130m With Apron
Apron (Concrete)		30	134	4,020	10	40,200	487,512	19,597,982,400	Width of Overflow section +4m(2+2)
Apron (Gabion)		15	134	2,010	10	20,100	306,952	6,169,735,200	Width of Overflow section +4m(2+2)
Embankment		18	1,800	32,400	2	64,800	27,084	1,755,043,200	
Excuvation for Groundsill		10	150	1,500	10	15,000	14,444	216,660,000	
Excuvation for Apron (Concrete and Gabion)		45	134	6,030	10	60,300	14,444	870,973,200	
Excuvation for Channel Works		304	1,500	456,000	1	456,000	14,444	6,586,464,000	Excwept exising River Channel
Excuvation for Depth of Embedment		2.5	1,800	4,500	2	9,000	14,444	129,996,000	For Bank Protection
Total								47,084,018,400	

Source: JICA Study Team

Table 7.14: Approximate Work Quantity and Cost for the Maswala River (Second Priority)

Type of Consruction	Structure	Cross section (m2)	Ave Length (m)	Volume (m3)	No	ΣV (m3)	Unit price (Tsh)	cost (Tsh)	Note
Bank Protection (Gabion)		7	1,200	8,400	2	16,800	306,952	5,156,793,600	Protection of river bank
Grandsill (Concrete)		8.75	150	825	3	2,475	487,512	1,206,592,200	Width of Overflow section : 130m With Apron
Apron (Concrete)		30	134	4,020	3	12,060	487,512	5,879,394,720	Width of Overflow section +4m(2+2)
Apron (Gabion)		15	134	2,010	3	6,030	306,952	1,850,920,560	Width of Overflow section +4m(2+2)
Excuvation for Groundsill		10	150	1,500	3	4,500	14,444	64,998,000	
Excuvation for Apron (Concrete and Gabion)		45	134	6,030	3	18,090	14,444	261,291,960	
Excuvation for Channel Works		304	40	12,160	1	12,160	14,444	175,639,040	Left Bank only
Excuvation for Depth of Embedment		2.5	1,200	3,000	2	6,000	14,444	86,664,000	For Bank Protection
Total								14,682,294,080	

Source: JICA Study Team

7.6.7 Kidibo River

(1) Current Conditions of Sediment Discharge

The current conditions of sediment disaster in this river are as follows:

i) A large alluvial fan deposit, which is an old one, is distributed at the confluence of the Kinyasungwe River. The reason for this is presumed to be that the Kinyasungwe River has a tractive force.

ii) Expanding of the remarkable erosion is observed on the right bank, but the left bank is protected by the bank protection works.

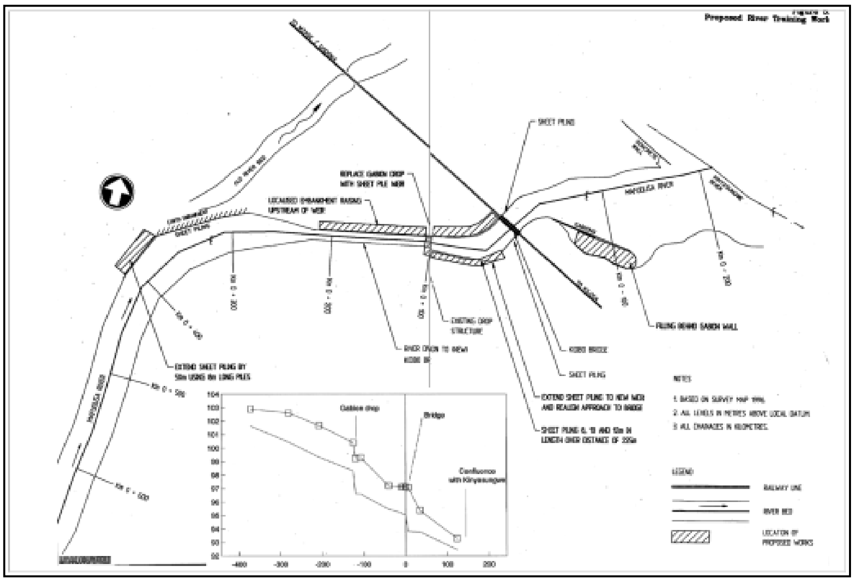
iii) The width of the Kidibo Bridge is about 20 m. Considering the current river width of 40 m at the eroded section, this bridge width seems to be insufficient to allow a smooth flow under the bridge section. Therefore, a washing away of ballast has happened occasionally due to flooding.

(2) Current Countermeasures

Channel works exist across the railway from the confluence of the Kinyasungwe River to the upstream flood area (Figure 7.81). According to the report "Flood Prevention Works on TRC Central Line Contract Nr 3806 Additional Works Volume I, Main Report, April 1997, Mott MacDonald" (hereinafter called "Document F"), the Kidibo Bridge, designed by Gauff Consulting Engineers, was constructed in 1991. Document F also notes a lack of flow cross-section area. Moreover, additional measures, such as sheet piles, were proposed. These countermeasures were constructed, however, about 15 years have passed since their completion.

However, in fact, the right bank was eroded remarkably even after this series of countermeasures, as shown in Figure 7.81A. The quantity of eroded sediment is estimated to be at least about 105,000 m^3 (21,000 m^2 by 5 m). The average erosion width is estimated to be about 4.7 m (21,000 m^3 / 300 m / 15 years = 4.7 m). This phenomenon is presumed to be due to a series of countermeasures. Therefore, it is strongly recommended that a re-examination of the flow cross-section of the river channel works should be conducted.

A: Old Right Bank (Red Line)



B: Preliminary Design Map at That Time

Source: Document F

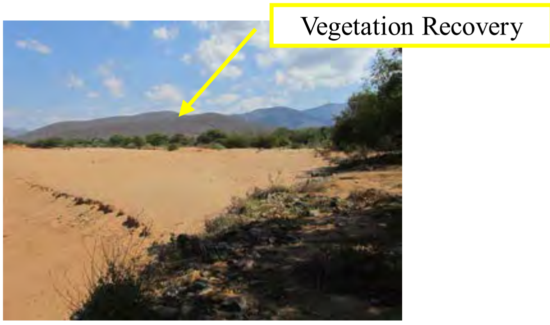
Figure 7.81: Current Coutermeasure (Kidibo)

Figure 7.82 shows the current river conditions. Figure 7.82A shows the condition of maintenance after the flood. Figure 7.82B and C shows the existing bank protection. Some vegetation recovery is observed along the left bank (Figure 7.82D), showing that recent river erosion has not occurred along the left bank.

A: Maintenance after Flood

B: Gabion Observed
at the Right Bank

C: Bank Protection along
the Left Bank (Sheet Piles)



D: Trees Observed along
the Left Bank

Figure 7.82: Current River Conditions and Bank Protection (Kidibo)

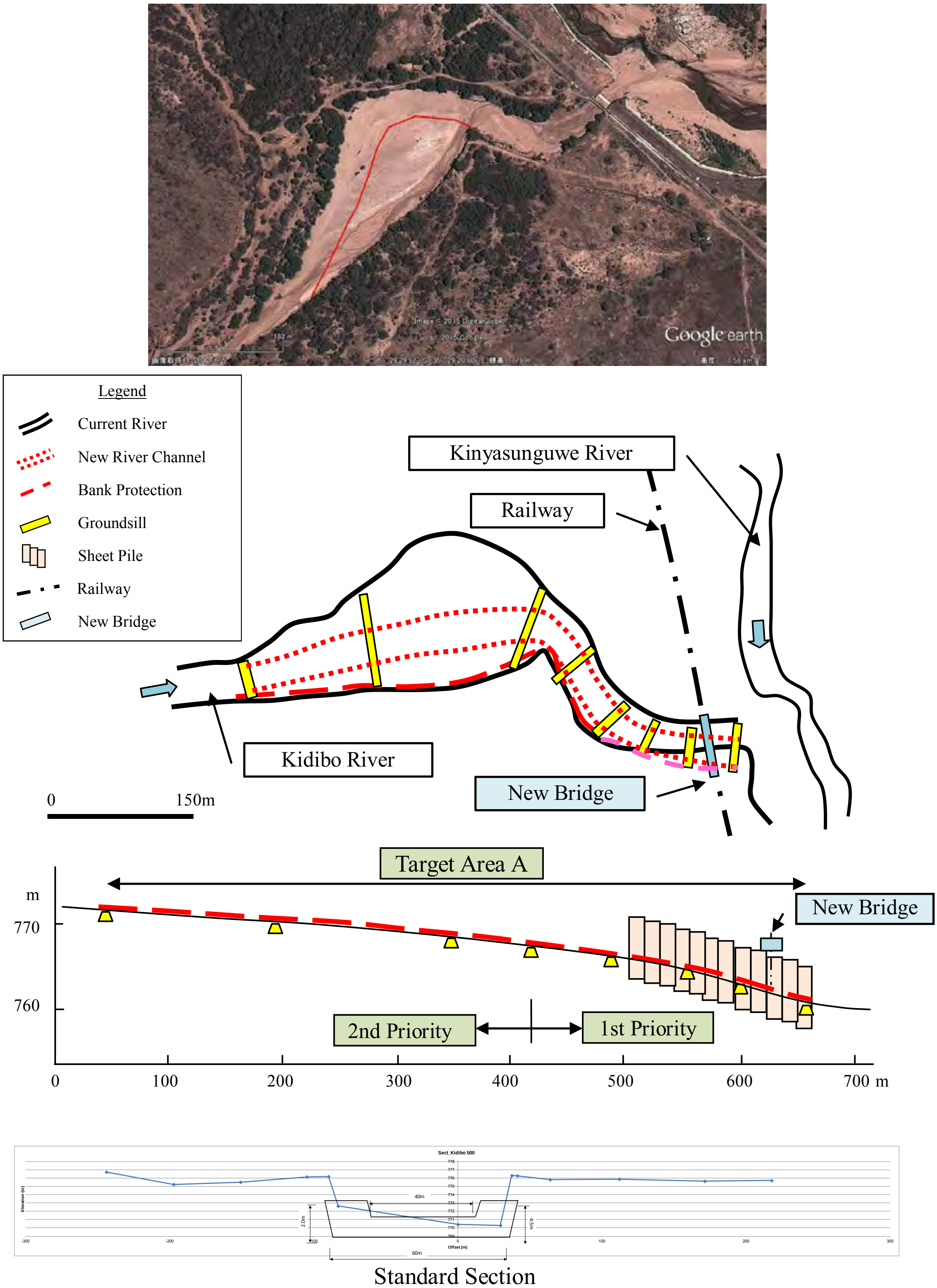
(3) Policy and Target Area of Countermeasure

The policy and target area of countermeasures for the Kidibo River is as follows (Figure 7.83):

i) The left bank is not currently eroded, because the existing bank protection is urged to be effective enough.
ii) However, the erosion of the right bank is proceeding. Therefore, it is required to fix the river channel and to prevent the right riverbank erosion in the flood area (Target Area A).
iii) To re-examine the flow cross section of the river channel works.
iv) The construction area can be prioritized considering the direct effects on the railway.

(4) Proposed Countermeasures

Figure 7.83 shows the proposed design of the sediment disaster countermeasures.



Source: JICA Study Team

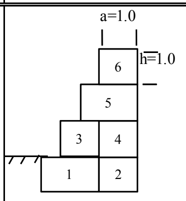
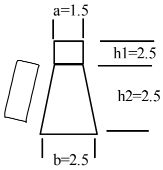
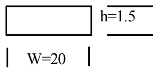
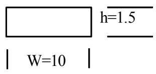
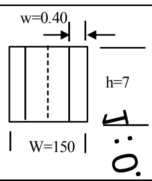
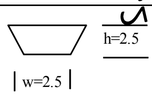
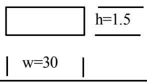
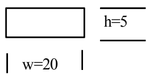
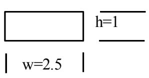
Figure 7.83: Proposed Countermeasures (Kidibo)

(5) Priority of Construction, Approximate Work Quantity and Cost

The first priority area is the downstream side, and the second priority area is the remaining upstream side.

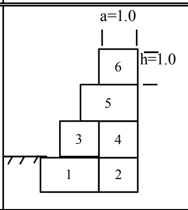
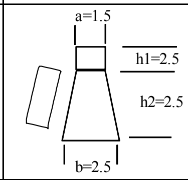
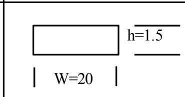
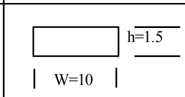
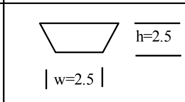
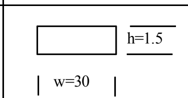
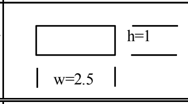
Table 7.15 shows the approximate work quantity and cost of first priority countermeasures for the Kidibo River, and Table 7.16 shows that of second priority ones.

Table 7.15: Approximate Work Quantity and Cost for the Kidibo River (First Priority)

Type of Consruction	Structure	Cross section * (m2)	Ave Length (m)	Volume * (m3)	No	ΣV * (m3)	Unit price (Tsh)	cost (Tsh)	Note
Bank Protection of Right bank (Gabion)		7	100	700	1	700	306,952	214,866,400	Right Bank only
Grandsill (Concrete)		8.75	54	323	5	1,613	487,512	786,113,100	Width of Overflow section : 40m With Apron
Apron (Concrete)		30	44	1,320	5	6,600	487,512	3,217,579,200	Width of Overflow section +4m(2+2)
Apron (Gabion)		15	44	660	5	3,300	306,952	1,012,941,600	Width of Overflow section +4m(2+2)
Sheet Pile (600*180*13.4 (mm))		7	375	2,625	1	2,625	180,560	473,970,000	* (m) For Right Bank
Excuvation for Groundsill		10	54	540	5	2,700	14,444	38,998,800	
Excuvation for Apron (Concrete and Gabion)		45	44	1,980	5	9,900	14,444	142,995,600	
Excuvation for Right bank		100	120	12,000	1	12,000	14,444	173,328,000	
Excuvation for Depth of Embedment		2.5	100	250	1	250	14,444	3,611,000	For Bank Protection
Total								6,064,403,700	

Source: JICA Study Team

Table 7.16: Approximate Work Quantity and Cost for the Kidibo River (Second Priority)

Type of Consruction	Structure	Cross section (m2)	Ave Length * (m)	Volume ** (m3)	No	ΣV ** (m3)	Unit price (Tsh)	cost (Tsh)	Note
Bank Protection of Right bank (Gabion)		7	360	2,520	1	2,520	306,952	773,519,040	
Grandsill (Concrete)		8.75	84	585	3	1,755	487,512	855,583,560	Width of Overflow section : 40m With Apron
Apron (Concrete)		30	44	1,320	3	3,960	487,512	1,930,547,520	Width of Overflow section +4m(2+2)
Apron (Gabion)		15	44	660	3	1,980	306,952	607,764,960	Width of Overflow section +4m(2+2)
Excuvation for Groundsill		10	84	840	3	2,520	14,444	36,398,880	
Excuvation for Apron (Concrete and Gabion)		45	44	1,980	3	5,940	14,444	85,797,360	
Excuvation for Depth of Embedment		2.5	360	900	1	900	14,444	12,999,600	For Bank Protection
Total								4,302,610,920	

Source: JICA Study Team

7.6.8 Total Cost of Countermeasures

Total cost of the countermeasures is shown in Table 7.17.

Table 7.17: Total Cost of Countermeasure

Tributary	Priority	Cost (Tsh)	Cost (Yen)
Mzase River	1st Stage	6,509,144,000	435,394,247
	2nd Stage	7,138,246,320	477,474,670
	Subtotal	13,647,390,320	912,868,918
Maswala River	1st Stage	47,084,018,400	3,149,432,669
	2nd Stage	14,682,294,080	982,093,249
	Subtotal	61,766,312,480	4,131,525,918
Kidibo River	1st Stage	6,064,403,700	405,645,732
	2nd Stage	4,302,610,920	287,800,062
	Subtotal	10,367,014,620	693,445,794
	Total	85,780,717,420	5,737,840,630

1Tsh= 0.07yen

Source: JICA Study Team

7.6.9 Sediment Preventive Effect by Countermeasure

Groundsill and bank protection countermeasures provide prevention against scouring of the riverbed and bank erosion. A quantitative evaluation of the effects is difficult, but can be calculated by the following assumptions:

- Scouring prevention of 0.5 m
- Bank erosion prevention of 2.0 m

Table 7.18 shows the quantitative evaluation for sediment preventive effects in each tributary. The countermeasures in the Mzase and the Maswala Rivers are basically equal to the existing total annual sediment yield, and the Kidibo River is one-third of the existing total annual sediment yield.

Table 7.18: Sediment Preventive Effect by Countermeasure

Tributary	By riverbed scouring protection[1]			By bank erosion protection[1]			Total volume (m3)	Note[2]
	Average construction width (m) (a)	Average construction length (m) (b)	Volume (m3) (a*b*h)	Average construction length (m) (x)	Scouring height (m) (y)	Volume (m3) (x*y*w)		Sediment Yield (m3/year)
Mzase	60	1,000	30,000	2,000	2.0	8,000	38,000	38,448
Maswala	150	3,000	225,000	6,000	4.0	48,000	273,000	277,084
Kidibo	60	600	18,000	600	5.0	6,000	24,000	77,134
Total			273,000			62,000	335,000	392,666
	Assumed scouring depth (m) (h)		0.5	Assumed scouring width (m) (w)		2.0		

1) ex) Mzase: 60*1,000*0.5=30,000(m^3), 2,000*2.0 *2.0=8,000(m^3) : Total 30,000+8,000=38,000(m^3)
2) Note: Refer to Table 7.8
Source: JICA Study Team

7.6.10 Future Issues

(1) Management for the Sediment

The purpose of each countermeasure is to fix the river channel and allow the smooth flow of sediment. Hereby, the area of countermeasures can be got the stable river channel. However, unless the conservation in the upstream area is definitely conducted, the sediment discharge will continue. The sediment deposition in the mainstream is concerned to generate the meandering affecting the riverbank erosion. Therefore, the monitoring for the sediment is required continuously.

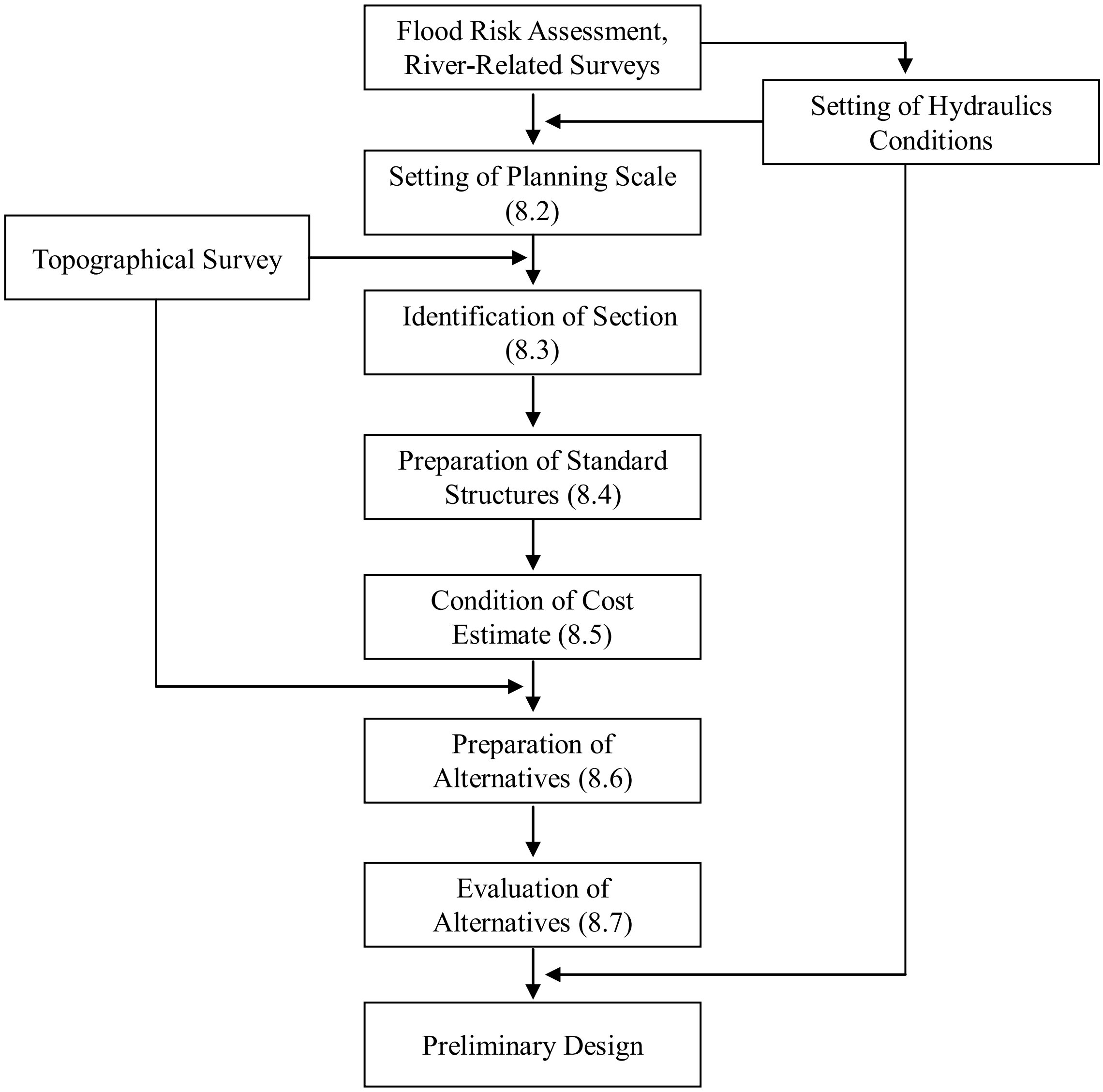
(2) Regarding Conservation for the Upstream Area

Conservation in the upstream areas of the watershed is required, as the sediment production in the upstream areas affects the meanderings of the mainstream of the Kinyasungwe River. As previously mentioned (Sections 7.5 and 7.6.1), a great deal of sediment is presumed to be produced from the cultivated lands in the upstream area. The forest in the direct vicinity of these areas is logged for fuel, and floods are assumed to more accelerate the land erosion in this already fragile area, which has lost its water retention capacity. Therefore, reforestation is judged a subject of tantamount important in this area.

8. Selection of the Alternatives for Flood Protection Measures

8.1 Methodology for Preparing Alternatives for Flood Protection Measures

Figure 8.1 presents the overall work flow of preparing alternatives for flood protection measures.



Note: Figures in parenthesis indicate the section of this Final Report.
Source: JICA Study Team

Figure 8.1: Work Flow of Preparation of Alternatives

8.2 Setting of Planning Scale for Preparation of Flood Protection Measures

8.2.1 Identification of Current Conditions

(1) Runoff Characteristics of Wami River Basin

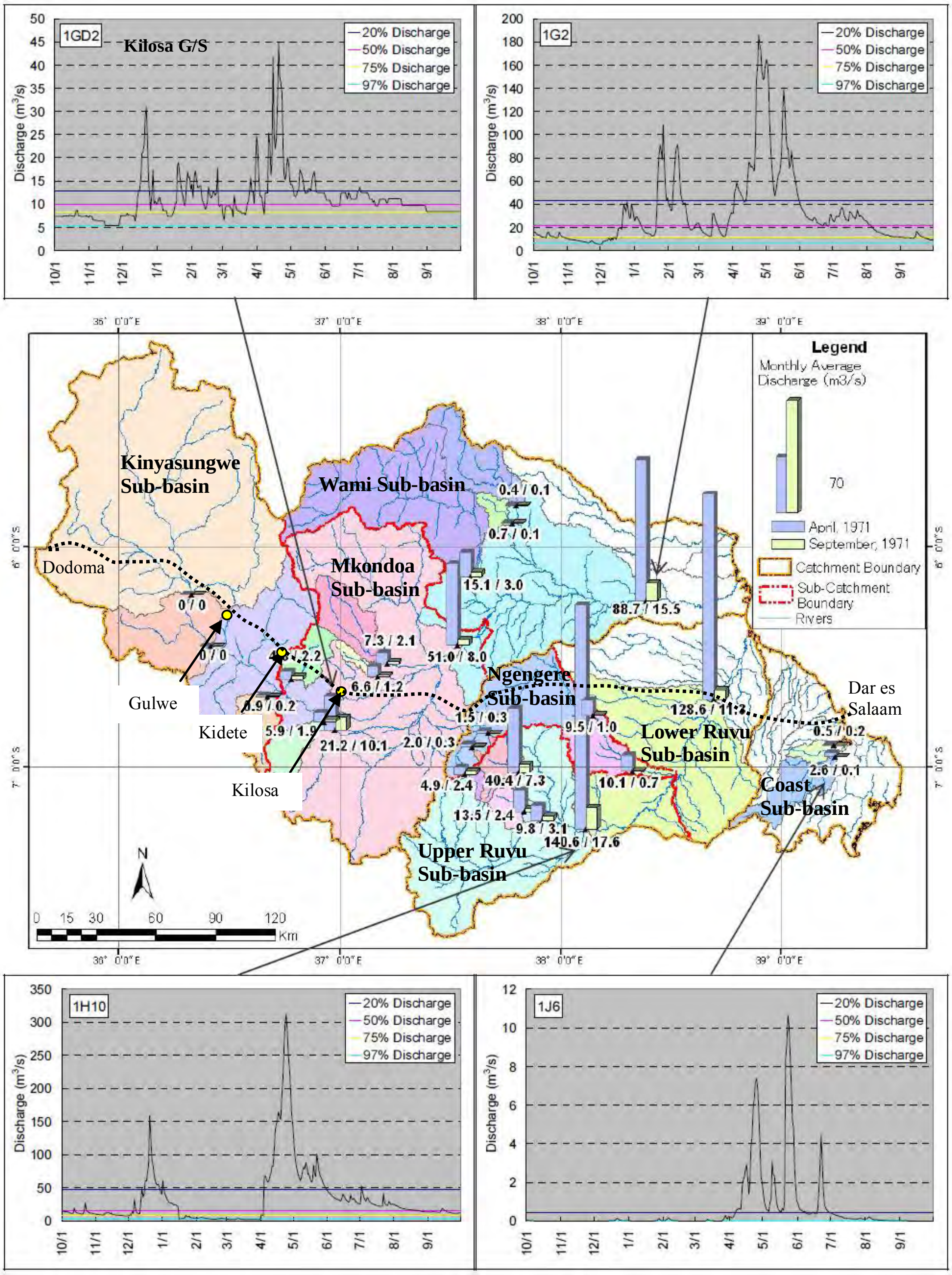
A map of the Wami River basin is shown in Figure 8.2, with its sub-basins and seasonal runoff fluctuation (mean daily discharge fluctuation in a year) statistics at major observatories. Through "the Study on Water Resources Management and Development in Wami/Ruvu Basin" under JICA in 2013, the study areas are divided into total seven sub-basins. The target area for this Study, stretching from Kilosa to Dodoma, is located across the (i) Kinyasungwe and (ii) Mkondoa sub-basins.

The runoff at Kilosa is relatively small with around 10 m^3/s of annual mean daily discharge and 45 m^3/s of annual maximum mean daily discharge. Further, although base flow (approx. 5 m^3/s: 97% dependable discharge) exist at Kilosa, areas upstream of the confluence with the Mkondoa River are seasonal rivers, and seems to have no surface flow for more than a half of year (May to October), based on the discharge measurements and field reconnaissance of this Study. This is one of key premises to discuss sediment transport in the main stream and fluctuations of the riverbed.

(2) Flood Characteristics in Target Areas

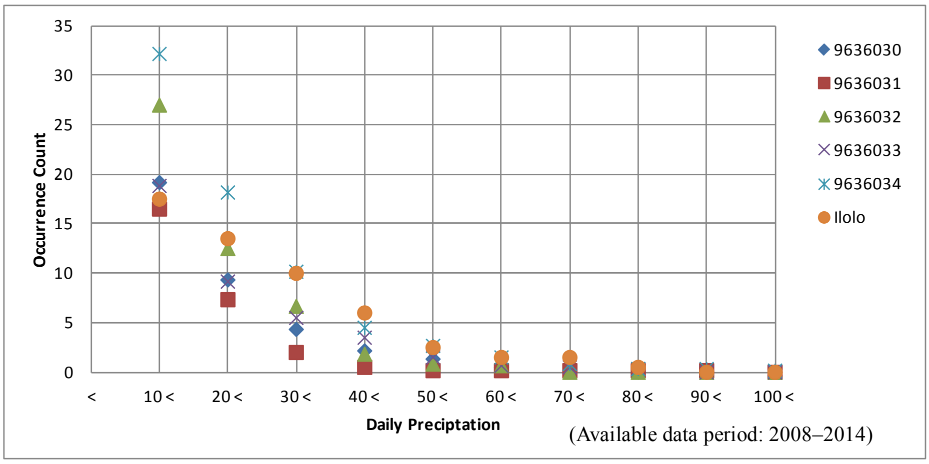
1) Frequency of Flood Occurrences

The frequency of heavy rainfall/short duration events at six major rainfall gauging stations in the Wami River basin is shown in Figure 8.3 (into 10 mm divisions). For instance, the frequency of 50 mm/day or more is counted fewer than three times a year at all stations, and 60 mm/day or more is even less frequent. This shows that frequency of flood occurrence is no so high in this basin. The locations of rainfall and water level gauging stations are shown in Figure 8.4.



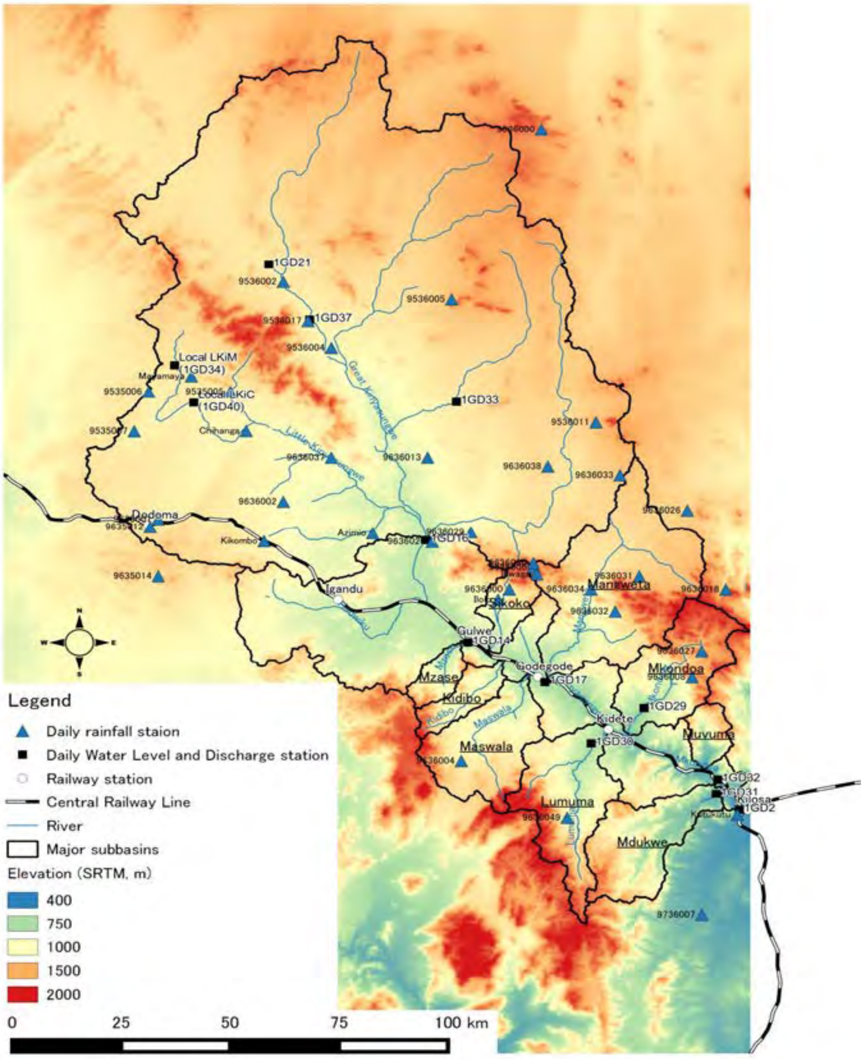
Source: The Study on Water Resources Management and Development in Wami/Ruvu Basin, Final Report, Nov. 2013, JICA

Figure 8.2: Runoff Characteristics of the Wami-Ruvu Basin



Source: JICA Study Team

Figure 8.3: Frequency of Heavy Rainfall Events in the Wami River Basin



Source: JICA Study Team

Figure 8.4: Location of Daily Rainfall Station/Daily Water Level and Discharge Gauging Stations in the Study Area

2) Relationship between Flood Marks and Railway Alignment

(a) Flood Mark Survey

The Flood Mark Survey was conducted between March and June 2015 by a sub-contractor of the JICA Study Team. The results are summarized as follows:

➢ Objective
To identify the flood marks on houses, buildings, trees, and ground, etc. through interviews with local residents, and to measure the elevation by connection with the bench marks established by the contractor of the river cross-section survey

➢ Name of Contractor
GeoHydro Consultants, Dar es Salaam, Tanzania

➢ 42 flood marks identified between Kilosa and Gulwe (on average, a mark every 2 km)
Marking of elevation was conducted on structures (such as revetments and culverts), house walls, tree trunks, and/or on the ground.

(b) Elevation of Flood Marks and Exiting Railway Truck

Three elevations of flood marks, the existing railway track level, and the level of the lowest riverbed (obtained by the river cross-section survey in March 2015) were compared between Kilosa and Gulwe. As a result, it was duly confirmed that flood water levels have reached to the level of the railway track in most of the river sections due to past floods. Furthermore, it was clarified that the flood marks were left by the two remarkable floods in 1997/1998 and 2009/2010, based on the interviews with villagers in the vicinity. Therefore, the survey results coincide with the evidence of devastating flood damage on the railway facilities experienced in most of the low-lying stretches of the existing railway from Kilosa to Gulwe.

(c) Computation of Experienced Maximum Flood Peak Discharge

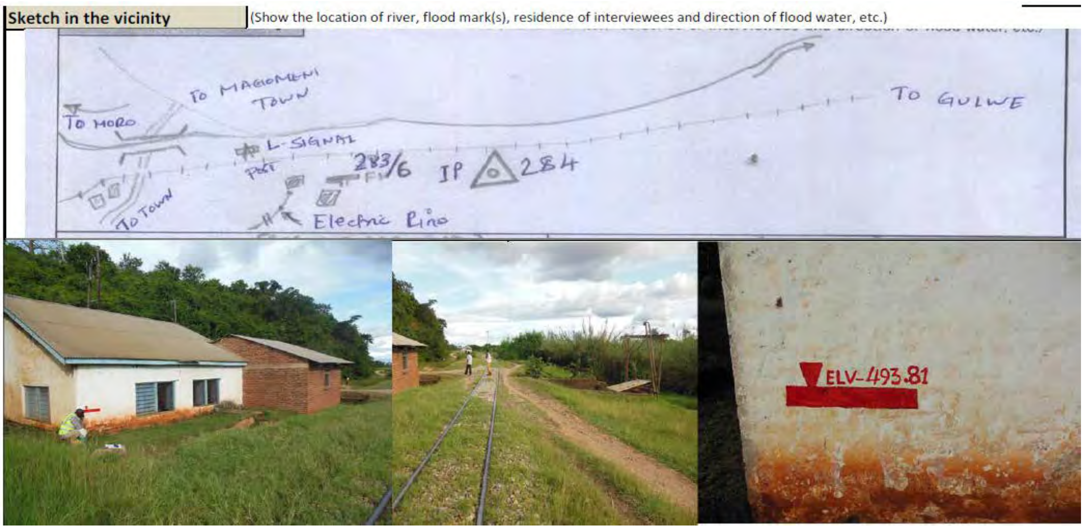
Reliable flood records of discharge and water levels are quite limited in the Wami River basin. Therefore, an attempt to find a discharge value corresponding with the past highest flood marks was conducted for the river section between Kilosa (Km 283) and Gulwe (Km 366).

(i) Basic conditions for computation

- Target section: From Kilosa to Gulwe (Km 283–Km 366)
- River cross-sections: Latest cross-sections by the 2015 survey (average 1.0 km interval)
- Computer software: One dimensional non-uniform flow model (HEC-RAS)
- Parameters for computations: Manning’s roughness coefficient n= 0.033 (low water channel) and 0.060 (high water channel)

(ii) Adjustment of peak discharge at downstream boundary (Kilosa)

Hydraulic computation was attempted to replicate the water level set by the flood mark near Km 294 in Kilosa. The site photo of the flood mark near Kilosa is shown in Figure 8.5. Through the trials, it was verified that the discharge of 2,000 m^3/s could represent the reliable flood mark elevation at Kilosa (Figure 8.8).



Source: JICA Study Team

Figure 8.5: Flood Mark at 283.6 km near Kilosa

(iii) Computation of flood peak discharge of a tributary (Lumuma River)

A reliable flood mark was confirmed at the gabion revetment of the railway bridge crossing the Lumuma River near Kidete (EL 670.89, H = 4.55 m) (Figure 8.6). The channel shape of the bridge section is formed by concrete abutment connected with gabion boxes at the up and downstream sides. A drop structure around 30 m downstream of the bridge section creates critical flow. Therefore, it can be judged that a theoretical hydraulic formula of rectangular weir (Figure 8.7) can be applied to estimate the discharge. Based on the flood mark elevation, the discharge corresponding with the water depth was estimated. The flood discharge was estimated at 326 m^3/s by the formula (Figure 8.7).

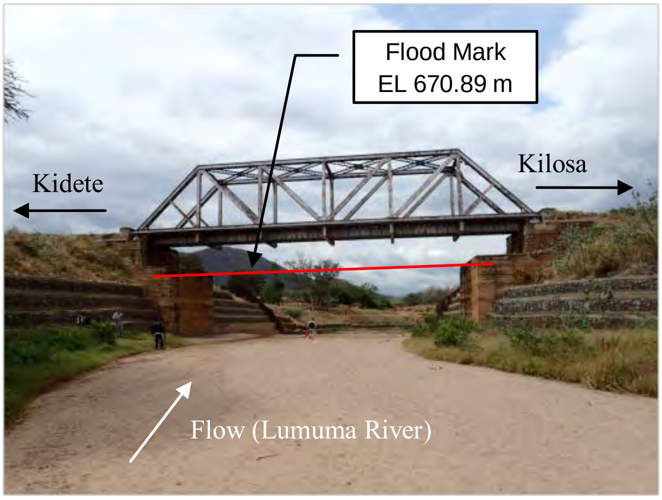
(d) Discharge Distribution to Major Tributaries

At this moment, the flood discharges of the tributaries are still under examination. Therefore, the discharge level at Kilosa was distributed amongst its major tributaries by catchment size, as follows:

- Specific discharge at Kilosa: 0.402 $m^3/s/km^2$ (= 2,000/4,975)
- Discharge at confluences of tributaries: As shown in Figure 8.8. The discharge at Lumuma is estimated at 330 m^3/s, which coincides with the result estimated in Clause (c) (iii) above.

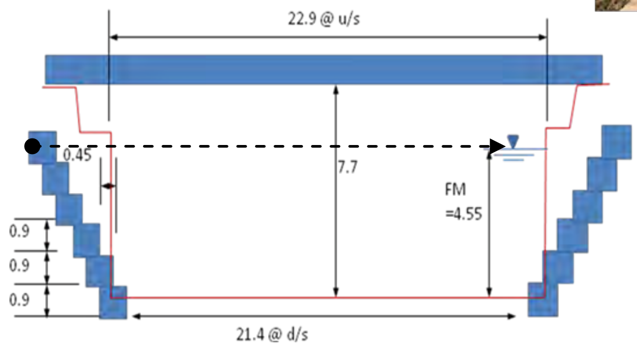
(e) Computation of Flood Water Levels along Mainstream

Based on the discharge distribution in Figure 8.4, the water levels were calculated and illustrated in Figure 8.6. Since the calculated water levels approximately represent the flood mark elevations between Kilosa and Gulwe, the discharge distribution is judged as appropriate.



Lumuma Bridge Section
(Photo taken on June 19, 2015)

Lumuma



Source: JICA Study Team

Figure 8.6: Lumuma Bridge Section and Remained Flood Mark

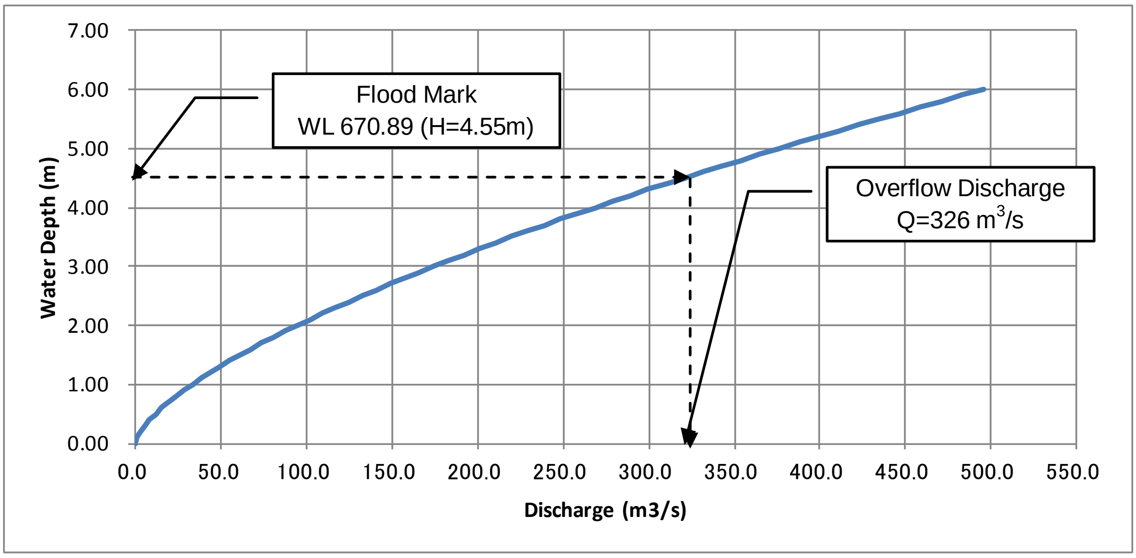
Rating Curve at Weir

Formula

$$Q=CBh^{3/2}$$

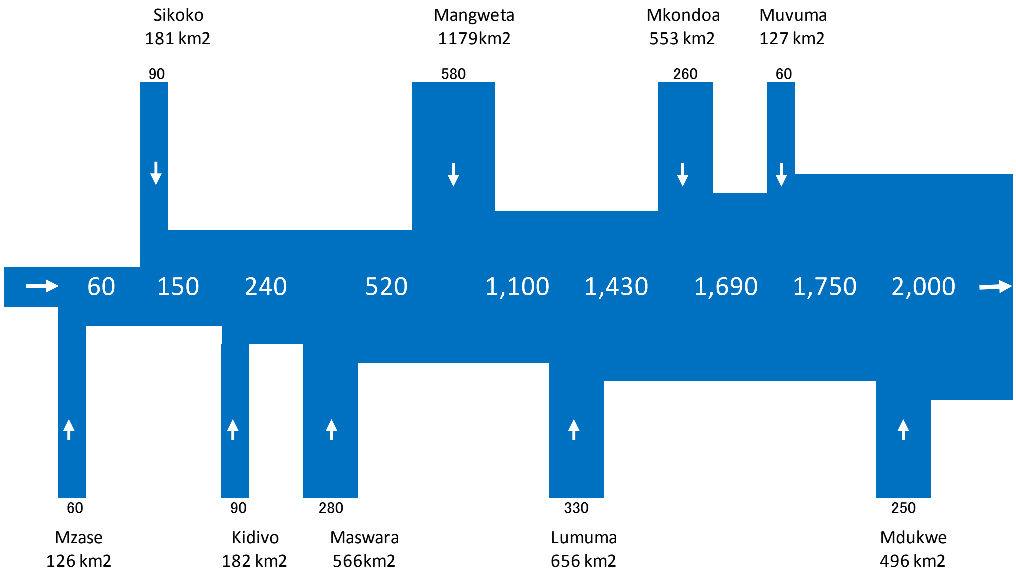
where,	Q:	Overflow discharge (m3/s)		
	C:	Coefficient		
	B:	Width of weir (m)	=	21.4 m
	h:	Overflow depth (m)		
	L:	Length of weir (m)	=	20.0 m
	W:	Height of weir (m)	=	0.01 m

$0 < h/L \leqq 0.1$:	$C = 1.642 (h/L) 0.022$
$0.1 < h/L \leqq 0.4$:	$C = 1.552 + 0.083 (h/L)$
$0.4 \leqq h/L \leqq (1.5 \sim 1.9)$:	$C = 1.444 + 0.352 (h/L)$
$(1.5 \sim 1.9) \leqq h/L$:	$C = 1.785 + 0.237 (h/W)$



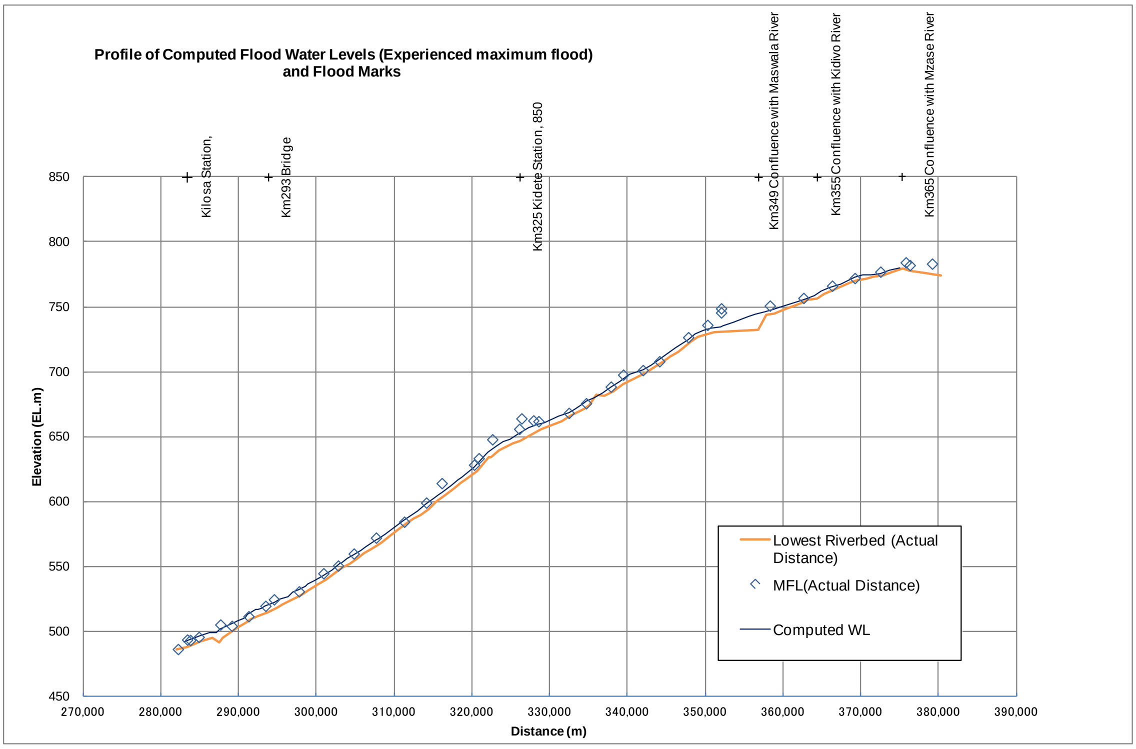
Source: JICA Study Team

Figure 8.7: Carrying Capacity at Lumuma Bridge Section



Note: Catchment areas include the remaining catchments between tributaries.
Source: JICA Study Team

Figure 8.8: Distribution of Design Flood Discharge between Kilosa and Gulwe



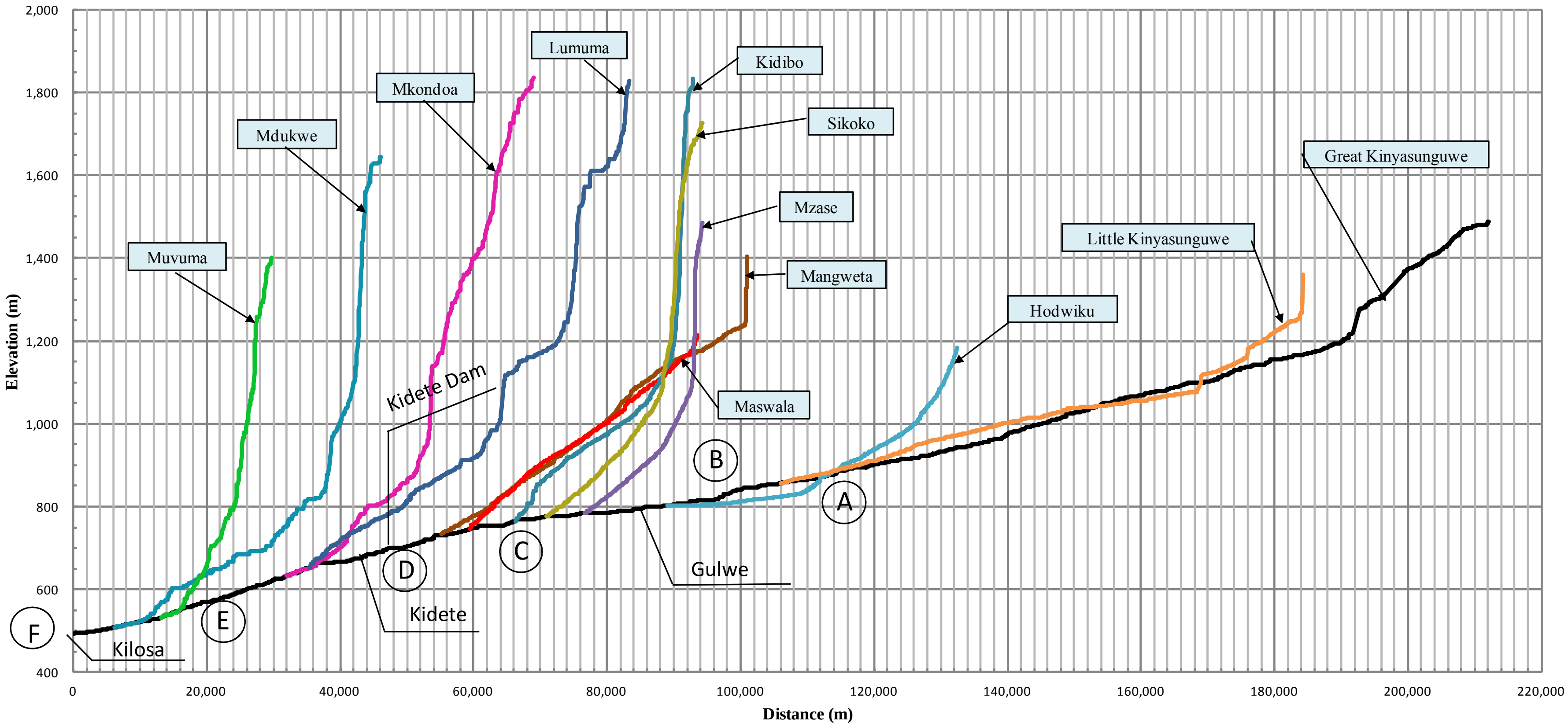
Source: JICA Study Team

Figure 8.9: Flood Marks and Results of Water Level Computation along Kilosa and Gulwe

(3) Characteristics of Sediment Discharge based on Present Riverbed Slope

Figure 8.10 shows the longitudinal profiles of the entire Wami watershed and the Kinyasungwe/ Mkondoa River from Kilosa to the origin. From these profiles, salient characteristics can be identified as follows:

1) The stretches near the confluence of the Great Kinyasungwe, Hodwiku, and upstream of Gulwe have gentle slopes, in low-lying wetlands. (A)
2) There is a rapid-flowing portion at approximately 11 km upstream of Gulwe (approximately 5 km downstream of Msagali). An outcrop of foundation rock is exposed and seems that the sediment deposition on the riverbed is not so significant. (B)
3) Mainly due to the extraordinary sediment inflow from three tributaries (Mzase, Kidibo, and Maswala) and active riverbank erosion (e.g., near Km 337), the riverbed slope is more gentle at this point. (C)
4) Between the vicinity of Kidete Dam and the confluence with the Lumuma River, sediment discharge, supplied by riverbank erosion, is significant, and the riverbed slope is gentle at this point. (D)
5) The downstream stretches from the confluence of the Mkondoa River are considered to be sediment-flushing areas, since the Mkondoa River is a perennial river and has constant discharges. The riverbed slope downstream of the confluence is steeper at its downstream than at its upstream. On the other hand, at water-hitting areas with high banks at meandering sections, active erosion at the toe portions can be observed (e.g., near Km 315). (E)
6) Downstream of Kilosa, the riverbed slope transforms to be gentle, and the Mkata Plain emerges. The river course seems to be relatively stable. (F)

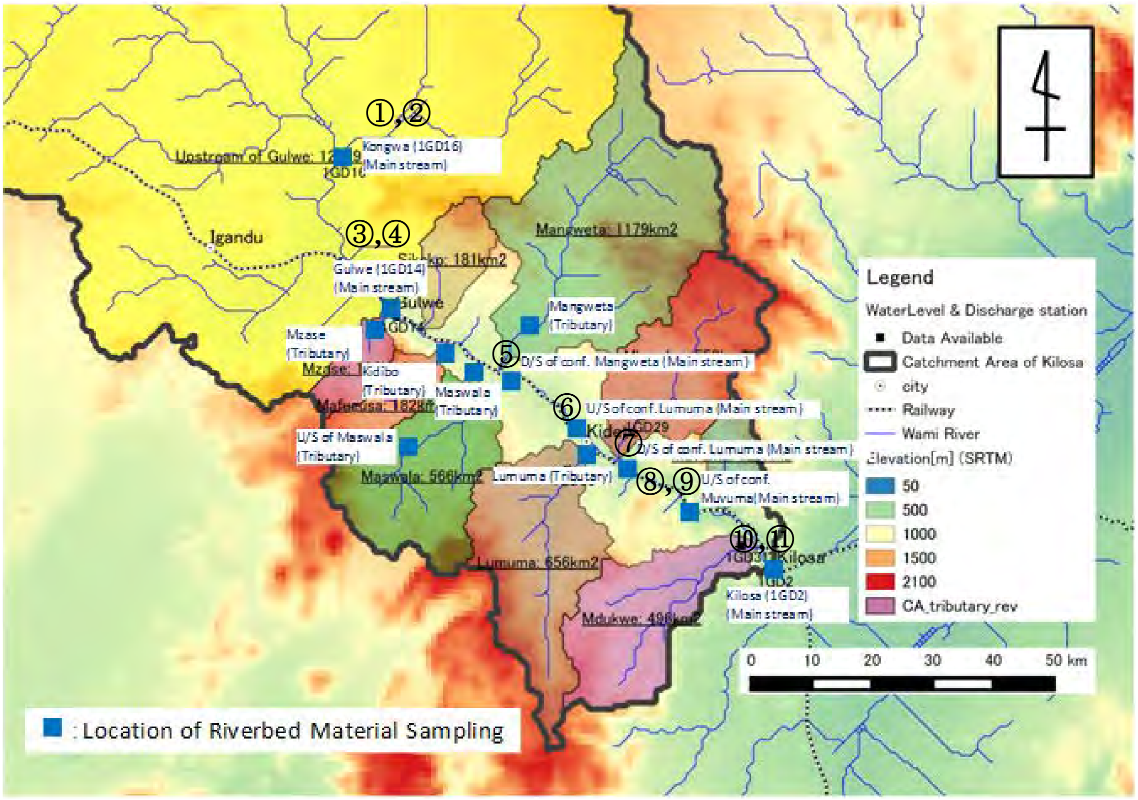


Source: JICA Study Team

Figure 8.10: Longitudinal Profile of Kinyasungwe/Mkondoa River (Origin–Kilosa)

(4) Characteristics of Riverbed Material

In the current study, in order to grasp the characteristics of riverbank and riverbed materials, sampling at a total 13 sites, and laboratory tests, were conducted. A map of the sampling locations is shown in Figure 8.11, and the grain size accumulation of the samples which were taken along the mainstream is tabulated in Table 8.1. (A detailed explanation of the sampling is presented in Chapter 4.)



Source: JICA Study Team

Figure 8.11: Map of Riverbed Material Sampling Locations

Table 8.1: Grain Size Distribution of Samples along Mainstream

Unit: %

Classification	Grain size (cm)	Lumuma MsD RB 1059	Lumuma MsU RB 1060	Lumuma MsU Cult 1061	Lumuma MsD LB 1062	Gulwe Ms RB 1068	Gulwe Ms Md 1070	Mangweta MsD RB 1073	
Clay	0.0002 - 0.002	3.44	4.36	10.00	7.00	25.04	1.00	4.78	
Silt	0.002 - 0.0075	0.56	0.64	1.95	5.96	4.96	7.04	0.22	
Very fine sand/Coarse silt	0.0075 - 0.025	4.26	3.36	10.00	7.95	25.04	1.00	11.55	
Medium sand	0.025 - 0.2	83.16	84.08	73.31	73.87	44.96	90.96	80.55	
Granule/very coarse sand	0.2 - 0.4	8.33	6.43	4.18	3.96	0.00	0.00	2.28	
Pebble	0.4 -	0.25	1.13	0.56	1.26	0.00	0.00	0.62	
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	
Classification	Grain size (cm)	Mangweta MsD Cult 1074	Kilosa Ms RB 1075	Kilosa Ms RBUB 1076	Muvuma MsU LB 1077	Muvuma MsU RB 1078	Kongwa Ms LB 1083	Kongwa Ma Md 1084	Ave. (cm)
Clay	0.0002 - 0.002	9.99	1.04	2.00	3.00	1.72	10.00	4.00	7.95
Silt	0.002 - 0.0075	14.18	4.96	4.79	1.04	3.28	3.98	0.16	3.05
Very fine sand/Coarse silt	0.0075 - 0.025	11.94	5.04	3.00	3.00	1.72	10.00	6.00	9.02
Medium sand	0.025 - 0.2	61.43	88.96	87.42	92.96	88.79	64.69	81.82	75.84
Granule/very coarse sand	0.2 - 0.4	2.35	0.00	1.72	0.00	3.94	10.82	4.12	3.60
Pebble	0.4 -	0.11	0.00	1.07	0.00	0.55	0.51	3.90	0.55
		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

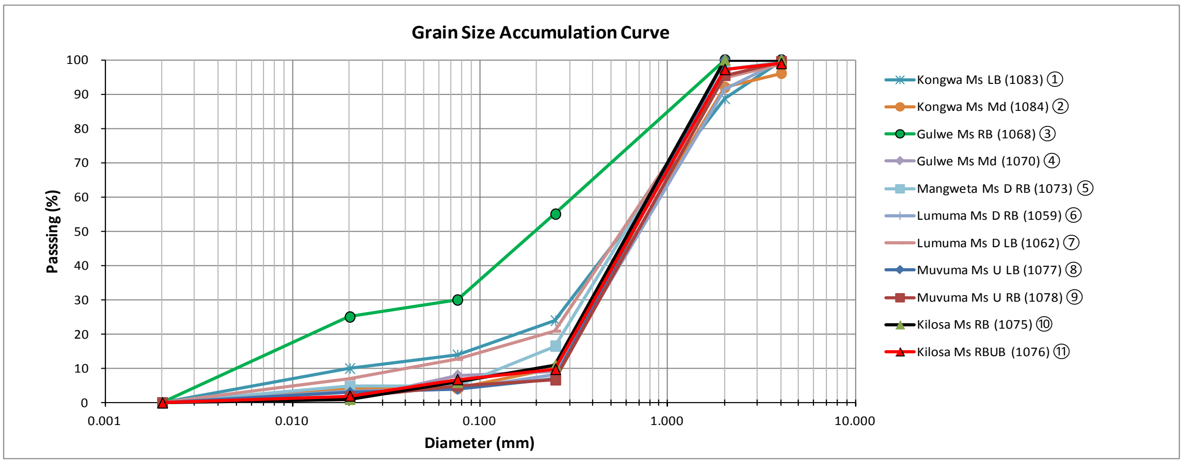
Source: JICA Study Team (results of sub-contract works)

Based on the laboratory tests conducted at the Sokoine University in Morogoro, parameters for tractive force and critical friction velocity, etc., were estimated (Table 8.2). Figure 8.12 shows the grain size accumulation curves of the samples along the mainstream between Kongwa (Mpwapwa) and Muvuma (Kilosa).

Table 8.2: Computation of Medium Grain Size and Other Parameters

Grain size (cm)	F (di) (%)	di (cm)	F (fi) di	di / dm	u_{*ci} / u_{*cm}	Each size u_{*ci} (cm/sec)	Ave size u_{*ci} (cm/sec)
0.0002 - 0.002	6.2	0.001	0.00	0.009	0.85	1.68	0.38
0.002 - 0.0075	3.8	0.004	0.01	0.055	0.85	1.68	0.94
0.0075 - 0.025	7.4	0.014	0.10	0.193	0.85	1.68	1.39
0.025 - 0.2	78.4	0.071	5.54	0.998	1.00	1.98	1.97
0.2 - 0.4	3.4	0.283	0.97	3.993	1.36	2.69	4.77
0.4 -	0.7	0.632	0.45	8.929	1.71	3.39	7.15
	100.0		7.08	dm = 0.071		u_{*cm}= 1.98	

Source: JICA Study Team

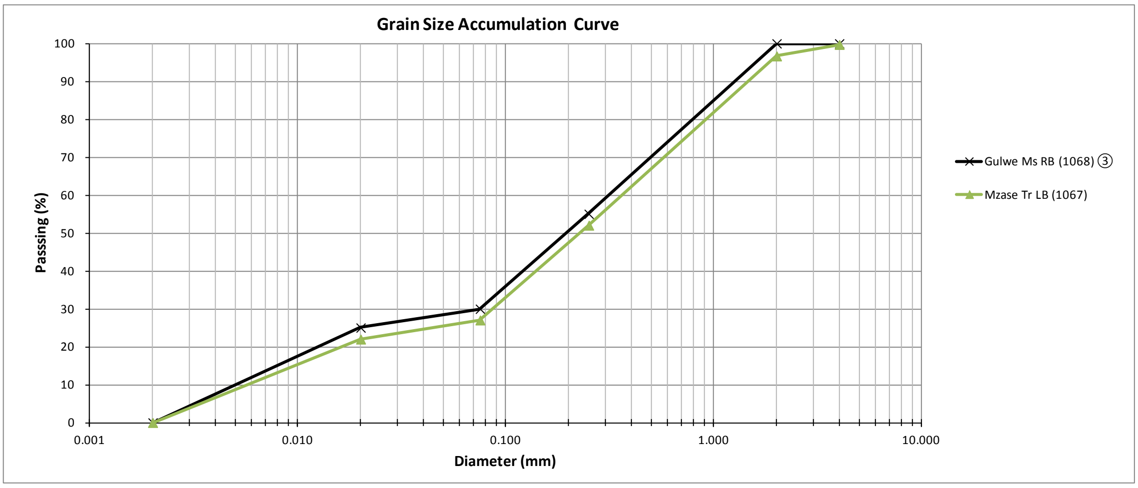


Source: JICA Study Team

Figure 8.12: Grain Size Accumulation Curves of Riverbed Material along the Mainstream

The results of the analysis above can be summarized as follows:

1) Except for the curve at Gulwe (green line), the same tendency of low contents of fine materials can be identified at all sites along the Kinyasungwe mainstream (grain size under 0.25 mm: lower than 20%).
2) As shifting toward upstream, higher proportion of fine material is seen in the samples along the mainstream. This might be caused by small quantity of surface discharge which transports fine material of riverbed and river banks toward downstream. Further, due to existence of natural retarding basin at upstream of Gulwe, continuity of soil transport along main stream of the Kinyasungwe is interrupted.
3) The curve at Gulwe is very similar to the one at Mzase. It seems that the sediment material from Mzase might be accumulated near the confluence (near Gulwe station). Since discharge levels from upstream of Gulwe is minimal (even in rainy seasons), the sediment material from the Mzase cannot be transported downstream by the river's tractive force, and fine material stays still in the riverbed. The grain size distribution curves at Gulwe (mainstream) and Mzase (tributary) are illustrated in Figure 8.13.



Source: JICA Study Team

Figure 8.13: Grain Size Accumulation Curves of Riverbed Material at Mzase and Gulwe

4) Along the mainstream, the riverbed consists mainly (76%) of coarse sand (0.25–2.0 mm), and the average size of all samples is calculated at 0.71 mm (Table 8.2).

8.2.2 Fluctuation of Riverbed

The information and materials which were utilized to verify the sediment deposition in the river channel (along the mainstream) is very limited. The only available river cross-sections (1999 and 2015) were compared to each other.

1) 1999 (Km 284.38–Km 314.6, total 15 sections)
The cross-sectional survey was conducted under supervision of a consultant. It was reported that the staff of TRC engaged in the survey. It was likely conducted between May to July 1999 (dry season), by the descriptions in the report.

2) 2015 (JICA Study Team)
Dunny Geoinformatics Inc. (Tanzania) conducted this survey as one of field sub-contract survey works of this Study. Although the kilometer posts of the railway at that time were not present on site, it was assumed that those points coincided with the existing ones, and perpendicular lines were surveyed at the points crossing over the assumed post locations.

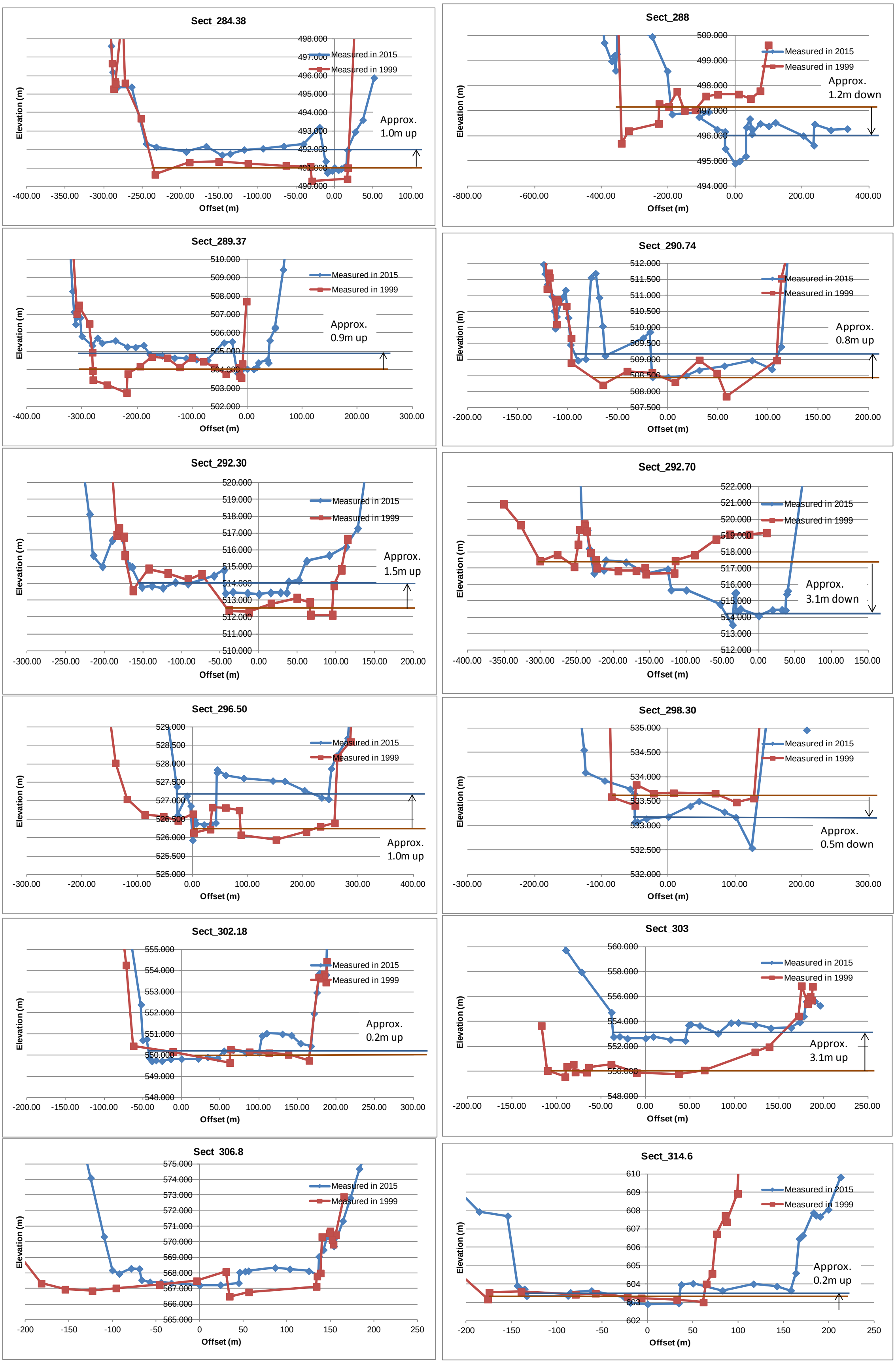
Assuming that the coordinates of kilometer posts are consistent between the surveys, the horizontal and vertical coordinates were overlaid and the average riverbed heights were compared to each other. The results are tabulated as follows:

Table 8.3: Comparison of Riverbed Elevation

No.	Section (km)	Difference of Avg. Riverbed Elevation (m)
1	284.38	+1.0
2	288.00	-1.2
3	289.37	+0.9
4	290.74	+0.8
5	292.30	+1.5
6	292.70	-3.1
7	296.50	+1.0
8	298.30	-0.5
9	302.18	+0.2
10	302.99	+3.1
11	306.80	+0.7
12	314.60	+0.2
Avg. of plus values		**+1.0**

Note: Plus values mean aggradations and minus values mean degradation.
Source: JICA Study Team

As seen in Table 8.3 above, the riverbed partially went down at (i) Km 292.70 (downstream of a steel bridge) and (ii) Km 288.0 (downstream of the confluence with the Mdukwi). However, the upward trend of aggradations in the riverbed in this stretch is obvious, and an average depth of deposition among nine sections, at +1.0 m over 16 years (1999–2015). Figure 8.14 shows the two kinds of cross-sections at the 12 sites, to evaluate aggradations and erosion.



Source: JICA Study Team

Figure 8.14: Comparison of River Cross-Sections (1999 and 2015)

8.2.3 Sediment Yield in Watershed

(1) Estimate of Sediment Yield Based on Land Cover in Tributaries

Sediment yield in a watershed composes of (i) sheet erosion, (ii) gully erosion on slopes, and (iii) bank erosion, etc. For this Study, satellite photos were utilized to examine sediment yield, because those are suitable for a wide array of analyses over a wide area. Satellite photos can distinguish geological conditions and vegetation cover by means of distinct color tones (five grades of colors). Using the land cover discerned from satellite images, sediment yield was estimated in reference to the sediment data of the dam reservoirs that were constructed in the 1970s in the Wami River basin.

The reservoir sediment volume data implies various erosion processes. Because it is difficult to estimate the erosion volume of individual events, the sediment volume of the reservoir was estimated by dividing by the catchment area and converting it to a sheet erosion rate. Further, the factors connected with sediment yield (such as land cover conditions, geological structure, riverbed gradient, and rainfall characteristics etc.) are different in the upstream and downstream areas of Kidete (as per through site reconnaissance). Therefore, the target areas (from Kilosa to Gulwe) are divided into two zones on either side of Kidete.

Two kinds of satellite photos, RapidEYE (2014) and SPOT5 (2007), were purchased and analyzed. The RapidEYE data, which has higher resolution of data (5 m cells), was used for this Study. Table 8.4 shows the sheet erosion rates estimated by tributaries and residual catchments, respectively. In the estimates for sediment production volume, the production levels are minimal in areas with a slope of less than 3 degrees (3°), and thus the sheet erosion rates were assumed small.

The color-coded sheet erosion rates were set in reference to the site reconnaissance results and reservoir sediment data (Table 8.5):

Table 8.4: Sheet Erosion Rate by Land Cover Classifications

Unit: mm/km^2

Colours on Satellite Images	Mzase, Kidibo, Maswala, Sikoko, R3, R4, R5, L4, L5, (Mangweta:Orange A)	Lumuma, Mdukwe, Mangweta, Mkondoa, Muvuma, R1, R2, L1, L2, L3
Green	0.01	0.01
Yellow Green (A)	0.05	
Yellow Green (B)		0.02
Orange(A)	0.80	
Orange(B)		0.05
Light Blue (A)	1.50	
Light Blue (B)		0.05
White	0.60	0.60

Source: JICA Study Team

Table 8.5: Estimated Annual Sediment Production Volume (Kilosa–Gulwe)

Tributary Watershed	Area (km^2)	RapidEYE (2012) Slope Classification	
		Total Sediment Yield (m^3/yr)	Specific Sediment Discharge (m^3/km^2/yr)
Mzase	124	38,448	309
Sikoko	175	70,008	399
Kidibo	171	77,134	449
Maswala	548	277,084	506
Mangweta	1,180	175,820	149
Sub-total (U/S)	2,198	638,494	290
Lumuma	629	16,834	27
Mkondoa	550	14,368	26
Muvuma	123	1,858	15
Mdukwe	512	6,478	13
Sub-total (D/S)	1,814	39,538	22
Tributaries Subtotal	4,012	678,032	169
L1	50	609	*12*
R1	10	118	*12*
L2	109	2,151	*20*
R2	266	4,430	*17*
Sub-total (D/S)	435	7,308	*17*
L3	149	5,413	*36*
R3	152	117,190	*771*
L4	139	61,397	*442*
R4	24	12,235	*510*
L5	29	17,784	*613*
R5	35	7,843	*224*
Sub-total (U/S)	528	221,862	*420*
Remaining Areas Subtotal (Gluwe～Kilosa)	963	229,170	*238*
Total (U/S)	2,726	860,355	*316*
Total (D/S)	2,249	46,847	*21*
Grand Total	4,975	907,202	*182*

Source: JICA Study Team

(2) Bank Erosion along the Mainstream

Bank erosion is progressive along the Kinyasungwe–Mkondoa mainstream. In the course of mainstream, bank erosion is remarkable at Km 297.3, Km 302.7, Km 315, and Km 337, located upstream of the Mkondoa confluence. In particular, the bank at Km 337 was encroached upon in the 2014/2015 rainy season. On 6 March 2015, the riverbank had been encroached about 20 m of width at Km 337 and shifted approximately 40 m to the mountain side.

The bank erosion volume was estimated by the following equation:

Bank height (H) x Annual erosion width (B) x Length of erosion = Annual average sediment yield due to bank erosion (Table 8.7).

8.2.4 Estimate of Future Riverbed Aggradations

(1) Methodology

The factors which determine sediment discharge volume are (i) riverbed slope, (ii) river width, (iii) riverbed material, and (iv) discharge volume. In the case of the Wami River basin, runoff conditions differ distinctly on either side of the Mkondoa confluence along the mainstream. The JICA Wami-Ruvu Study presents the surface water resources potential of seven sub-basins (Table 8.6) (refer to Figure 8.2 above for sub-basin divisions).

Table 8.6: Potential of Surface Water Resources at Seven Sub-Basins (10-year Probable Drought Year and Normal Year)

Sub-basin	Area (km^2)	10-year Probable Drought Year: Annual Yield (million m^3/ year)	10-year Probable Drought Year: Specific Yield (million m^3/ year/km^2)	Normal Year: Annual Yield (million m^3/ year)	Normal Year: Specific Yield (million m^3/ year/$km^{2)}$
Kinyasungwe	16,509	37.84	2,292	312.98	18,958
Mkondoa	12,964	443.89	34,240	788.83	60,848
Wami	14,270	612.33	42,910	1,118.60	78,388
Upper Ruvu	7,623	774.58	101,611	1,223.44	160,494
Ngerengele	2,913	73.42	25,203	115.00	39,477
Lower Ruvu	7,253	26.96	3,716	220.23	30,363
Coast	4,763	103.58	21,747	209.39	43,963

Source: Final Report of Wami-Ruvu Water Resources Development Study, 2013, JICA

In accordance with Table 8.6, the specific discharge in the Kinyasungwe sub-basin (upstream area) is 31% (=18,958/60,848) in a normal year and only 7% (=2,292/34,240) in the 10-year probable drought year, compared with the one for the Mkondoa sub-basin (downstream area). These figures indicate that the variations in discharge may influence sediment transport and transformation of the riverbed slope in the survey area. Further, the water resources potential for the 10-year probable drought year is approximately 12% of normal year in the Kinyasungwe sub-basin (37.84/312.98). In the aspect of water resources utilization (surface water), it can be easily recognized that Kinyasungwe sub-basin might suffer from severe water deficits in drought years. At the same time, the movement of sediment deposit accumulated on the riverbed toward downstream might be disturbed.

Water revel records during floods are not available at observatories in the study area. Therefore, conducting an assessment of the return period of flood occurrence through statistical analysis of actual observed records is rather difficult. In addition, since the Kinyasungwe/Mkondoa River has huge sediment discharge potential from its tributaries, and tends to meander its main river course after every flood events, common methods of hydraulic calculations (by one-dimensional riverbed fluctuation) cannot be appropriately adapted to model it. Because of this, the following methodology was applied for this Study:

1) Setting of River Stretches Division
The river stretches are divided into two segments: (i) from Kilosa to the confluence of Lumuma, and (ii) from the confluence of Lumuma to Gulwe, to the Lumuma confluence (near Kidete) where there is the transition point of riverbed gradient and tractive force of sediment. (The division coincides with the division of water resources sub-divisions as well.)

2) Target Time Span
In order to assess future riverbed aggradations along the mainstream, the target time span of flood protection structures was determined to be 30 years, considering the following:

- In the long term, riverbed degradation and aggradations will be balanced normally based on the dinamic riverbed equilibrium theory. However, sediment transport from several tributaries is significant and currently a rising trend of riverbed in the mainstream is obvious although only two series of data (river cross sections) are available for comparison. Therefore, it was judged that influence for such riverbed rising by sediment deposit should be considered to decide design high water levels.
- Since it is not certain how the rising trend will change in the future, a height of accumulated sediment deposition during a certain period should be assumed as the worst scenario in order to avoid unfavorable design change in the future.
- As for a period of assumed sediment deposition, in many cases 20 to 30 years is normally applied as a time span of one group of river improvement works in Japan. Therefore, 30 years was applied for the target time span in the current study.

3) Future Sediment Deposition in River Channels
Based on the average annual rising of riverbed elevation due to sediment deposition downstream of the Lumuma confluence, the accumulated depth of sediment deposition in 30 years was estimated.

(2) River Stretches between Kilosa and Lumuma Confluence (Downstream Stretches)

Through the comparison of river cross-sections (Section 8.2.2), riverbed aggradations were confirmed to be approximately 1.0 m per 16 years (1999–2015). Based on the rate, it is assumed that the riverbed in the subject stretches will rise approximately 2.0 m over the 30-year period.

(3) River Stretches between Lumuma Confluence and Gulwe (Upstream Stretches)

Applying the average rate of sediment density in water of 0.1 % (which was actually measured through discharge measurement and suspended load sampling survey), the average riverbed rise was estimated at approximately 2.5 m (Table 8.7). That rate is 25% faster than that of the downstream stretches:

Table 8.7: Computation of Sediment Balance (Lumuma Confluence–Gulwe)

No.	Descriptions	Values	Unit
1	Inflow sediment discharge from u/s of Gulwe (A)	0	m^3/yr
2	Inflow sediment discharge from tributaries (B)	860,355	m^3/yr
3	Volume of river bank erosion (C)	63,000	m^3/yr
4	Volume of sediment transport to downstream (D)	51,680	m^3/yr
5	Volume of sediment deposition in river channel (E) (E) = (B) + (C) – (D)	871,675	m^3/yr
6	Total sediment deposition in 30 years (F) = (E) x 30	26,150,265	m^3
7	Average sediment depth in river channel (G)	**2.47**	m
	Conditions for estimate: • Catchment area : A=2,726 km^2 • Average river width: W= 200 m • River length: L=53 km • Density of sediment contents: 0.1 % (B) = Ref. Table 8.5 (C) = 20 m (W) x 4.5 m (H) x 700 m (L) (Assumed that the same scale of bank erosion at Km 337, which happened in March 2015, might occur every year in the stretches between the Lumuma confluence and Gulwe.) (D) = 312.98 x 10^6 x (2,726/16,509) x 0.001 (Ref. Table 8.6) Where, 313.98=Annual volume of discharge in the whole Kinyasungwe River basin 2,726: Catchment area between Gulwe and Lumuma confluence 16,509: Catchment area between Gulwe and Kilosa (G) = (F) / (53,000 x 200)		

Source: JICA Study Team

8.2.5 Estimation of Flood Water Level Rising in the Future

As discussed in the previous subsection 8.2.4, riverbed aggradations are separately estimated in the river sections (i) from Kilosa to the confluence of Lumuma, and (ii) from the confluence of Lumuma to Gulwe, because situation of sediment production and transport seems to be different. Therefore,, the required heightening level is examined in the two cases to provide the conditions for the alternative study of railway re-routing as below:

(1) Target Planning Scale for Heightening

It is to be the equivalent scale of the experienced maximum flood level between Kilosa and Gulwe.

(2) Design Flood Discharge

Peak discharge of 2,000 m^3/s at Kilosa is estimated to coincide with the flood marks in the vicinity.

(3) Estimation of Water Level Rise due to Sediment Deposition on Riverbed

The conditions of heightening for flood protection were set as follows:

1) Conditions of Hydraulic Calculations

- **River section**: From Kilosa to Gulwe (Km 283 – Km 366)
- **Topography**: Results of river cross-section survey (average 1.0 km interval)
- **Discharge**: Flood discharge values were examined to meet the flood mark elevations near Kilosa, and found that the peak discharge at Kilosa (2,000 m^3/s) can represent the experienced maximum flood discharge. This discharge value was distributed among major tributaries by the ratio of catchment areas.
- **Hydraulic analysis**: One-dimensional non-uniform flow computation (by HEC-RAS)

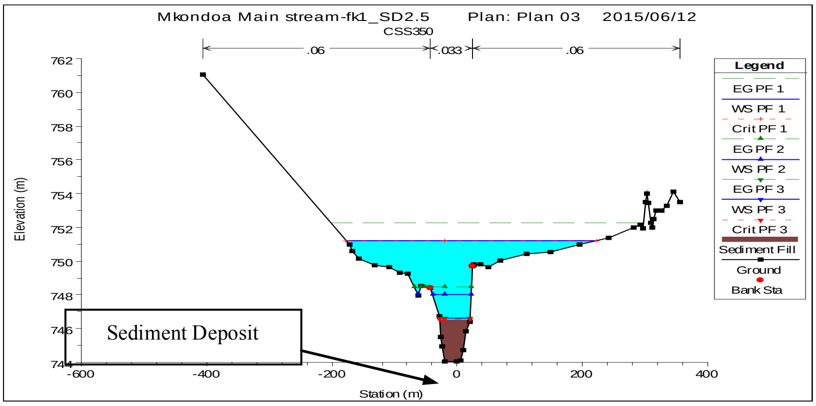
2) Condition of Sediment Deposition

- **Shape of riverbed**: Assumed that sediment material is accumulated and flattened horizontally at each cross-section. The sediment deposition area is treated as dead space of flow. Movable riverbed was not considered in the hydraulic calculations. The typical cross-section is shown in Figure 8.15.

3) Calculation Cases

Since the trend of aggradations between areas at upstream and at downstream of the Lumuma confluence seems rather different, two cases of calculation were examined:

- Case 1: Sediment deposition +2.0 m
- Case 2: Sediment deposition +2.5 m



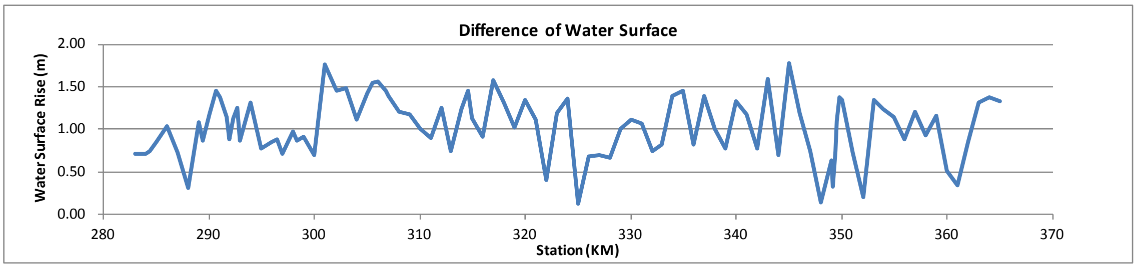
Source: JICA Study Team

Figure 8.15: Example of Sediment Deposition in River Channel (near Km 350)

(4) Results of Computations

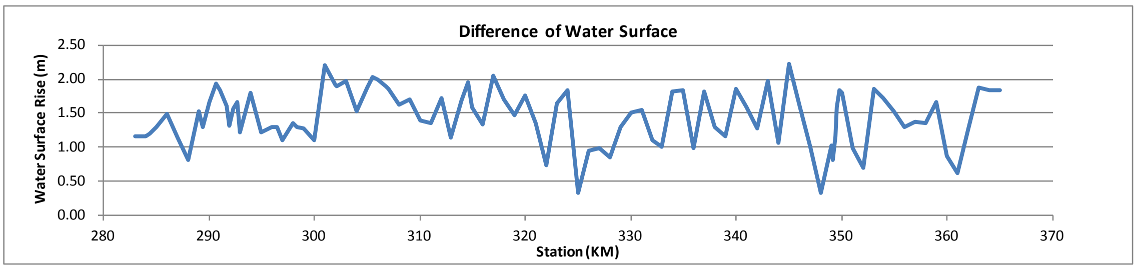
The results of the hydraulic computations of the two cases are illustrated in Figure 8.16 and Figure 8.17. The rise of water levels can be summarized as follows:

1) Case 1: Average water level rise due to sediment deposition of 2.0 m
= +1.04 m ≈ 1.1 m
2) Case 2: Average water level rise due to sediment deposition of 2.5 m
=+1.45 m ≈ 1.5 m



Source: JICA Study Team

Figure 8.16: River Water Rising due to Sediment Deposit of 2.0 m



Source: JICA Study Team

Figure 8.17: River Water Rising due to Sediment Deposit of 2.5 m

8.2.6 Setting of Planning Scale for Alternative Study of Re-Routing

River water levels are affected by wave action, sediment deposit on riverbeds, debris flowing down, etc. Additionally, the accuracy of flood marks, which were identified through the field survey, has some level of uncertainty, because they are principally based on interviews with villagers. Therefore, in order to provide an additional allowance for a conservative estimate, a freeboard is given above the Design High Water Level as follows:

(1) Freeboard subject to the magnitude of design flood discharge (Design Standard of Tanzania)
(2) Water rise due to riverbed aggradations by sediment deposition

An explanation of these two factors is as follows:

(1) Freeboard Subject to the Magnitude of Design Flood Discharge

The design standards in Tanzania, which are currently applied by TANROADS, were similarly applied for this Study. The standard for clearances under bridges was interpreted as the required free board for earth embankments as well.

Table 8.8: Free Board of Vertical Clearance for Bridges

Discharge (m^3/s)	Minimum Vertical Clearance (m)
< 0.3	0.15 m
0.3 < to 3.0	0.45 m
3.0 to 30.0	0.60 m
30 to 300	0.90 m
> 300	1.20 m

Source: TANROADS[1]

(2) Water Rise due to Riverbed Aggradations by Sediment Deposition (including the Height of Sediment Deposition)

From the results of Subsection 8.2.5, water level rising due to sediment depositions on the riverbed is set 1.5 m and 1.1 m for the upstream and downstream sections, respectively.

Based on the examination above, the freeboard in the planning scale (heightening of rail) is summarized in Table 8.9:

Table 8.9: Freeboard for Structures Applied to Alternative Study

Item	Segment 1 Upstream of Lumuma Confluence Km 283–318	Segment 2 Downstream of Lumuma Confluence Km 318–366
(1) Freeboard subject to Design Discharge (Design Standard of Tanzania, via TANROADS)	1.2 m (Q=1,690–2,000 m^3/s)	1.2 m (Q=60–1,690 m^3/s)
(2) Estimated rising of water level due to sediment deposition	1.1 m	1.5 m
Total Freeboard	**2.3 m**	**2.7 m**

Note: This assumes flood water levels rising due to Kidete Dam construction, further agricultural development, and deforestation in the upstream watershed of the Kinyasungwe River basin, etc.
Source: JICA Study Team

[1] Source: "OVERSEAS ROAD NOTE 9, A Design Manual for Small Bridge", International Division, Transport Research Laboratory

8.3 Identification of Section of Flood Protection Measures

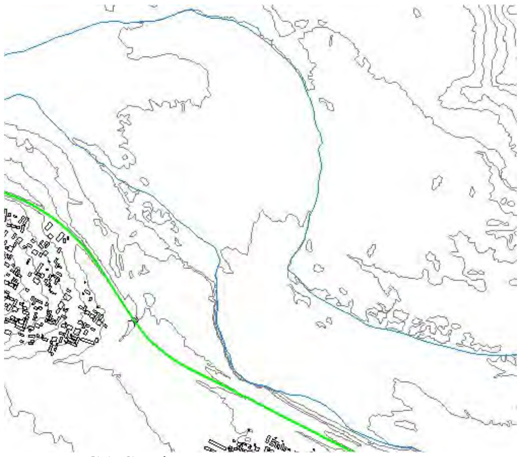
8.3.1 Proposed Section of Flood Protection Measures to be Implemented by Yen Loan Project

Of the study area from Kilosa to Dodoma, the section requiring flood protection measures has been identified based on the careful review of the following data and documents:

- Site inspection and survey data including photos.
- Table 3.23: "Classified Damage Patterns to the Railway, Possible Measures and Protection Priority".
- High-resolution color aerial photos taken in March/April 2015 (e.g., Figure 8.18).
- Topographical maps with 2.0 m contours (e.g., Figure 8.19).
- Data obtained from the river-related surveys, including the River Cross-Section and Longitudinal Profile Survey, Discharge Measurement and Suspended Load Sampling, Flood Mark Survey, River Material Sampling, and Satellite Image Analysis and Flood Risk Assessment (e.g., Figure 8.20 and Figure 8.21).
- Planning scale set in Section 8.2.

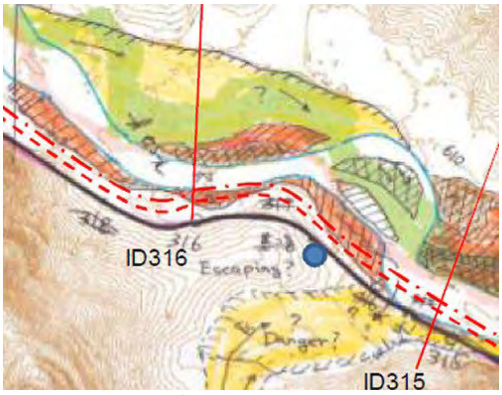
Source: JICA Study Team

Figure 8.18: An Example of High-Resolution Color Aerial Photos (near Km 315)



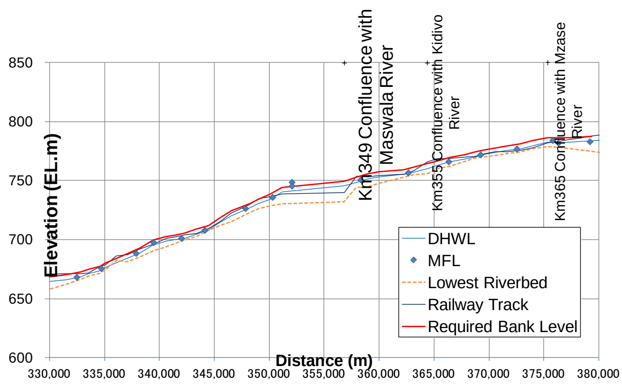
Source: JICA Study Team

Figure 8.19: An Example of Topographical Maps



Source: JICA Study Team

Figure 8.20: An Example of Data from the Analysis of the Past Flood Traces



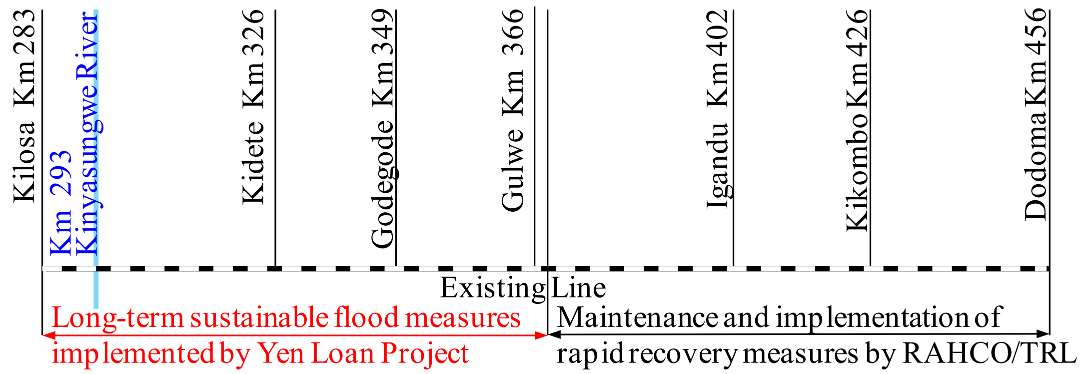
Source: JICA Study Team

Figure 8.21: An Example of a Longitudinal Profile of Kinyasungwe River

Through extensive technical discussions between the Railway Group and the River Group, the following conclusions have been reached:

- **Long-term sustainable flood protection measures are required for the Kilosa–Gulwe section, which will be included in the Yen Loan Project.** In the case of relocating the existing Mzase Bridge and/or Gulwe Station, an additional new track is required to connect the re-routed line to the existing line around Km 370.
- **The Gulwe–Dodoma section will not be included in the Yen Loan Project.** According to Appendix D, neither "Medium" nor "High" areas exist in terms of priority for flood protection on the Gulwe–Dodoma section, except Igandu, where the priority for flood protection is "Medium". Aside from this, in this section including Igandu, both RAHCO and TRL have been maintaining the railway structure, and have been implementing rapid recovery measures whenever the railway structure has been damaged by floods.

Figure 8.22 summarizes the above conclusions.



Source: JICA Study Team

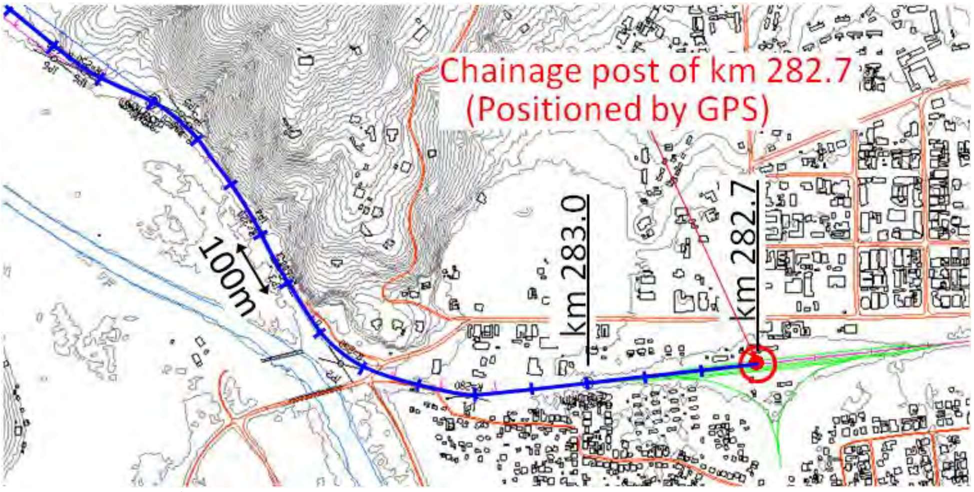
Figure 8.22: Proposed Section to be Implemented by the Yen Loan Project

Box 8.1: Use of New Kilometrage

The Kilometrage shown on the posts along the existing railway line do not show the actual railway length. For example, the actual length from Km 349 to Km 350 on site is not 1.0 km, but approximately 3.9 km.

From the following section, a new Kilometrage, calculated based on the AutoCAD drawings produced with the aerial survey data, will be used to carry out the design work and cost estimation.

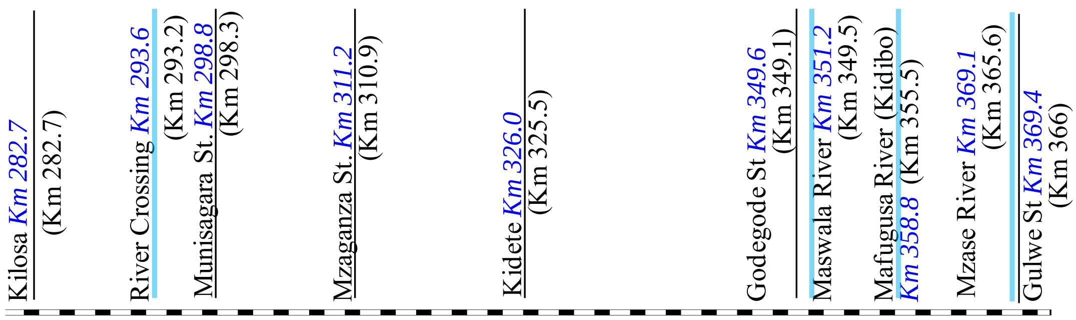
It is noted that the starting point of the new Kilometrage is the chainage post at the center of Kilosa Station (i.e., Km 282.7), the same as the old Kilometrage shown in Figure 8.23.



Source: JICA Study Team

Figure 8.23: Starting Point of Kilometrage

The difference between the old Kilometrage and the new Kilometrage is shown in Figure 8.24, in which the old Kilometrage is indicated in black and the new Kilometrage is indicated in blue. (Hereinafter, the new Kilometrage is displayed in italics.)



Note: Old kilometrage is quoted from the Governments of Tanzania, Rwanda and Burundi, Phase II of the Dar es Salaam–Isaka–Kigali/Keza–Musongati Railway Project Study, Final Report, Volume 2B, March 2014.
Source: JICA Study Team

Figure 8.24: Difference between Old and New Kilometrage

8.4 Standard Structures to be Applied in the Flood Protection Measures

8.4.1 Overview

Table 8.10 shows the list of key design parameters that have been applied to alternatives of flood protection measures, with details provided in Subsection 8.4.2 for the river structures and Subsection 8.4.3 for the railway structures.

Table 8.10: List of Key Design Parameters for Alternative Study

Item	Parameter
River Structures	
1. Riverbed aggradation rate	1.0 / 16 yrs (≈ 2.0 m / 30 yrs)
2. Total sediment deposition (30 years)	26,150,265 m^3
3. Total freeboard above DHWL	
Upstream of Lumuma confluence	2.3 m
Downstream of Lumuma confluence	2.7 m
4. River channel design parameters	see Table 8.13
5. Embankments	
Crest width	5.0 m
Side slope	1:3.0
6. Spur dikes	
Length	< 10% of river width
Width	0.2-0.3 times design flood water depth; higher than normal water level by 0.5-1.0 m
Interval	2-4 times length of dike, 10-30 times the height
Slope	downward, 1/20-1/100 to river center
Direction	Perpendicular to riverbank
Railway Structures	
7. Minimum curve radius	
Common	400 m
Unavoidable	200 m
8. Max vertical gradient	1.0%
9. Vertical curve radius	3000 m
10. Station track	
Straight track length	apx. 700 m
Track gradient	apx. 0.2%
11. Embankments (standard)	
Max height	apx. 15 m
Max cutting height	19 m
Slope (height < 6 m)	1:1.5
Slope (height > 6 m)	as per Japanese standards
12. Embankments (width > ROW; non-standard)	
Slope	1:1.5
Formation width	4.572 m
Height	18.3 m
13. Berms	
Included if	embankment height > 6.0 m
Width	4.0 m
14. Cutting earth	
Max gradient	1:0.35
15. Culverts	
Draft standard dimensions	2 m x 2 m; 3 m x 3 m (at the time of ITR only)
16. Steel bridges	
Span < 15 m	kept, if proven track record
Span > 15 m	tandem arrangement of 15 m girders
Miscellaneous	
17. New kilometerage	
Kilosa Station	Km 282.7
Gulwe Station	Km 369.4

Source: JICA Study Team

8.4.2 River Structures

(1) Design Condition

1) Design Water Level

As mentioned in Section 8.2, the design scale was determined referring to the experienced maximum flood level obtained through the Flood Mark Survey. It is considered that the previous flood marks represent the maximum flood level in the past 30 years at the site as per result of interview to local residents. The Design High Water Level (DHWL) is set to envelope the previous maximum flood level (in the longitudinal section).

2) Freeboard

(Refer to Subsection 8.2.6 for a calculation of the freeboard adopted for this design.)

3) Required Bank Level

The required bank level is determined as the total of the DHWL elevation and the freeboard.

4) Design Velocity

A non-uniform flow analysis was carried out to simulate hydraulic conditions in the case of the maximum flood levels. Based on this analysis, the design velocity along the river channel varies ranging from 1.0 to 6.0 m/s (Table 8.11).

Table 8.11: Design Velocity of River Channel

Section	Flow Velocity (m/s)
Km *283.5*–Km *293.6*	3.0 – 6.0
Km *293.6*–Km *317.7*	2.5 – 4.5
Km *317.7*–Km *329.3*	2.5 – 4.5
Km *329.3*–Km *348.2*	1.5 – 4.0
Km *348.2*–Km *355.1*	1.5 – 2.5
Km *355.1*–Km *370.1*	1.0 – 3.5

Note: Figures in italics indicate new Kilometrage, as set in Box 8.1.
Source: JICA Study Team

5) Geotechnical Conditions

The Results of geotechnical investigations carried out in this Study and Gauff's previous study[2] at the bridge at Km 349/450 are referred to for the design of structures.

(2) Basic Properties of River Channel

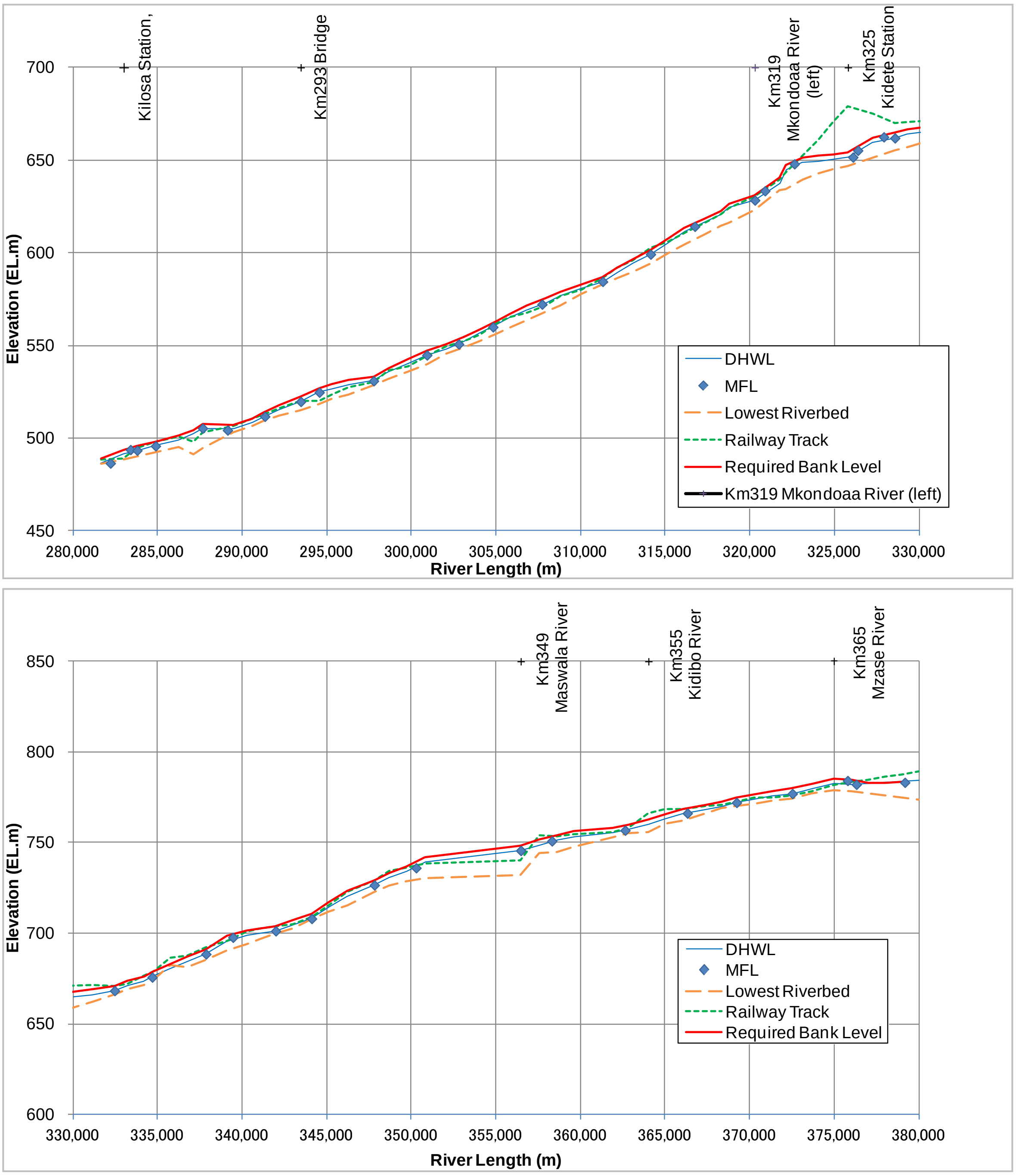
The basic properties of the river channel, such as the riverbank level, lowest riverbed level, river width of existing channel, DHWL, required bank level, and design velocity of the designed channel are presented in Table 8.12. The longitudinal profile of the Kinyasungwe River from Kilosa to Gulwe, showing the existing riverbed level and railway track level together with DHWL and required bank level, is presented in Figure 8.25.

2 "Consultancy Services in Relation to Design and Supervision of Bridge at Km 349/450 and Associated Works Between Godegode and Gulwe Stations on the Central Railway Line: Volume 2 Materials and Geotechnical Investigation", November 2014, Ministry of Transport, Reli Assets Holding Company (RAHCO), JBG/Gauff Ingenieure.

Table 8.12: Basic Properties of Designed River Channel

ID	Location Name	Accumulated Distance along River Center Line	Existing River Channel				Railway Track	Flood Record	Design River Channel				
			River Width (LW)	Left Bank	Right Bank	Lowest Riverbed	Crest Elevation	Maximu Flood Level	Design Discharge	Freeboard	Required Bank Level	Design Height of Dike	Computed Velocity
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(-)	(-)	(m)	(m)	(El.m)	(El.m)	(El.m)	(El.m)	(El.m)	(m3/s)	(m)	(m)	(m)	(m/s)
Km282		281,652	40.75	487.17	487.50	485.98	488.15	486.51	2,000	2.30	488.81	0.66	
Km283	Km283 Kilosa Station	283,000	36.66	489.41	489.85	488.33	489.13	491.38	2,000	2.30	493.68	4.54	2.01
Km284		283,789	40.30	491.98	491.96	490.04	494.72	493.44	2,000	2.30	495.74	1.02	3.89
Km285		284,880	37.47	493.02	492.02	492.64	498.09	495.82	2,000	2.30	498.12	0.03	2.40
Km286		286,239	49.49	493.87	493.43	495.45	500.59	499.00	2,000	2.30	501.30	0.71	3.61
Km287		287,116	60.38	495.62	495.49	491.16	498.27	502.19	2,000	2.30	504.49	6.22	1.12
Km288		287,662	156.38	494.93	495.28	494.90	503.11	505.37	2,000	2.30	507.67	4.56	5.01
Km289		289,502	107.77	495.58	495.84	502.93	506.67	504.98	2,000	2.30	507.28	0.60	2.75
Km290	Km290 Mdkwe River (right)	290,608	70.62	497.32	497.44	506.40	510.18	508.20	2,000	2.30	510.50	0.32	3.57
Km291		291,242	106.80	504.70	504.52	509.19	512.70	511.43	1,750	2.30	513.73	1.02	2.79
Km292		292,201	89.86	506.29	506.49	512.05	515.85	515.54	1,750	2.30	517.84	1.99	2.66
Km293	Km293 Bridge	293,459	122.84	508.23	508.31	514.87	519.86	519.76	1,750	2.30	522.06	2.20	2.95
Km294		294,554	123.50	510.00	509.54	518.36	520.21	524.76	1,750	2.30	527.06	6.85	5.38
Km295		295,330	84.00	510.94	510.67	520.95	523.59	526.82	1,750	2.30	529.12	5.52	1.90
Km296	Km296 Muvuma River (left)	296,321	59.72	513.09	513.97	523.52	527.42	528.87	1,750	2.30	531.17	3.76	4.82
Km297		297,766	94.03	513.98	513.94	528.49	530.51	530.93	1,690	2.30	533.23	2.72	3.21
Km298	Munisagara Station	298,640	105.56	514.70	515.18	531.90	536.49	535.56	1,690	2.30	537.86	1.38	4.05
Km299		299,817	69.44	515.51	515.43	536.06	538.63	540.20	1,690	2.30	542.50	3.87	4.12
Km300		300,914	65.93	515.96	516.05	539.91	544.56	544.83	1,690	2.30	547.13	2.57	2.19
Km301		302,080	68.44	518.75	518.91	545.44	549.40	548.32	1,690	2.30	550.62	1.23	3.82
Km302		303,100	71.52	522.65	522.13	549.18	552.57	552.09	1,690	2.30	554.39	1.82	3.66
Km303		304,017	77.26	525.28	524.48	552.46	555.88	556.48	1,690	2.30	558.78	2.90	4.44
Km304		305,016	76.01	526.81	526.81	556.52	561.86	560.81	1,690	2.30	563.11	1.25	3.64
Km305		305,809	72.60	528.67	529.09	559.83	565.25	564.90	1,690	2.30	567.20	1.95	3.54
Km306		306,814	105.10	532.81	532.52	563.71	567.77	568.99	1,690	2.30	571.29	3.52	3.99
Km307		307,941	251.02	534.41	535.17	568.25	571.68	573.03	1,690	2.30	575.33	3.64	2.87
Km308		308,820	144.02	535.84	536.83	571.81	576.46	576.85	1,690	2.30	579.15	2.70	3.95
Km309		310,059	353.94	541.63	541.21	577.54	579.88	580.68	1,690	2.30	582.98	3.10	2.61
Km310		311,298	241.75	545.02	544.69	583.04	586.26	584.51	1,690	2.30	586.81	0.55	3.61
Km311	Muzaganza Station	312,152	123.07	548.05	547.75	586.48	591.79	589.41	1,690	2.30	591.71	-0.07	2.44
Km312		313,109	114.31	550.43	550.22	589.68	595.93	594.32	1,690	2.30	596.62	0.68	3.48
Km313		314,130	119.13	552.82	552.38	594.41	602.37	599.22	1,690	2.30	601.52	-0.85	3.39
Km314		315,167	72.10	556.29	556.68	600.06	606.00	605.22	1,690	2.30	607.52	1.52	2.60
Km315		316,129	112.30	560.61	559.96	604.57	610.46	611.23	1,690	2.30	613.53	3.07	3.36
Km316		317,356	165.40	562.97	561.61	609.91	616.44	616.25	1,690	2.30	618.55	2.11	3.50
Km317		318,273	142.71	563.50	563.49	614.47	620.56	620.30	1,690	2.30	622.60	2.04	3.05
Km318		318,752	115.82	566.03	565.82	616.48	624.40	624.34	1,690	2.30	626.64	2.25	4.37
Km319	Km319 Mkondoaa River (left)	320,290	142.57	569.27	568.94	623.27	630.16	628.39	1,430	2.70	631.09	0.93	2.98
Km320		321,782	124.48	571.69	571.38	633.79	639.41	637.57	1,430	2.70	640.27	0.86	3.97
Km321		322,152	169.98	575.37	574.52	634.15	643.56	644.49	1,430	2.70	647.19	3.64	2.38
Km322		323,102	339.83	581.31	578.86	639.23	652.41	648.45	1,430	2.70	651.15	-1.27	3.54
Km323		324,063	227.02	586.59	586.84	642.57	661.01	649.43	1,430	2.70	652.13	-8.88	2.53
Km324		324,933	247.61	591.59	591.69	644.96	670.57	650.41	1,430	2.70	653.11	-17.46	2.17
Km325	Km325 Kidete Station	325,796	205.43	595.83	595.63	646.75	679.16	651.40	1,430	2.70	654.10	-25.06	4.65
Km326		327,248	358.66	600.92	600.42	651.24	675.21	659.20	1,100	2.70	661.90	-13.31	3.03
Km327		328,565	268.59	603.03	602.86	655.19	670.03	661.92	1,100	2.70	664.62	-5.41	1.76
Km328		329,306	182.83	604.50	604.60	656.95	670.62	664.05	1,100	2.70	666.75	-3.87	4.65
Km329		331,173	179.65	606.41	606.72	661.92	671.38	666.17	1,100	2.70	668.87	-2.50	1.78
Km330		332,462	151.36	611.79	613.02	666.01	670.85	668.30	1,100	2.70	671.00	0.15	4.06
Km331		333,219	229.34	614.53	616.43	668.85	671.87	670.87	1,100	2.70	673.57	1.69	2.00
Km332		334,202	240.19	617.85	619.06	671.42	676.86	673.44	1,100	2.70	676.14	-0.73	3.86
Km333		334,737	189.84	622.07	621.55	674.35	678.87	676.16	1,100	2.70	678.86	-0.01	3.10
Km334		335,737	215.52	631.35	630.23	682.36	686.39	680.28	1,100	2.70	682.98	-3.42	2.03
Km335		336,768	205.24	639.43	637.64	681.34	687.53	684.39	1,100	2.70	687.09	-0.44	4.00
Km336		337,863	329.56	645.84	647.17	685.30	692.03	688.51	1,100	2.70	691.21	-0.82	2.72
Km337		339,097	261.43	654.27	653.81	690.56	695.67	695.59	1,100	2.70	698.29	2.61	3.23
Km338		340,296	347.16	652.88	660.39	694.18	700.87	698.63	1,100	2.70	701.33	0.46	2.99
Km339		341,115	293.14	659.14	663.71	696.80	702.58	699.94	1,100	2.70	702.64	0.06	2.46
Km340		341,985	194.22	662.35	664.26	699.58	704.03	701.25	1,100	2.70	703.95	-0.08	1.45
Km341		343,011	184.27	659.97	662.27	702.64	705.16	704.66	1,100	2.70	707.36	2.21	2.96
Km342		344,111	169.31	660.07	661.11	707.51	708.99	708.08	1,100	2.70	710.78	1.79	2.09
Km343		345,127	138.07	662.77	663.84	711.81	715.07	714.24	1,100	2.70	716.94	1.87	3.68
Km344		346,211	97.58	665.77	666.33	715.10	722.54	720.41	1,100	2.70	723.11	0.57	3.17
Km345		347,817	65.09	668.71	668.53	722.98	729.37	726.58	1,100	2.70	729.28	-0.09	2.46
Km346	Km346 Mangweta River (left)	348,700	126.83	672.37	672.83	726.56	734.50	730.37	1,100	2.70	733.07	-1.43	3.25
Km347		349,728	175.53	675.71	676.48	728.80	736.32	734.16	520	2.70	736.86	0.54	2.19
Km348		350,838	147.31	677.20	677.20	730.37	738.52	739.25	520	2.70	741.95	3.42	1.62
Km349	Km349 Maswala River (right)	356,470	326.36	681.36	681.84	732.33	739.96	745.62	520	2.70	748.32	8.36	1.36
Km350	Godegode Station	357,584	185.56	684.20	684.31	744.03	754.00	748.71	240	2.70	751.41	-2.58	2.76
Km351		358,621	147.54	687.66	686.95	744.74	753.29	751.45	240	2.70	754.15	0.86	1.07
Km352		359,619	156.49	689.20	688.25	747.56	754.46	753.36	240	2.70	756.06	1.59	2.36
Km353		361,932	173.87	690.29	689.26	752.80	755.61	755.26	240	2.70	757.96	2.36	0.90
Km354		362,813	191.25	691.38	690.26	755.22	758.05	757.34	240	2.70	760.04	1.99	1.48
Km355	Km355 Kidibo River (right)	364,017	269.83	763.61	764.95	755.88	766.13	760.11	240	2.70	762.81	-3.32	1.12
Km356		364,986	82.10	764.78	765.22	760.26	768.60	762.88	150	2.70	765.58	-3.01	3.14
Km357		366,048	54.68	765.20	765.46	762.34	768.67	765.66	150	2.70	768.36	-0.32	1.30
Km358		367,397	55.93	767.07	767.12	765.90	769.91	767.89	150	2.70	770.59	0.68	2.30
Km359		368,369	577.93	769.99	770.31	768.91	770.75	769.99	150	2.70	772.69	1.95	0.61
Km360	Km 360 Sikoko River (left)	369,226	6.50	772.01	771.82	770.26	772.54	772.10	150	2.70	774.80	2.26	3.12
Km361		370,270	23.87	773.69	772.90	771.28	774.68	773.74	60	2.70	776.44	1.76	0.87
Km362		371,309	25.38	773.50	773.57	772.90	774.54	775.38	60	2.70	778.08	3.54	0.34
Km363		372,525	16.79	775.09	775.09	774.22	775.69	777.03	60	2.70	779.73	4.04	2.05
Km364		373,705	78.14	777.58	777.46	776.97	777.98	779.79	60	2.70	782.49	4.50	0.64
Km365	Km365 Mzase River (right)	375,006	47.04	779.97	779.87	779.09	782.00	782.55	60	2.70	785.25	3.25	1.19
Km366	Gulwe Station	376,006	120.41	782.03	780.92	778.00	783.45	782.10	60	2.70	784.80	1.35	1.61

Source: JICA Study Team



Abbreviations: DHWL = Design High Water Level, MFL = Maximum Flood Level
Source: JICA Study Team

Figure 8.25: Longitudinal Profile of Kinyasungwe River

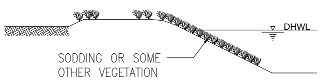
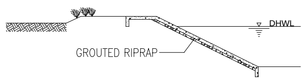
(3) Standard Design of Each Structure

1) Riverbank Protection

Riverbank protection is necessary to protect riverbanks from erosion and local scouring. A standard design for the riverbank protection works for the Project is studied comparing three typical types: (A) Vegetation, (B) Rigid type, and (C) Flexible type.

Riverbank protection of vegetation is not recommended due to the erodible soil materials of the riverbank and faster flow velocity in the objective channel. For minor erosion section, we apply the Flexible type; for serious erosion sections, we apply the Rigid type (Table 8.13).

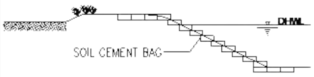
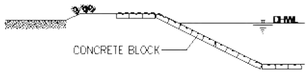
Table 8.13: Comparison of Standard Type of River Bank Protection

Type	(A) Vegetation	(B) Rigid type	(C) Flexible type
Illustration of section			
Type of revetments	Sodding, sodding with pile fence, etc.	Wet masonry, Reinforced Concrete Wall, Sheet Pile, etc.	Sand bag, Gabion, Concrete block/frame, Dry boulder riprap etc.
Recommended side slope	>1:2.0		>1:1.5
Characteristics	- surface soil of more than 30cm in thickness is needed - bank slope shall be designed gentler than 1:2.0 - sodding above normal water level		- stones or blocks shall be designed not to move against design velocity - countermeasure against turning up should be considered
Allowable Design Velocity	Va<2.0 m/s	Va>5.0 m/s	Va<5.0 m/s
Advantage	- cheapest construction cost - faster construction work - easiness for repair - environmental friendless	- high durability	- flexibility against settlement of bank - relatively simple construction - easiness for repair
Disadvantage	- weakness against erosion - proper periodic D10maintenance of vegetation	- weakness against settlements of bank - longer construction works	- weakness against suction of bed soils under the protection - longer construction works
For minor erosion section	**Not recommendable**	**Not recommendable**	**Applicable**
For serious erosion section	**Not applicable**	**Applicable**	**Not recommendable**

Source: JICA Study Team

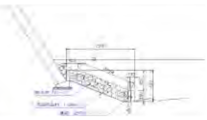
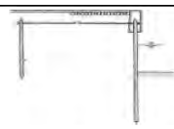
There are several kinds of riverbank protection works, for both Flexible type and Rigid types (Table 8.14 and Table 8.15). In this Study, the type of riverbank protection will be selected among the above standard types considering site conditions and design velocity.

Table 8.14: Comparison of Flexible Types of Riverbank Protection

Type	(C-1) Sand Bag	(C-2) Gabion	(C-3) Concrete Block/Concrete Frame
Photo			
Illustration of section			
Allowable Design Velocity*	Va > 3.0 m/s	Va > 5.0 m/s	Va > 5.0 m/s
Advantage	- effective usage of local sourced materials (sand deposits) - faster construction work	- high durability against erosion	- high durability against erosion
Disadvantage	- relatively less durability against erosion	- weakness against suction of bed soils under the protection - relatively longer construction works	- most expensive among the alternatives - weakness against suction of bed soils under the protection - relatively longer construction works

Source: JICA Study Team

Table 8.15: Comparison of Rigid Types of Riverbank Protection

Type	(B-1) Wet Masonry	(B-2) Concrete Wall	(B-3) Sheet Pile
Photo			
Illustration of section			
Allowable Design Velocity*	Va > 5.0 m/s	Va > 5.0 m/s	Va > 5.0 m/s
Advantage	- most economical measure among the alternatives	- high durability against erosion	- high durability against erosion - high durability against local scouring - faster construction work
Disadvantage	- weakness against local scouring - relatively longer construction works	- weakness against local scouring - relatively longer construction works	- most expensive among the alternatives - not applicable for higher river bank

Source: JICA Study Team

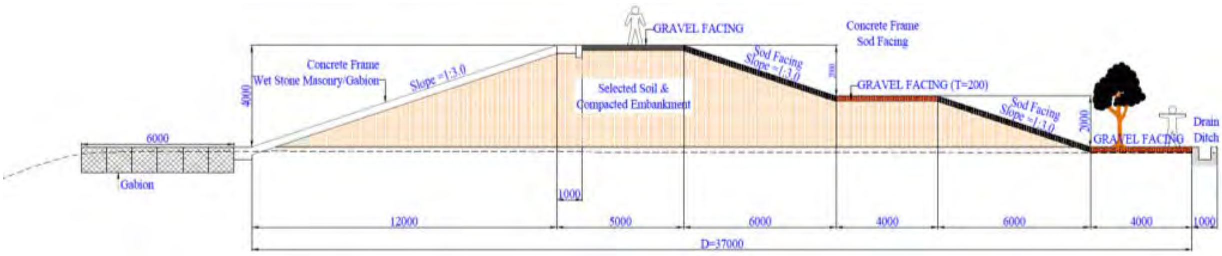
2) Riverbed Protection

Riverbed protection is designed to protect from local scouring at the toe of the riverbank and at the adjacent areas of river structures, such as bridge piers, abutments, and groundsills. The standard type of riverbed protection, gabion works, is applied in consideration of the experience and practice of previous works in the objective river.

3) Embankment/Flood Wall

In the railway sections which have a risk of overtopping of the railway track during flood events, embankments and/or flood walls are proposed to protect the railway. The height of embankments and flood walls are designed based on the required bank level. Embankments have an advantage in terms of construction cost when compared to flood walls, but the construction of embankments requires a wider land area (i.e., right of way). Therefore, if there is enough land area at the proposed site, we recommend embankment construction, but if not, we recommend flood walls.

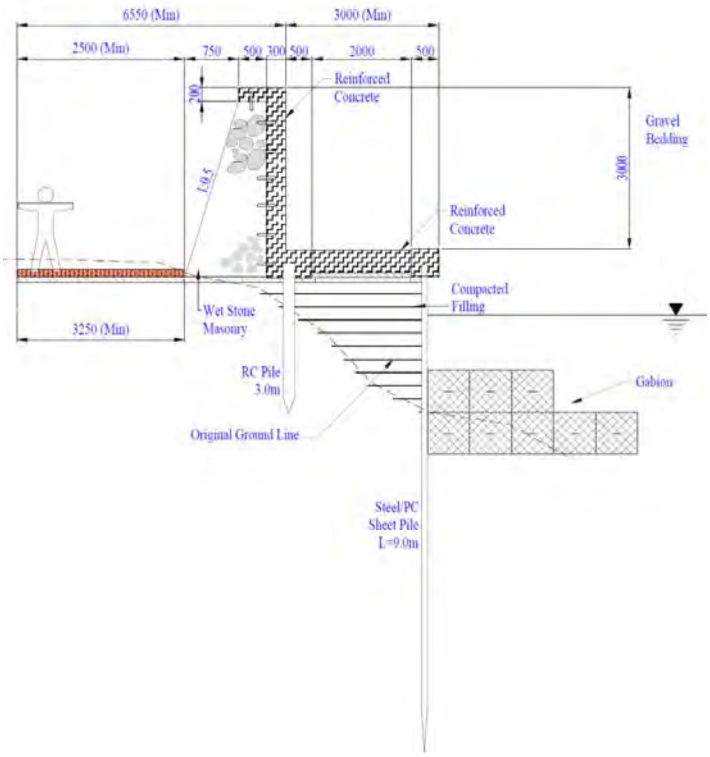
The standard design for embankments is presented in Figure 8.26. It is considered that soil materials from local sources can be used for the embankment. Taking into account the stability of the embankment, the crest width is designed at 5.0 m and the side slope is designed at 1:3.0 with a berm of 4.0 m on the land-side. Slope protection works are included: concrete frame on the river-side slope, and vegetation on land-side slope.



Source JICA Study Team

Figure 8.26: Standard Design of Embankment

The standard design of flood walls is presented in Figure 8.27. To secure the stability and durability of the structure, a gravity type of retaining wall, using wet masonry, is proposed. Concrete piles are provided at the bottom of flood wall for support of foundation. The surface of the riverside wall is covered with lining concrete, and the toe of the flood wall is protected with sheet piles and gabion to cope with erosion and local scouring, since the flood walls will be constructed directly adjacent to the existing riverbank.



Source JICA Study Team

Figure 8.27: Standard Design of Flood Wall

4) River Training Works

River training works are proposed to stabilize the river channel, through channel excavation and provision of slope protection works along the riverbank. The river training works are to be adapted in the areas where the river channel is meandering due to an unstable/erratic mainstream flow. This option is studied for each river section and each tributary.

5) Spur Dikes

Spur dikes are to be adopted to protect the riverbanks from erosion and/or deflect flow direction. There are mainly two kinds of structural type of spur dikes (Table 8.16).

Table 8.16: Structural Types of Spur Dike

No.	Purpose	Height	Weight	Type of Permeability	Arrangements
1	Reduction of flow velocity	Low	Light	Permeable or Impermeable with low height	Group units
2	Deflection of flow direction	High	Heavy	Impermeable	Single or a few unit

Source: JICA Study Team

Spur dikes are designed by adopting the following criteria of length, height, and interval to protect from riverbank erosion as well as to mitigate the impacts to opposite banks (Table 8.17). The direction of spur dike is selected as perpendicular to the bank, which can be the most economical option. In this Study, the spur dike will be studied if it is judged as necessary, in consideration of the site conditions and design velocity.

Table 8.17: Basic Dimensions of Spur Dikes

No.	Basic Dimension of Spur Dike	Criteria
1	Length	less than 10% of river width
2	Height	0.2–0.3 times of design flood water depth, and higher than normal water level by 0.5–1.0 m
3	Interval	2-4 times of length of spur dike, 10–30 times of height
4	Slope	Downward slope of 1/20–1/100 toward center of river
5	Direction of Spur Dike	Perpendicular to the riverbank

Source: JICA Study Team

6) Culverts

Culverts are structures to be installed across embankments, flood walls, and railway track to drain rainwater from mountainous areas to the river channel. There are around 200 culverts installed along the existing railway track on the Kilosa–Gulwe section. These function as drainage mechanisms as well as passageways for locals.

The main problem with the existing culverts is their inadequate drainage capacity, caused by clogging from sediment depositions. A major reason for this is that some culverts are lower than natural ground level in the surrounding area, and no drainage channel is provided for some culverts to drain water and sediment to the river.

In this Study, the standard design of culverts was prepared to improve drainage capacity. Invert levels and opening of culverts and outlet channels were designed in consideration of the site conditions of each proposed culvert.

7) Others

There are some bridges along the railway line across the river and its tributaries. These bridges are designed as railway structures.

8.4.3 Railway Structures

(1) Design Condition

1) Alignment

The minimum curve radius is defined as 400 m in the re-routed line, in order to facilitate speedups. In unavoidable cases, the curve radius could be reduced to 250 m (Table 8.18). In the present alignment, the minimum curve radius is 300 m. According to the Civil Engineering Manual (Table 8.19), train speed increases along a larger curve radius.

Table 8.18: Minimum Curve Radius

Case	Curve Radius
Common	400 m
Unavoidable	250 m

Source: JICA Study Team

Table 8.19: Maximum Train Speed

Curve Radius	Bogie Wagon	4 Wheel Wagon	Remarks
R=300 m	75 (km/h)	66 (km/h)	Degree: 4.0
R=400 m	82 (km/h)	72 (km/h)	Degree: 5.0

Source: TRC, Civil Engineering Manual, 1998

2) Vertical Alignment

The maximum gradient is defined as 1.0% in this Study. The gradient of the existing line between the Kilosa Station and Dodoma Station is generally less than 1.0%. (Incidentally, according to the Civil Engineering Manual, a gradient of 2.2% is shown as an example of existing railway and the vertical curve radius is defined as 3,000 m). Conflicts of the vertical curve and the transition curve shall be avoided as far as possible.

Table 8.20: Maximum Vertical Gradient

Maximum Vertical Gradient
1.0%

Source: JICA Study Team

Table 8.21: Vertical Curve Radius

Vertical Curve Radius
3,000 m

Source: JICA Study Team based on TRC Civil Engineering Manual, 1998

3) Station Alignment

The station track alignment is defined as a straight line of more than approximately 700 m. The gradient in the station in the re-routed section shall be less than 0.2%, in order to safely stop trains.

Table 8.22: Station Alignment

Straight Track Length	Gradient
Approximately 700 m	Less than 0.2%

Source: JICA Study Team

4) Future Water Level

The future water level of the river is from results of Section 6.2.

5) Embankment Height

The maximum embankment height on the center of rerouting line is defined as around 15 m in this Study. In the case where the embankment width is wider than the ROW (=60 m), the following parameters are set: (i) slope gradient = 1:1.5, (ii) formation width = 4.572 m, (iii) embankment height = 18.3 m.

Table 8.23: Maximum Embankment Height

Maximum Embankment Height
Approximately 15 m

Source: JICA Study Team

6) Cutting Height

The maximum cutting height along the center of rerouting line is defined as approximately 19 m. (In Japan, when the cutting height is more than 19 m, a tunnel is constructed.)

Table 8.24: Maximum Cutting Height

Maximum Cutting Height
Approximately 19 m

Source: JICA Study Team

(2) Standard Design

1) Embankment

According to the Civil Engineering Manual, the slope gradient for embankments is defined as 1:1.5. Following suit, the slope gradient for embankments shall be defined as 1:1.5 in this Study. For embankments higher than 6 m, berms shall be provided as per Japanese standards, as there is no existing standard for high embankments. The preliminary design was carried out at the time of the Draft Final Report. For detailed information, refer to Chapter 10.

2) Cutting Earth

According to the Civil Engineering Manual, the slope gradient for cut earth is defined as 1:1 for normal soil. However, the slope gradient is not defined for rock formations. In the study area, cut earth areas along the existing line all contain exposed rock formations, with the gradient being nearly vertical. Therefore, the gradient of cut earth shall be defined as 1:0.35 in this Study. Moreover, slope protection works shall be considered. The preliminary design was carried out at the time of the Draft Final Report. For detailed information, refer to Chapter 10.

3) Culverts

Culverts shall be designed to collect and drain water from the mountain side of embankments of the re-routed line to the river-side. Two types of culverts, [2 m x 2 m] and [3 m x 3 m], shall be proposed based on the results from Section 6.4. Moreover, the preliminary design was carried out at the time of the Draft Final Report. For detailed information, refer to Chapter 10.

4) Bridges

Steel bridges (15 m span) which have a proven local track record shall be adopted for this Study. In cases where the total bridge length exceeds 15 m, a tandem arrangement of 15 m girders shall be provided. Moreover, the preliminary design was carried out at the time of the Draft Final Report. For detailed information, refer to Chapter 10.

8.5 Condition of Cost Estimate

(1) Objective of Cost Estimate

In this section, the construction cost is estimated for Flood Protection Works, including both the river and the railway structures. The purpose is to establish the basis for the Project components and implementation schedule. The cost estimation is carried out for the following scope of works: (i) mobilization, (ii) temporary road, (iii) river structures including (a) flood wall and bank protection, and (b) measures for tributaries, and (iv) railway structures including (a) track works, (b) earth work, (c) protection works, (d) bridge and culvert works, and (e) drainage work.

(2) Basic Conditions of Cost Estimate

The basis for the cost estimate is described as follows:

1) Cost estimates are based on the current market prices in June and July 2015 of construction materials, labor rates, and construction equipment rates prevailing in Tanzania (at Dar es Salaam and surrounding areas) and other countries. Recent quotations submitted by contractors to RAHCO are also used.

2) The cost estimated for each item will consist of a foreign currency portion computed in Japanese YEN (JPY) and a local currency portion computed in Tanzanian Shilling (TZS). The total cost is shown in TZS, using the exchange rate of May 2016 below:

   - US$ 1= JPY 113.1
   - US$1 = TZS 2,189.67
   - TZS 1 = JPY 0.0516

3) The quantities are roughly computed on the basis of the drawings produced for the river and railway structures, bridges and culverts, and assumptions set forth for the alternatives.

4) The estimated costs for both the civil works and equipment include indirect costs. The indirect costs including profit are assumed to be 35% of the direct costs.

5) Wage rates and local material costs are examined on the basis of the Tanzanian labor law and current market prices.

6) Physical contingency for construction works and consulting services is assumed to be 5% of each cost.

7) Sales tax of 18% (VAT) is applied to the construction cost. For estimation purposes, each component of the unit prices will be computed on the basis of prices without VAT. VAT will be added to the total cost of the works, including construction, procurement of equipment, and engineering.

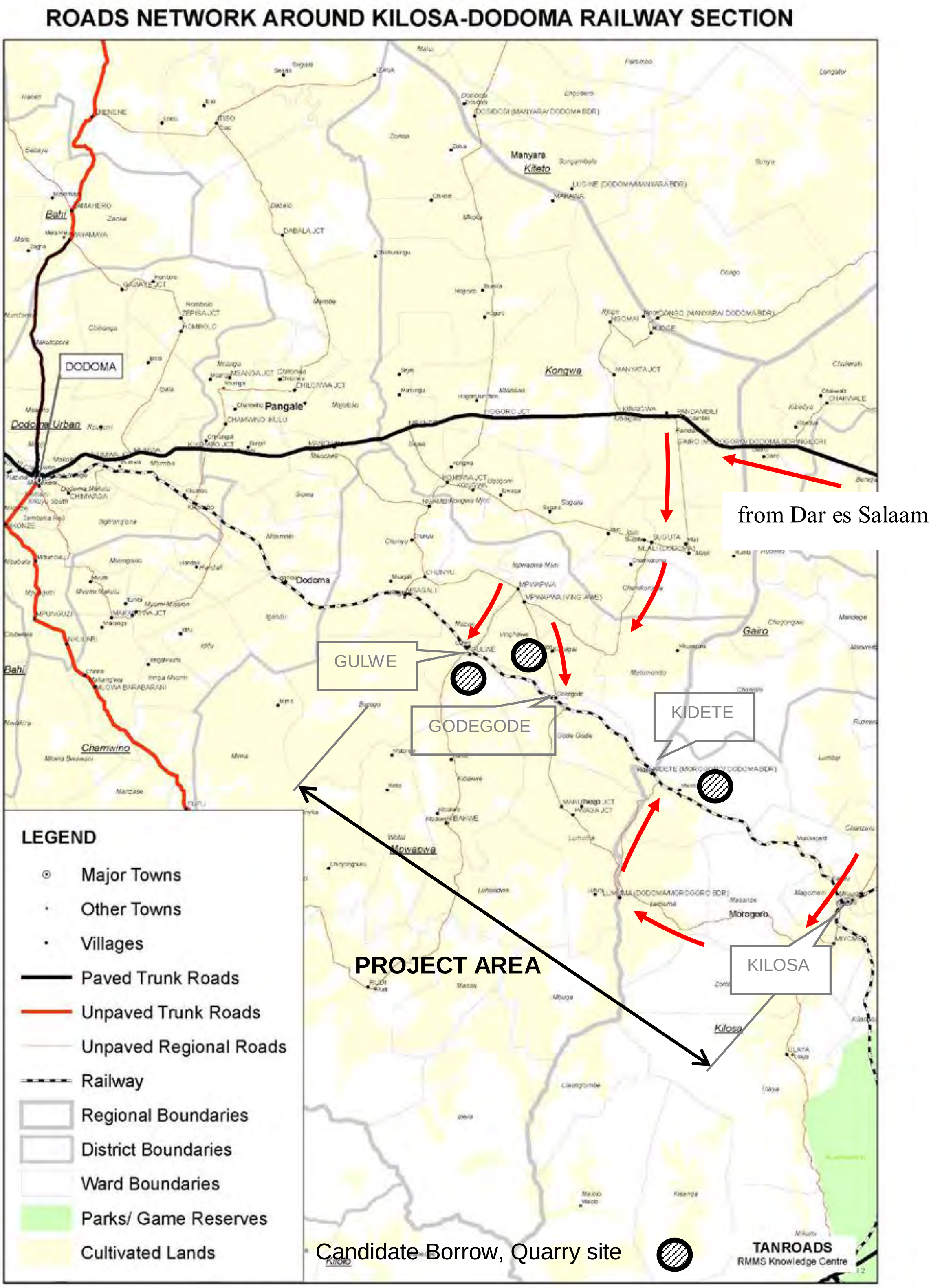
(3) Access Road

The project site is located around 50 km south of highway B129 between Dar es Salaam and Dodoma. Bifurcated unpaved regional roads (4-6 m width) are connected to Kilosa, Kidete, Godegode, and Gulwe Stations (Figure 8.28). Kidete Station is located in the middle of a construction site. These roads are available for transportation of construction machines, equipment, and materials.

As most of the construction area does not have roads along the Kilosa–Gulwe section, (i) main access roads along with the rivers from station to station, (ii) branch roads connecting to construction sites, and (iii) branch roads connecting to construction sites at tributaries from stations will be required.

The access roads from Kilosa, Kidete, Godegode, and Gulwe Stations are designed to pass though the construction sites along with the railway line.

After completing the Project, the access roads are expected to be utilized for the continuing maintenance of the railway structures.



Source: JICA Study Team

Figure 8.28: Road to the Project Area

8.6 Preparation of Alternatives

8.6.1 Process of Preparing Alternatives for Flood Protection Measures

The Study considers comprehensive flood protection measures consisting of the following hard and soft measures.

(1) Hard Measures

The Study proposes flood protection measures that combine flood protection works with maintenance after completion of the Project.[1] Conducting annual proper maintenance is essential to keep the Project effectiveness. Thus, the proposed measures are planned based on the assumption that proper maintenance will be carried out afterwards.

Maintenance includes the management of discharged sediment in the vicinity of the railway track, namely, the removal of deposited sand in and around culverts and drainage infrastructure. The cost for removing deposited sand is included as part of the maintenance cost, and will be considered when comparing alternatives.

(2) Soft Measures

1) Considerations for the safety of train operations during Floods

Following the analysis of railway accidents in recent years, it is considered that accidents are mainly attributed to (i) a lack of sharing of instantaneous information based on collected/analyzed elementary data on meteorology and hydrology among the concerned personnel, including station masters, track maintenance gangs, and train drivers; and (ii) insufficient awareness and information dissemination on flood risk management. However, the rain area is small and its duration is relatively short in the Project area, making it difficult to predict the occurrence of floods. The Study prepared hazard maps indicating, among other things, the critical sites requiring the utmost attention (e.g., track sections repeatedly damaged by erosion, and areas of intersection of the track and the tributaries where severe sedimentation is observed), past flood records, and flood marks (See Appendix T).

While accumulating data through (i) regular observation of rainfall in the river basin and water levels in rainy seasons (at Gulwe and Kilosa), and (ii) continuous record of river-bank erosion progress, it is desired that these data (including the hazard maps) be utilized for ensuring the safety of train operations (i.e., speed restrictions, service suspensions).

Principal rules regarding the operation and maintenance of railway faclities during the rainy season and individual rain event are described in the General Rules[2] and the Civil Engineering Manual[3]. It is required to confirm the actual operation of these rules/manuals, and verify whether (i) the contents are in line with the actual conditions at the flood sites, in light of recent flood disasters, and (ii) there is a need to update/revise rules to promote the prevention of accidents caused by flood disasters.

In the long-term, the establishment of a viable system enabling improvements in the safety of train operations during floods should be executed (see Box 8.2). As its first step, it is considered extremely effective to implement a technical assistance program, and its prompt implementation is essential.

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[1] See Subsections 8.6.3-8.6.5 for the flood protection works.
[2] See 230. Warning Order (p.157) and 236. Floods and Landslides (p.167)
[3] See 15.3.12 Precautions before and during rains (p.15-20)

Box 8.2: Key Points for Ensuring Safety in Train Operations

Basically, no disaster can be allowed for safe train operations. Ideally, train operations must be halted when there is a likelihood of disasters. In reality, however, it is true that railways will suffer disasters on occasion. Thus, the following measures can be taken to prevent disaster damages:

- When rainclouds appear during the rainy season, operate train carefully.
- Detect the intensity and area of rainfall, and stop trains if the rainfall exceeds the threshold that has caused disasters in the past (it is considered to be possible to equip simplified rain gauges at gang camps, and control train operations during heavy rains based on the observed values).

Furthermore, the following are key points to consider toward minimizing the impact of disasters:

- It is difficult to entirely eliminate disaster damages (due to economic rationale).
- Prepare train operation patterns that avoid disaster risk.
- Prevent accidents by (i) reducing train speeds when a disaster may occur, and (ii) halting train services when the water level around embankments exceeds a certain level (set in advance).
- Establish a system (structure, staffing, and monitoring system) that enables these measures.

2) Budget Allocation for Annual Maintenance after Completion of the Project

An outline of the annual maintenance work was considered at the interim stage based on the results of the preliminary design. It includes a work structure, staffing, work type, work quantity, and cost, as well as required equipment. In order to materialize this system of preventative maintenance, instead of post-disaster works in response, a yearly budget allocation for maintenance work is imperative. In the course of preparation of the Draft Final Report, annual maintenance cost as well as annual recovery cost were substantially reviewed and updated. The updated amounts are presented in Subsection 10.3.3.

(3) Other than Flood Protection Measures (River Basin Management)

It is difficult to solve the problem of railway flood disasters solely by structural measures. In fact, sediment discharge, attributed mainly to human-induced activities (including excessive tree cutting and cultivation) has intensified the flood damages not only in the vicinity of the railway, but also in the areas away from it.[4] It is against this background that river basin management is considered to be required in view of a medium- and long-term perspective. This includes, among other things, tree-planting, control of sediment discharge from cultivated areas, livestock grazing control, land use regulations, sediment control, and river improvements. Nevertheless, river basin management is closely related to the livelihood of residents along with the basin, and cannot be implemented solely by the MOT and RAHCO. Recommendations regarding medium- and long-term river basin management are presented in Chapter 15.

8.6.2 Key Points for Consideration in Preparing Flood Protection Measures

Considering the damages to railway facilities and train operations, flood protection measures were prepared by (i) relocating the track to higher ground in high-risk areas, and (ii) preventing wash-aways of track by bank protection in other areas.

[4] The Study Team has found that the sediment inflow from several tributaries from Kilosa to Gulwe is outstanding, and has caused severe trouble in managing the railway infrastructure. On the other hand, the rainfall characteristics that cause floods in the study area have revealed that the rain area is small and its duration is relatively short, leading in many cases to flash floods. Therefore, the assurance of safety in railway transportation is a pressing issue to be dealt with by strengthening the monitoring structure in cooperation with the Ministry of Water (MOW) and the Tanzania Meteorological Agency (TMA).

Railway re-routing: At serious bank erosion sites the track will be shifted to the mountain-side, with the embankment height being above the Design High Water Level (which assumed sediment deposition over a 30-year period).

Riverbank protection: Bank protection works were arranged with the basic approach of (i) allowing temporary track submergence, and (ii) maintaining the existing track while preventing riverbank erosion.

With respect to the selection between rerouting of track and protection of bank erosion, following three evaluation criteria were applied:

(i) Horizontal distance from bank shoulder to the existing rail (D m) at subject section
- High risk: D < 110 m
- Low Risk: D > 110 m

(ii) Extent of bank erosion at present
- Three ranks, i.e., Very progressive, Progressive, and Moderate, were considered based on the results of site reconnaissance and geomorphological analysis

(iii) Bank height at subject location of erosion (H m)
- High risk: H > 3.0 m
- Low Risk: H< 3.0 m

Table 8.26 and Table 8.27 show the results of site selection for the rerouting of track and bank protection between Kilosa and Gulwe.

However, the results of the evaluation on bank erosion areas were further reviewed in the preliminary design stage (November to December 2015). Subsequently, configuration of the protection areas was changed slightly from the interim stage. The results are presented in Subsection 10.1.9.

8.6.3 Proposed Alternatives

Based on the planning scale discussed in Subsection 8.2.6, an alternative was considered which fully meets the design flood water level of the scale for the entire segment between Kilosa and Gulwe, namely, as Alternative C. In addition, since the total investment cost of Alternative C had been presumed rather high – beyond the critical level to keep economic viability of the proposed project – the other two alternatives (i.e., Alternatives A and B) were studied.

Alternative A protects selected serious bank erosion sites by (i) rerouting the existing railway with revetments for bank protection, and (ii) rerouting the existing railway. On the other hand, Alternative B covers the protection works under Alternative A as well as the sites which have the potential for flood inundations causing a longer period of suspension of railway services. Alternatives A and B involve less costs compared with Alternative C for securing economic viability. Further, all alternatives include a series of groundsill to stabilize the riverbed and strengthening of existing revetment, etc., of three tributaries (i.e., Maswala, Kidibo, and Mzase Rivers) as common protection measures against sediment disasters.

Table 8.25 provides a summary of the Alternatives with the flood damages and proposed measures. The core elements of the alternatives are as follows, with details provided in Subsections 8.6.3-8.6.5:

(1) Alternative A

- This alternative aims at providing flood protection measures in areas where serious bank erosion has occurred or might occur in the future due to shorter distance between the bank shoulder and the existing rail, current condition of bank erosion, bank height, etc.

- In case of design floods for the sections where no protection is provided by Alternative A, it may result in (i) track damages due to large-scale floodwaters overtopping the track, and (ii) wash-aways of ballast, roadbed, and some riverbank protections (e.g., gabions, spur dikes, etc.), leading to small-/medium-scale restoration works and suspension of train service.

(2) Alternative B

- This alternative aims at providing flood protection measures in areas where inundation has occurred in the low terrain at mountain skirts together with overtopping by landside flood flow resulting acceleration of flood damage, in addition to the bank erosion areas covered by Alternative A.

- In case of design floods for the sections where no protection is provided by Alternative B, it may result in a similar magnitude of flood damage to track, ballast, roadbed, and some riverbank protections (e.g., gabions, spur dikes, etc.) as anticipated in Alternative A, leading to small-/medium scale restoration works and suspension of train service.

(3) Alternative C

- This alternative aims at providing flood protection measures in areas with possibility of track submergence in case of design floods, and is intended to minimize flood damages through the most strengthened/extended hard measures among the three alternatives. Therefore, even if design floods occur, this alternative will not be subject to track submergence; however, suspension of train services is needed.

- Among the three alternatives, this will entail the largest vertical movement of the track and installation of flood walls and flood embankments, meaning that it will reduce flood risk to the greatest extent. Therefore, no flood restoration works will be needed.

It is important to note that:

- Alternative B covers the entire scope of Alternative A, and Alternative C covers the entire scope of Alternative B (let alone Alternative A).

- In case of the railway alignment traversing villages, an additional alignment is drawn considering the reduction of the number of buildings slated for relocation, and is depicted as Alternatives A-2, B-2, and C-2 (as compared to these, alternatives favoring track alignments are depicted as Alternatives A-1, B-1, and C-1).

- All the alternatives may require speed restrictions or suspension of train services in case of partial submergence of railway embankments and bank erosion.

- These alternatives were prepared by applying the same specifications (e.g., minimum curve radius, maximum gradient, etc.) used throughout the entire Central Railway Line, so that the re-routing of sections would not restrict future improvements in transport capacity.

- There would be no difference in terms of the resulting transport capacity among alternatives, as future traffic demand (both freight and passenger) were assumed equal.

Table 8.25: Alternatives with Flood Damages and Proposed Measures

Alternatives	Flood Damages	Causes	Sites	Proposed Railway Measures	Proposed River Measures
A, B, C	Loss of bridge	Loss of girder Collapse of abutment	Bridge around Km 293	Prevention of bridge at Km 293 from falling[1]	Bank protection around the left bank abutment
A, B, C	Loss of bridge	Collapse of abutment	Kidibo River (Km 355)	-	River channel work in downstream (bank protection with sheet pile)
A, B, C	Loss of roadbed and subgrade	Riverbank erosion	Kidibo River (Km 355)	-	River channel work in downstream (bank protection with sheet pile)
A, B, C	Loss of roadbed and subgrade	Riverbank erosion	Areas susceptible to bank erosion	Relocation of the track	Installation of bank protection with gabions, gigantic stones, and spur dikes
A, B, C	Large-scale wash-aways of track	Large-scale overtopping	Maswala River (Km 349.5)	Relocation of the bridge (box culverts) at Maswala	River channel work in downstream (groundsill and embankment)
A, B, C	Large-scale wash-aways of track	Large-scale overtopping	Mzase River (Km 365.6)	Relocation of the existing railway structures (box culverts) at Mzase and Gulwe Station	River channel work in downstream (groundsill and bank protection)
B, C	Medium-scale wash-aways of track	Medium-scale overtopping	Km 363–Km 368	Relocation of the track	-
C	Track submergence	Small-scale overtopping	Areas where the existing railway level is below the design flood level	Elevation of the track by re-routing	-
C	Track submergence	Small-scale overtopping	Areas susceptible to bank erosion	-	Installation of steel sheet pile/pipe
C	Track submergence	Small-scale overtopping	Maswala River (Km 349.5)	-	River channel works in upstream (groundsill)
C	Track submergence	Small-scale overtopping	Kidibo River (Km 355)	Relocation of the bridge at Kidibo	River channel works in upstream (groundsill and bank protection)
C	Track submergence	Small-scale overtopping	Mzase River (Km 365.6)	-	River channel works in upstream (groundsill and bank protection)

Note: Alternative C requires the replacement of the bridge at Km 293.
Source: JICA Study Team

Table 8.26: Evaluation of Risk of Bank Erosion to Select Protection Measures (1/2)

No.	Section (km)	Distance	Water-hit area	Criteria 1: Distance from Bank Shoulder (D m)		Criteria 2: Extent of bank erosion	Criteria 3: Bank height (H m)		Numbers of criteria evaluated as "H" or "Progressive"	Overall evaluation	Re-routing section (Alt-B2)		Section of bank protection (Alt-B2)		Major concerns for selection of re-routing and/or river bank protection
				Shortest	Rank			Rank		Rank	Section	Code No.	Section	Code No.	
1	285.5 - 286.3	0.8	Y	140	L	Progressive	3.0	H	2	–					
2	288.7 - 293.0	4.3	Y	130	L	Progressive	1.5	L	1	-					
3	293.0 - 293.4	0.4	Y	30	H	Progressive	2.0	L	2	–					
4	293.4 - 294.2	0.8	Y	existing bridge	H	V. Progressive	2.3	L	2	○	293.8 - 295.5	1			Since immediate upstream section of existing steel bridge at km293 will be endangered by floods, re-routing of rail is planned.
5	295.8 - 296.2	0.4	Y	240	L	Moderate	2.5	L	0	-					
6	297.2 - 297.4	0.2	Y	40	H	Moderate	2.1	L	1	-					
7	297.4 - 298.2	0.8	Y	30	H	V. Progressive	1.7	L	2	△			297.4 - 298.15	1	The site is endangered by further bank erosion due to directly hitting by the flood current.
8	298.5 - 299.3	0.8	Y	70	H	V. Progressive	1.8	L	2	△			298.5 - 299.0	2	Similar situation to site No.1
9	299.7 - 300.1	0.4	Y	40	H	Progressive	1.3	L	2	–					
10	300.1 - 301.2	1.1	Y	30	H	V. Progressive	3.0	H	3	○			300.2 - 300.45	3	Similar situation to site No.1
11	301.2 - 301.6	0.4	Y	130	L	Moderate	0.8	L	0	-					
12	301.6 - 301.7	0.1	Y	290	L	Moderate	0.8	L	0	-					
13	301.7 - 301.9	0.2	Y	250	L	Moderate	1.4	L	0	-					
14	301.9 - 302.0	0.1	Y	250	L	Moderate	3.0	H	1	-					
15	302.0 - 302.1	0.1	Y	240	L	Moderate	1.2	L	0	-	302.0 - 308.0	2			These sections of existing railway run along the the Mkondoa River and only short distances between the rail and bank shoulder remain at several sections. Bank protection is also to be provided at where is judged high risk, because due to topographic conditions enough distance can not be secured even after re-routing.
16	302.1 - 302.2	0.1	Y	110	H	Progressive	1.0	L	2	–					
17	302.2 - 302.5	0.3	Y	40	H	Progressive	1.0	L	2	–					
18	302.5 - 302.6	0.1	Y	90	H	Progressive	2.2	L	2	△					
19	302.6 - 302.9	0.3	Y	50	H	V. Progressive	2.2	L	2	△			302.7 - 303.0	4	
20	302.9 - 303.5	0.6	Y	30	H	V. Progressive	3.0	H	3	○			303.1 - 303.45	5	
21	303.8 - 304.0	0.2	Y	160	L	Moderate	3.0	H	1	-					Sites No.4 to No.7 has similar morphological feature that are characterized of unstable foundation of sediment deposit from small scale of tributaries. Therefore, bank protection is necessary to strengthen against flood current.
22	305.7 - 306.0	0.3	Y	50	H	Progressive	3.0	H	3	○			304.1 - 304.5	6	
23	306.0 - 306.5	0.5	Y	40	H	Progressive	3.0	H	3	○			306.0 - 306.5	7	
24	306.5 - 306.8	0.3	Y	130	L	Progressive	3.0	H	2	–					
25	308.0 - 308.2	0.2	Y	130	L	Progressive	1.5	L	1	-					
26	308.4 - 308.6	0.2	Y	200	L	Progressive	2.5	L	1	–					
27	308.9 - 309.7	0.8	Y	40	H	V. Progressive	1.4	L	2	△			308.6 - 310.1	8	Main river course is approaching to the bank very closely at this site. Further, the river flow seems very unstable and easy to change during floods. Bank protection is prerequisite.
28	309.9 - 310.3	0.4	Y	340	L	Progressive	1.5	L	1	–					
29	310.3 - 311.0	0.7	Y	90	H	Moderate	4.3	H	2	–			310.2 - 314.3	9	Similar situation to Site No.8
30	312.5 - 312.7	0.2	Y	80	H	Progressive	3.4	H	3	○					
31	312.7 - 313.2	0.5	Y	40	H	Moderate	3.0	H	2	–					
32	313.2 - 313.9	0.7	Y	100	H	Moderate	4.0	H	2	–	313.3 - 316.0	3			This site is one of the most progressive bank erosion site, where has been damaged repeatedly by floods. Re-routing combined with bank protection is recommended to avoid flood damage.
33	313.9 - 315.0	1.1	Y	60	H	Progressive	4.4	H	3	○					
34	315.0 - 315.2	0.2	Y	40	H	Most progressive	6.0	H	3	○			315.2 - 316.9	10	Serious bank erosion has occurred in last 3 years and still very aggressive at Site No.10. Rigid structure of bank protection will be required to make the river bank stable against strong flood current.
35	316.6 - 317.0	0.4	Y	100	H	Moderate	3.7	H	2	–					

○: Evaluated as "High" or "Progressive" for all 3 criterion and in particular "Most or Very Progressive" in extent of bank erosion, or a tributary connected → Re-routing

△: Evaluated as "High" or "Progressive" for all 3 criterion or even relevant to 2 or 1 criteria but with "Most or Very Progressive" in extent of bank erosion → Bank protection

Source: JICA Study Team

Table 8.27: Evaluation of Risk of Bank Erosion to Select Protection Measures (2/2)

No.	Section (km)	Distance	Water-hit area	Criteria 1 Distance from Bank Shoulder Shortest	Criteria 1 Rank	Criteria 2 Extent of bank erosion	Criteria 3 Bank height (H m)	Criteria 3 Rank	Numbers of criteria evaluated as "H" or "Progressive"	Overall evaluation Rank	Re-routing section (Alt-B2) Section	Re-routing section (Alt-B2) Code No.	Section of bank protection (Alt-B2) Section	Section of bank protection (Alt-B2) Code No.	Major concerns for selection of re-routing and/or river bank protection
36	328.3 - 328.5	0.2	Y	100	H	Moderate	8.0	H	2	–					
37	329.0 - 329.2	0.2	Y	50	H	Progressive	2.0	L	2	–					
38	329.2 - 329.5	0.3	Y	50	H	Moderate	4.8	H	2	–	329.4 - 331.4	4			Since the risk level is judged lower than others, re-routing will be canceled to reduced the total cost. Instead, bank protection should be provided to strengthen the river bank.
39	329.5 - 329.8	0.3	Y	80	H	Moderate	3.0	H	2	–					
40	329.8 - 330.5	0.7	Y	70	H	V. Progressive	2.5	L	2	△			330.1 - 330.6	11	
41	330.7 - 331.6	0.9	Y	500	L	Progressive	3.0	H	2	–					
42	334.5 - 335.0	0.5	Y	210	L	Moderate	3.0	H	1	–					
43	337.2 - 338.0	0.8	Y	40	H	Most progressive	4.5	H	3	○	337.3 - 339.2	5			The railway alignment was recently shifted immediately after serious bank erosion occurred due to strong flood current in March 2015. Re-routing is essentially required with bank protection. (Since budget for bank protection has been approved by the Tanzanian Government, this site is excluded here.)
44	339.2 - 340.8	1.6	Y	190	L	Progressive	1.4	L	1	–			339.7 - 340.2	12	The flow direction seems to be shifting toward right bank and the land will be gradually encroached. In order to mitigate the trend, bank protection is necessary. Site condition of No.12 is similar to No.4. Sites No. 13 and No.14 are located in the low terrain consisting of sediment debris of mountain and requiring bank protection.
45	340.8 - 343.8	3.0	Y	190	L	Progressive	2.1	L	1	–	340.9 - 343.8	6	341.6 - 342.8 343.2 - 344.7	13 14	
46	346.2 - 348.0	1.8	Y	130	L	Moderate	2.7	L	0	○ (Mangweta join)	346.2 - 348.0	7	345.0 - 345.25	15	Site No.15 is directly water hitting site susceptible further bank erosion. Since the Mangweta River has large potential of sediment discharge in its watershed, big amount of sediment deposition caused heavy damage to the railway at the confluence might be notable risk.
47	351.0 - 353.8	2.8	Y	440	L	Progressive	3.0	H	2	○ (Maswala cross)	351.0 - 352.8	8			Sediment discharge from the Maswala River should be appropriately controlled with re-routing to higher ground.
48	355.0 - 355.5	0.5	Y	Kidibo Bridge	-	Progressive	5.4	H	2	○ (Kidibo cross)					Abutment of Kidibo Bridge and embankment connected should be strengthened against flood flow.
49	355.5 - 358.0	2.5	Y	90	H	Moderate	2.4	L	1	-					
50	362.4 - 371.6	9.2	N	40	H	Moderate	0.8	L	2	○ (Mzase cross)	362.4 - 371.6	9			Because the existing railway runs through low terrain in this section, inundation by mainstream and overtopping by land-side flood flow likely accelerate flood damage. In addition, the crossing point of the Mzase River should be improved with securing enough flow area. Re-routing is essentially recommended.
	Total	32.3	Y only	110 > D 110 < D	High Low		3.0 < H 3.0 > H	High Low							

○: Evaluated as "High" or "Progressive" for all 3 criterion and in particular "Most or Very Progressive" in extent of bank erosion, or a tributary connected → Re-routing

△: Evaluated as "High" or "Progressive" for all 3 criterion or even relevant to 2 or 1 criteria but with "Most or Very Progressive" in extent of bank erosion → Bank protection

Source: JICA Study Team

8.6.4 Study for Alternative A

(1) Target

Alternative A aims at providing flood protection measures in areas where serious bank erosion has recently occurred or might occur in the future because bank erosion can cause long interruption of railway operation until restoration of the damaged track, embankment, bridges, etc. This alternative is intended to address severe railway damages, and therefore, prevent cancelations of train service that last over several days. It is assumed that potential severe railway damages include (i) loss of roadbed and subgrade due to riverbank erosion, (ii) loss of bridges due to loss of girder and collapse of abutment, and (iii) large-scale wash-aways of the track due to large-scale floodwaters overtopping the track.

Riverbank erosion areas have been identified both in the mainstream and the tributaries. These areas are mainly located in Km 293-Km 318, and also scattered throughout Km 329-348 in the mainstream, while also found at the crossing point with Kidibo River.

Measures against loss of bridges will be applied to (i) the bridge crossing the mainstream at around Km 293 and (ii) the bridge at Kidibo River. Although the bridge crossing the mainstream at around Km 293 was replaced in 2014, there is a concern that (i) the bridge does not provide adequate clearance under the girder relative to design floods (see Section 8.2), and (ii) the bank protection around the left bank abutment (i.e., water-colliding front) is insufficient. While the bridge at Kidibo River (Kidibo Bridge) provides adequate clearance under the girder, there is a concern that bank protection around the abutment with steel sheet piles is insufficient.

Large-scale overtopping measures will be implemented at the Maswala and Mzase Rivers. These tributaries have suffered from (i) wash-aways of rail, ballast, and sleepers, and (ii) embankment damages due to floodwaters overtopping the track. The overtopping is attributed to riverbed aggradation due to sediment deposition.

Table 8.28 summarizes the sites/issues covered in Alternative A.

Table 8.28: Sites/Issues Covered in Alternative A

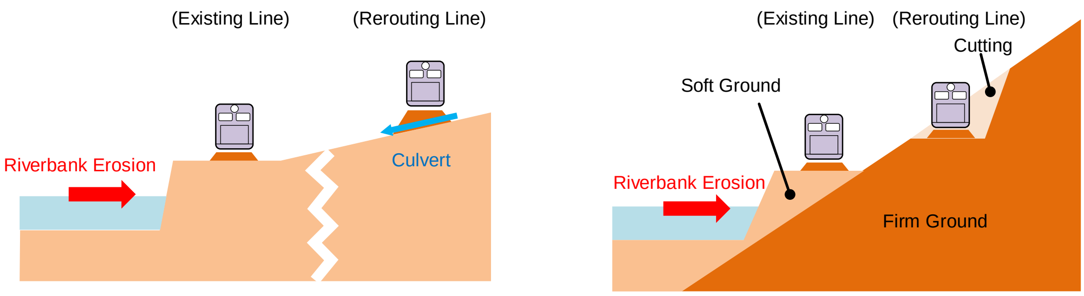
No.	Target
1	Riverbank erosion in the mainstream
2	Three tributaries (Maswala, Kidibo, and Mzase)
3	Bridge crossing the mainstream at around Km 293

Source: JICA Study Team

(2) Measures

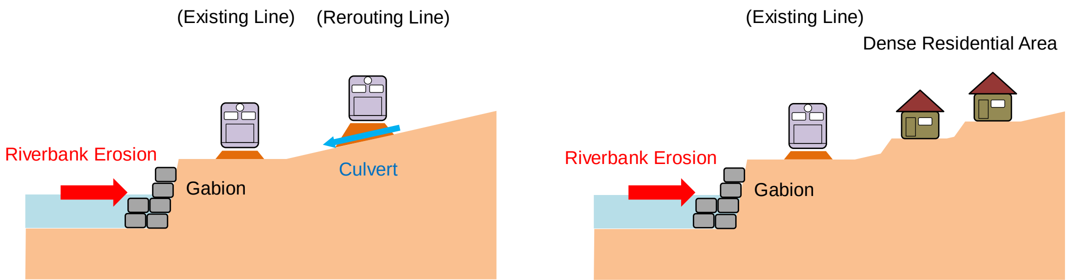
1) Riverbank Erosion in the Mainstream

The basic approach of Alternative A is to relocate the track to areas not susceptible to riverbank erosion (Figure 8.29). Sites for relocation include those away from riverbank erosion areas, and those with relatively hard ground. If it is difficult to relocate the track to the mountain-side, for example, due steep terrain and/or considerations for resettlement, then gabions/spur dikes will be installed (Figure 8.30).



Source: JICA Study Team

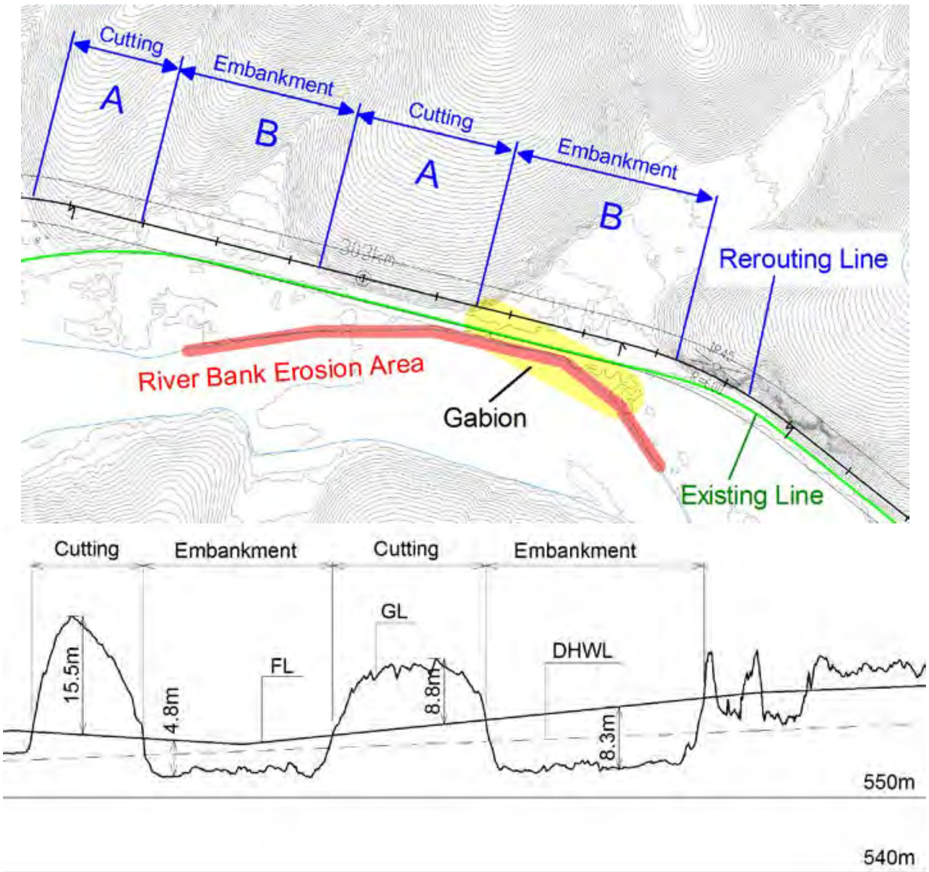
Figure 8.29: Basic Approach of Re-Routing, Alternative A



Source: JICA Study Team

Figure 8.30: Basic Approach of Re-rerouting, Alternative A (Unavoidable Case)

Figure 8.31 shows an example of re-routing to steep mountain areas. While area A is not susceptible to riverbank erosion (i.e., mountain-side ground is hard), area B is susceptible to riverbank erosion. Re-routing further to the mountain-side is inappropriate as the height of embankment and cutting becomes too large.



Source: JICA Study Team

Figure 8.31: An Example of Unavoidable Case, Alternative A

2) Three Tributaries (Maswala, Kidibo, and Mzase)

Maswala River: The first priority of the proposed measures in Subsection 7.6.6 will be implemented. It includes (i) relocation of the bridge at Maswala, and (ii) river channel works on the downstream side using groundsill and embankment. These measures will decrease aggradation of the riverbed due to sediment deposition, and therefore avoid large-scale overtopping at the crossing point with the tributary.

Kidibo River: The first priority of the proposed measure (i.e., river channel works using groundsill, bank protection, and steel sheet pile on the downstream side) as proposed in Subsection 7.6.7 will be implemented, except for the construction of a new bridge. However, after evaluation of flood risks to the existing bridge, the flood levels along the abutment and embankment were concluded to be not as high as in the Mazase and Maswala. Therefore, only extension of existing steel sheet pile revetment was included to protect those structures against flood current.

Mzase River: Overtopping damage at the tributary will be avoided by constructing a new bridge on the upstream side. The existing box culverts (3 m x 10), which have led to sediment deposition, will be removed, and the existing Gulwe Station will be relocated, while river channel works will be conducted on the downstream side using groundsill and bank protection.

3) Bridge Crossing the Mainstream at around Km 293

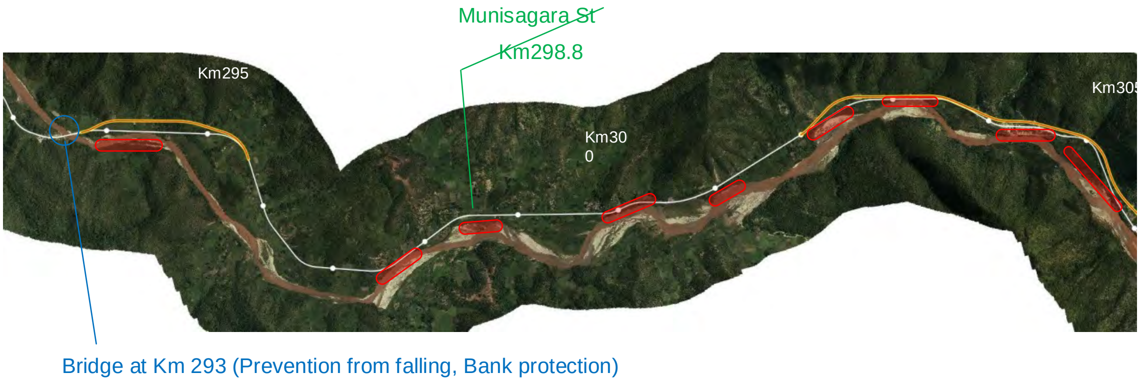
In order to prevent wash-away of the girder due to the design flood set in Section 8.2, bridge fall prevention devices will be equipped. Moreover, as the left bank abutments are on the water-colliding front, wash-aways of abutments and bridge will be avoided by providing bank protection around the abutment.

(3) Social Considerations

As presented in 8.6.2 (2), the basic approach of Alternative A was to relocate the track to hard ground not susceptible to riverbank erosion. However, much of the suitable hard ground is located in higher places that already have many residential buildings built throughout, for the same reason as it is suitable for rail: it is less susceptible to flood damages. As a result, Alternative A will entail a great deal of resettlement. Thus, Alternative A-1 is proposed favoring track alignment, and Alternative A-2 favors avoiding villages (densely-populated areas).

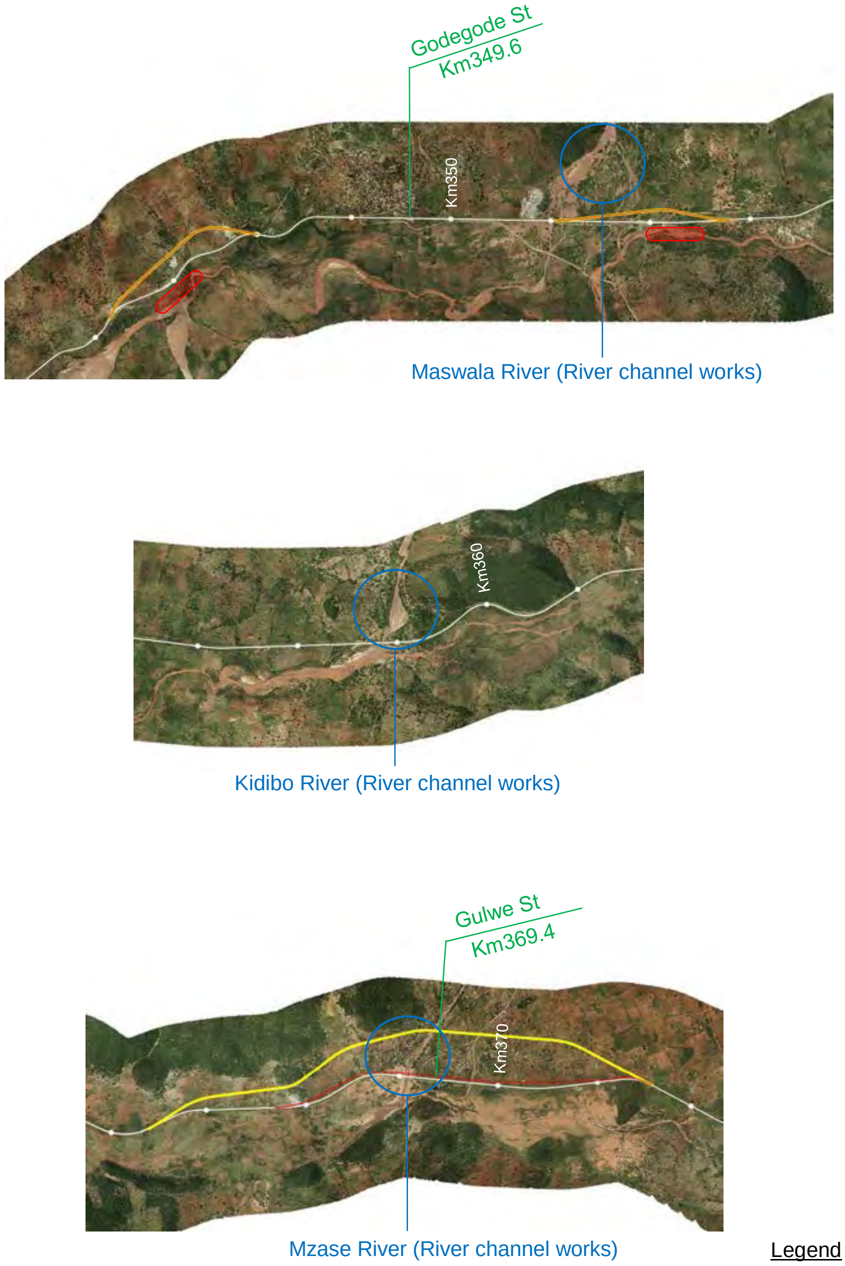
(4) Study Results

Based on the considerations made above, the alignment of Alternative A is drawn in Figure 8.32, and the quantity and costs of Alternatives A-1 and A-2 are summarized in Table 8.29 and Table 8.30 respectively.



Legend

Yellow:	Alternative A-1 Line
Red:	Alternative A-2 Line
White:	Existing Line
(red outlined shape)	River Bank Erosion Area



Legend

Yellow:	Alternative A-1 Line
Red:	Alternative A-2 Line
White:	Existing Line
(red oval)	River Bank Erosion Area

Source: JICA Study Team

Figure 8.32: Study Results of Alternative A

Table 8.29: Quantity and Cost of Alternative A-1

	Quantity	Unit	Cost (TZS mil)
Riverbank erosion measure			
Embankment work	788,000	m^3	37,795
Cutting work	385,000	m^3	28,652
Embankment protection work	28,000	m^2	9,631
Cutting protection work	110,000	m^2	36,884
Riverbank protection work	9	km	28,006
Bridge work	90	m	2,853
Culvert work	200	site	22,085
Measure at Maswala River			
River work	See Subsection 7.6.6		31,645
Bridge work	150	m	4,137
Measure at Kidibo River			
River work	See Subsection 7.6.7		473
Bridge work	0	m	0
Measure at Mzase River			
River work	See Subsection 7.6.8		3,814
Bridge work	45	m	1,427
Bridge measure at Km 293			
Bridge collapse prevention work	1	set	105
Bank protection work	1	set	35
Others			
Temporary road (river structure)	14.0	km	2,293
Temporary road (railway structure)	82.6	km	13,526
Procurement of track materials	11.4	km	5,298
Installation of track	28.0	km	20,899
1)Subtotal (railway structure)			**183,291**
2)Mobilization (10% for railway structure)			**18,329**
3)Subtotal (river structure)			**66,266**
4)Mobilization (10% for river structure)			**6,627**
5)Direct cost 1)+2)+3)+4)			**274,513**
6)Indirect cost (35% of direct cost)			**96,080**
Total 5)+6)			**370,593**
Total of railway structure (including direct and indirect costs)			**272,188**
Total of river structure (including direct and indirect costs)			**98,405**

Source: JICA Study Team

Table 8.30: Quantity and Cost of Alternative A-2

	Quantity	Unit	Cost (TZS mil)
Riverbank erosion measure			
Embankment work	594,000	m^3	28,490
Embankment protection work	281,000	m^3	29,912
Cutting work	29,000	m^2	9,975
Cutting protection work	78,000	m^2	26,154
Riverbank protection work	14.3	km	53,628
Bridge work	90	m	2,853
Culvert work	139	site	15,363
Measure at Maswala River			
River work	See Subsection 7.6.6		31,645
Bridge work	150	m	4,137
Measure at Kidibo River			
River work	See Subsection 7.6.7		473
Bridge work	0	m	0
Measure at Mzase River			
Rover work	See Subsection 7.6.8		3,814
Bridge work	45	m	1,427
Bridge measure at Km 293			
Bridge collapse prevention work	1	set	105
Bank protection work	1	set	35
Others			
Temporary road (river structure)	14.0	km	2,293
Temporary road (railway structure)	82.6	km	13,526
Procurement of track materials	11.4	km	5,298
Installation of track	20.0	km	14,928
1)Subtotal (railway structure)			**143,168**
2)Mobilization (10% for railway structure)			**14,317**
3)Subtotal (river structure)			**91,888**
4)Mobilization (10% for river structure)			**9,189**
5)Direct cost 1)+2)+3)+4)			**258,561**
6)Indirect cost (35% of direct cost)			**90,496**
Total 5)+6)			**349,058**
Total of railway structure (including direct and indirect costs)			**212,604**
Total of river structure (including direct and indirect costs)			**136,453**

Source: JICA Study Team

8.6.5 Study for Alternative B

(1) Target

Alternative B aims at providing flood protection measures in areas that have caused train service cancellations lasting longer than 24 hours during 2011-2014, in addition to the areas covered by Alternative A. Table 8.31 summarizes the cases that have lasted longer than 24 hours before restoration during 2011-2014.[7]

Table 8.31: Records of Flood Damages Lasted Longer than 24 Hours for Restoration, 2011–2014

Location (Re-calculated Kilometerage)		Date	Duration Time (Hour: Min.)	Typical Damage
Km 352	Maswala	2014/1/20	34:03	Ballast washed away
Km 352	Maswala	2014/1/19	28:10	Ballast washed away
Km 363-Km 375	Aound Gulwe	2014/1/2	81:15	12 feet deep, sleeper hanging, flowing over track ,track pushed away
Km 336-Km 338	Erosion Area	2013/2/19	40:05	NA
Km 368	Aound Gulwe	2012/3/23	39:00	NA
Km 352	Maswala	2012/1/16	168:00	Ballast and formation washed away Culvert broken
Km 352	Maswala	2011/12/23	85:00	Ballast and formation washed away
Km 368	Aound Gulwe	2011/12/22	95:00	Rail damaged
Km 368	Aound Gulwe	2011/12/18	40:00	Ballast and formation washed away

Notes: (i) Duration time indicates that the section was closed to traffic, meaning an order was issued to stop train movements into that section. Trains approaching the section are stopped at a convenient station before the closed section. (ii) “Formation” means the subgrade on which the ballast and sub-ballast is laid. In the wash-away reports from TRL, sometimes there is loose use of the term “formation”.
Abbreviations: NA = data not available
Source: TRL

Km 352 and Km 336–Km 338, listed in Table 8.31 above, are covered by Alternative A. Therefore, through implementation of measures against medium-scale overtopping and water-remaining from Km 363 to Km 368 (where the re-routing line connects with the existing line), in addition to measures taken in Alternative A, Alternative B aims to prevent train service cancelations longer than 24 hours, with measures listed as follows:

Table 8.32 summarizes the sites/issues covered in Alternative B.

Table 8.32: Sites/Issues Covered in Alternative B

No.	Target
1	Target in Alternative A including:
	Riverbank erosion in the mainstream
	Three tributaries (Maswala, Kidibo, and Mzase)
	Bridge crossing the mainstream at around Km 293
2	Overtopping from Km 363 to Km 368

Source: JICA Study Team

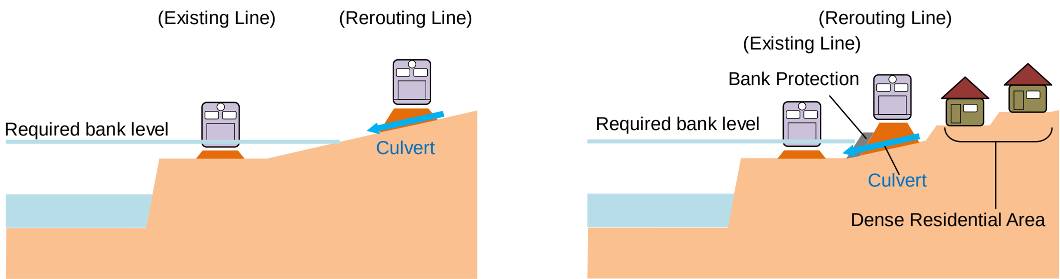
[7] The data was extracted from the Appendix A.

(2) Measures

1) Target in Alternative A
(Refer to Subsection 8.6.2 (2).)

2) Overtopping from Km 363 to Km 368
Overtopping from Km 363 to Km 368 may have been caused by (i) the inability to drain water from hinterlands due to siltation of the existing drainage facilities, and/or (ii) the high elevation of water level in the mainstream due to inflow from Mzase and/or Sikoko Rivers (which inflows from the opposite side of the bank).

The basic approach countering this issue is to relocate the track to ground higher than the design flood level, and install culverts with adequate cross-section areas of flow so that water from the hinterlands will not remain. If it is difficult to relocate the track (considering resettlement), then track will be installed on railway embankments reinforced with partial water-proofing works.



Source: JICA Study Team

Figure 8.33: Basic Approach of Re-Routing, Alternative B

(3) Social Considerations

As presented in Subsection 8.6.3 (2), the basic approach of addressing the overtopping from Km 363 to Km 368 was to relocate the track to ground higher than the design flood level. However, as higher ground is not subject to flood damages, many houses have already been built from Km 363 to Km 368. As a result, Alternative B will entail a great deal of resettlement. Thus, Alternative B-1 is proposed favoring track alignment, and Alternative B-2 favors avoiding villages (densely-populated areas).

(4) Study Results

Based on the considerations made above, the alignments of Alternative B are drawn in Figure 8.34, and the quantity and costs of Alternatives B-1 and B-2 are summarized in Table 8.33 and Table 8.34 respectively.

Source: JICA Study Team

Figure 8.34: Study Results of Alternative B

Table 8.33: Quantity and Cost of Alternative B-1

	Quantity	Unit	Cost (TZS mil)
Riverbank erosion measure			
Embankment work	891,000	m^3	42,735
Embankment protection work	387,000	m^3	28,801
Cutting work	28,000	m^2	9,631
Cutting protection work	111,000	m^2	37,220
Riverbank protection work	8.6	km	28,006
Bridge work	90	m	2,853
Culvert work	220	site	24,294
Measure at Maswala River			
River work	See Subsection 7.6.6		31,645
Bridge work	150	M	4,137
Measure at Kidibo River			
River work	See Subsection 7.6.7		473
Bridge work	0	M	0
Measure at Mzase River			
River work	See Subsection 7.6.8		3,814
Bridge work	45	m	1,427
Bridge measure at Km 293			
Bridge collapse prevention work	1	set	105
Bank protection work	1	set	35
Others			
Temporary road (river structure)	14.0	km	2,293
Temporary road (railway structure)	82.6	km	13,526
Procurement of track materials	11.4	km	5,298
Installation of track	32.0	km	23,885
1)Subtotal (railway structure)			**193,911**
2)Mobilization (10% for railway structure)			**19,391**
3)Subtotal (river structure)			**66,266**
4)Mobilization (10% for river structure)			**6,627**
5)Direct cost 1)+2)+3)+4)			**286,195**
6)Indirect cost (35% of direct cost)			**100,168**
Total 5)+6)			**386,363**
Total of railway structure (including direct and indirect costs)			**287,958**
Total of river structure (including direct and indirect costs)			**98,405**

Source: JICA Study Team

Table 8.34: Quantity and Cost of Alternative B-2

	Quantity	Unit	Cost (TZS mil)
Riverbank erosion measure			
Embankment work	729,000	m^3	34,965
Embankment protection work	284,000	m^3	21,135
Cutting work	30,000	m^2	10,319
Cutting protection work	80,000	m^2	26,825
Riverbank protection work	14.3	km	53,628
Bridge work	90	m	2,853
Culvert work	159	site	17,558
Measure at Maswala River			
River work	See Subsection 7.6.6		31,645
Bridge work	150	M	4,137
Measure at Kidibo River			
River work	See Subsection 7.6.7		473
Bridge work	0	M	0
Measure at Mzase River			
River work	See Subsection 7.6.8		3,814
Bridge work	45	m	1,427
Bridge measure at Km 293			
Bridge collapse prevention work	1	set	105
Bank protection work	1	set	35
Others			
Temporary road (river structure)	14.0	km	2,293
Temporary road (railway structure)	82.6	km	13,526
Procurement of track materials	11.4	km	5,298
Installation of track	25.0	km	18,660
1)Subtotal (railway structure)			**156,808**
2)Mobilization (10% for railway structure)			**15,681**
3)Subtotal (river structure)			**91,888**
4)Mobilization (10% for river structure)			**9,189**
5)Direct cost 1)+2)+3)+4)			**273,565**
6)Indirect cost (35% of direct cost)			**95,748**
Total 5)+6)			**369,313**
Total of railway structure (including direct and indirect costs)			**232,860**
Total of river structure (including direct and indirect costs)			**136,453**

Source: JICA Study Team

8.6.6 Study for Alternative C

(1) Target

This alternative aims at providing flood protection measures in areas with possibility of track submergence in case of design floods, and is intended to minimize flood damages through the most strengthened/extended measures among the three alternatives. Therefore, even if design floods occur, this alternative will not be subject to track submergence, and therefore, enables train service to continue with speed restrictions.

As Alternative C takes measures against overtopping of floodwaters, in addition to the measures covered in Alternative B (and further in Alternative A), it prevents against the cancellation of train service. According to Section 8.2, in the past, overtopping may have occurred outside of the following four sections (Table 8.35):

Table 8.35: Section not Susceptible to Overtopping due to Design Flood

No.	Section	Length
1	Km 287.0 – Km 288.2	1.2 km
2	Km 321.5 – Km 329.3	7.8 km
3	Km 332.3 – Km 333.9	1.6 km
4	Km 357.8 – Km 359.0	1.2 km

Source: JICA Study Team

While Alternatives A and B have been prepared considering the possibility of maintaining the railway system (through emergency response repairs) after a certain level of damages to the railway structures during floods, Alternative C aims at minimizing the required level of repairs after the completion of the Project.

Table 8.36 summarizes the sites/issues covered in Alternative C.

Table 8.36: Sites/Issues Covered in Alternative C

No.	Target
1	Target in Alternative B including:
	Riverbank erosion in the mainstream
	Three tributaries (Maswala, Kidibo, and Mzase)
	Bridge crossing the mainstream at around Km 293
	Overtopping from Km 363 to Km 368
2	Overtopping (except the sections in Table 8.35)
3	Sedimentation in three tributaries including:
	Maswala (second priority)[1]
	Kidibo (remaining first and second priorities)[2]
	Mzase (second priorities)[1]
4	Riverbank erosion (steel sheet pile/pipe)

Notes: (1) The first priority of the proposed countermeasures at Maswala and Mzase Rivers is fully included in Alternatives A and B. (2) The first priority of the proposed countermeasures at Kidibo River is partially included in Alternatives A and B.
Source: JICA Study Team

(2) Measures

1) Target in Alternative B
(Refer to Subsections 8.6.2 (2) and 8.6.3 (2).)

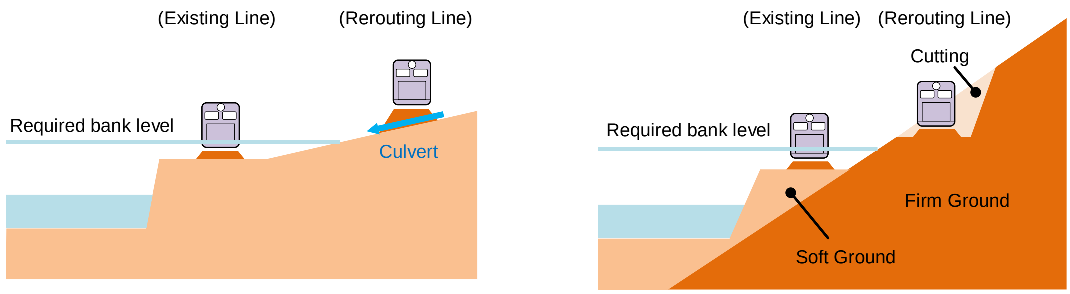
2) Overtopping

The basic approach of addressing this issue is to (i) install flood walls and flood embankments when the overtopping height is relatively low (Table 8.37), and (ii) relocate the track above the design flood water level when the overtopping height is relatively high. In case of relocating the track, culverts with adequate channels for each opening will be installed so that water from the hinterlands will not remain. Moreover, if it is difficult to relocate the track to the mountain-side (due to steep terrain and/or considerations for resettlement), then track will be installed on railway embankments reinforced with partial water-proofing works.

Table 8.37: Sections Installing Flood Wall and Flood Embankment

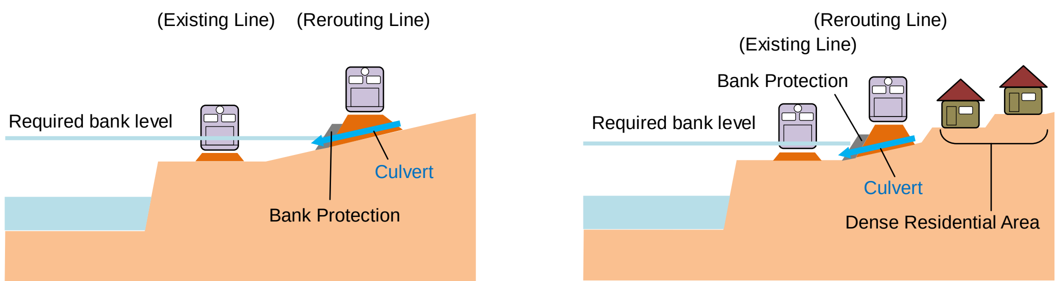
No.	Section	Length
Flood Wall	Km 283.5 – Km 287.0	3.5 km
	Km 288.2 – Km 292.0	3.8 km
Flood Embankment	Km 317.7 – Km 321.5	3.8 km

Source: JICA Study Team



Source: JICA Study Team

Figure 8.35: Basic Approach of Re-Routing, Alternative C



Source: JICA Study Team

Figure 8.36: Basic Approach of Re-Routing, Alternative C (Unavoidable Case)

As the level of the existing bridge crossing the mainstream at around Km 293 is lower than the design flood level by 2.2 m, the bridge will be relocated (replaced) to a higher area.

3) Sedimentation in Three Tributaries

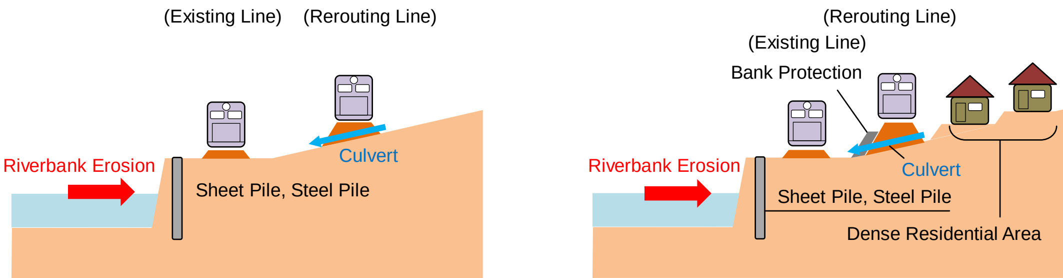
<u>Maswala River:</u> The second priority of the proposed measures in Subsection 7.6.6 will be implemented, in addition to the first priority measures included in Alternatives A and B. These measures include river channel works on the upstream side using groundsill, and will decrease aggradation of the riverbed due to sediment deposition, and therefore, avoid large-scale overtopping.

<u>Kidibo River:</u> The remaining first and second priorities of the proposed measures in Subsection 7.6.7 will be implemented, in addition to the partial first priority included in Alternatives A and

B. These measures include river channel works on the upstream side using groundsill and bank protection, and will prevent the erosion of the railway embankment and scouring of the existing abutment, as well as avoid the loss of roadbed/subgrade and bridge.

Mzase River: The second priorities of the proposed measures in Subsection 7.6.5 will be implemented. These measures include river channel works on the upstream side using groundsill and bank protection, and will decrease aggradation of the riverbed due to sediment deposition, and therefore, avoid large-scale overtopping.

4) Riverbank Erosion (Steel Sheet Pile/Pipe)
While Alternative A is basically intends to relocate the railway, the installation of gabions and spur dikes is in some cases unavoidable. On the other hand, Alternative C will install steel sheet piles/pipes in consideration of minimizing the repair works after completion of the Project.

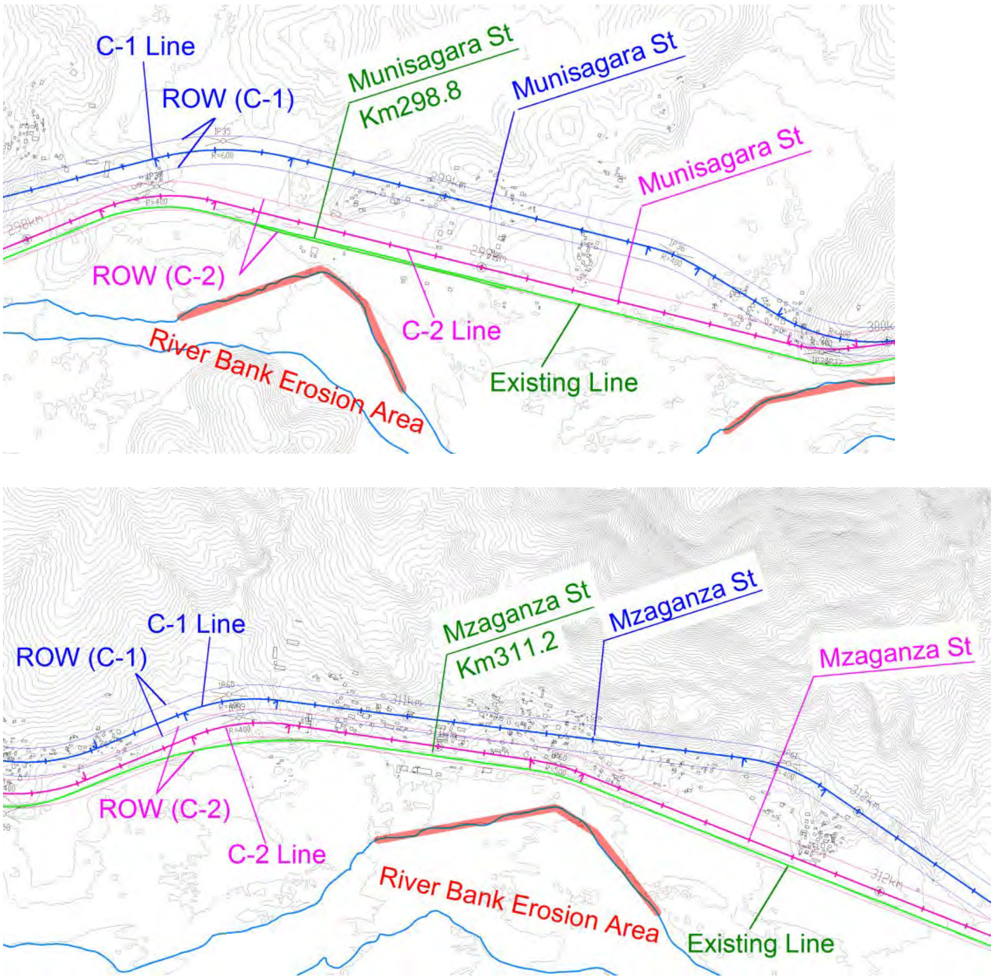


Source: JICA Study Team

Figure 8.37: Basic Approach of Re-Routing, Alternative C (Unavoidable Case)

(3) Social Considerations

As presented in Subsection 8.6.4 (2), the basic approach of Alternative C is to relocate the existing track above the design flood level as a measure against riverbank erosion and overtopping. It is desirable that the track will be relocated on hard ground with high elevation. However, as higher ground is not susceptible to flood damages, many houses have already been built in these areas. Therefore, Alternative C will also entail a great deal of resettlement. Thus, Alternative C-1 is proposed favors track alignment, and Alternative C-2 favors avoiding villages (densely-populated areas). Figure 8.38 shows an example of Alternative C-2. As this alternative requires elevation of the track above the design flood level, it requires the construction of embankments in the vicinity of the existing line, where some houses are already is located. Therefore, some level of resettlement is unavoidable, even in Alternative C-2.

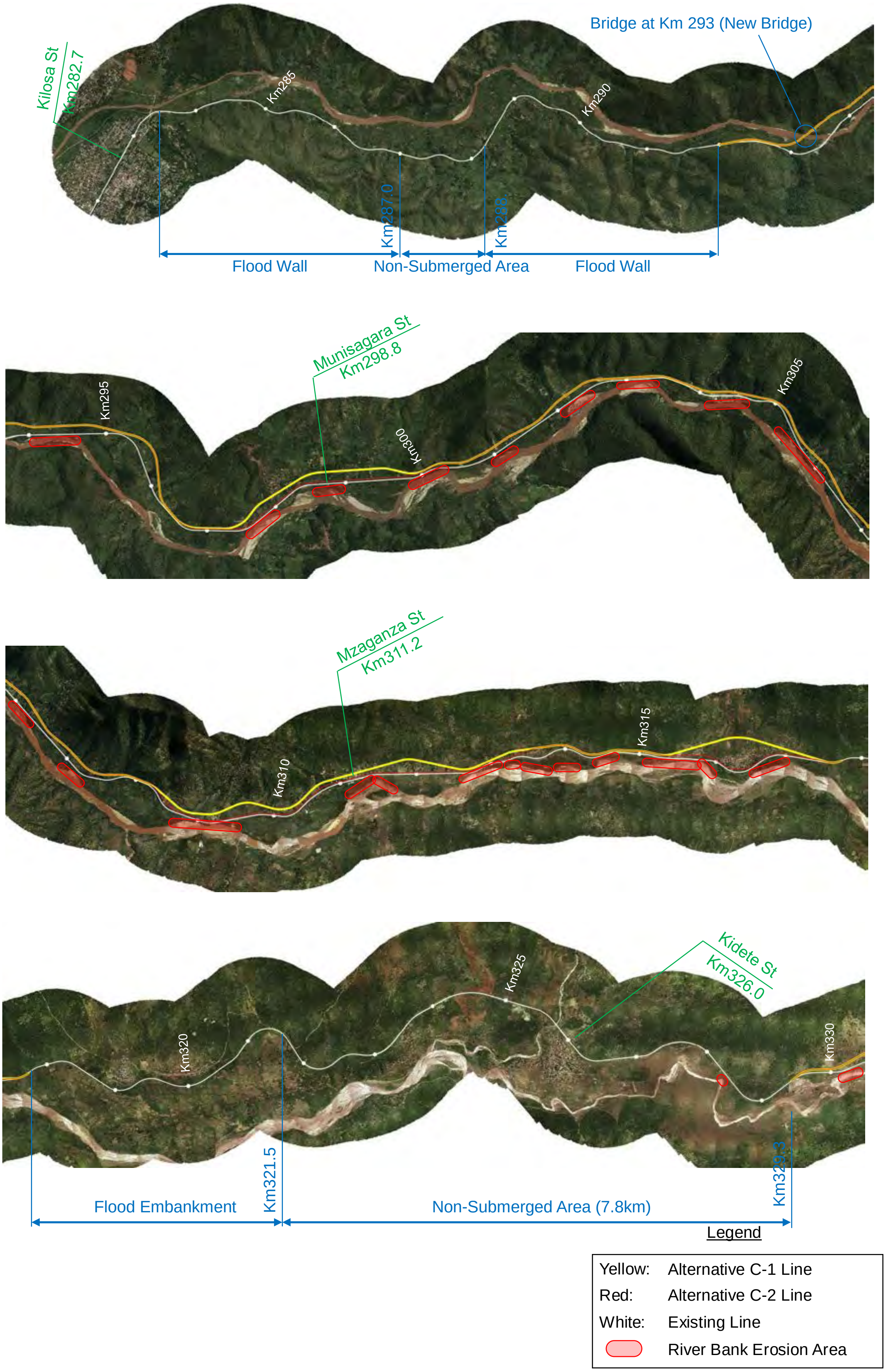


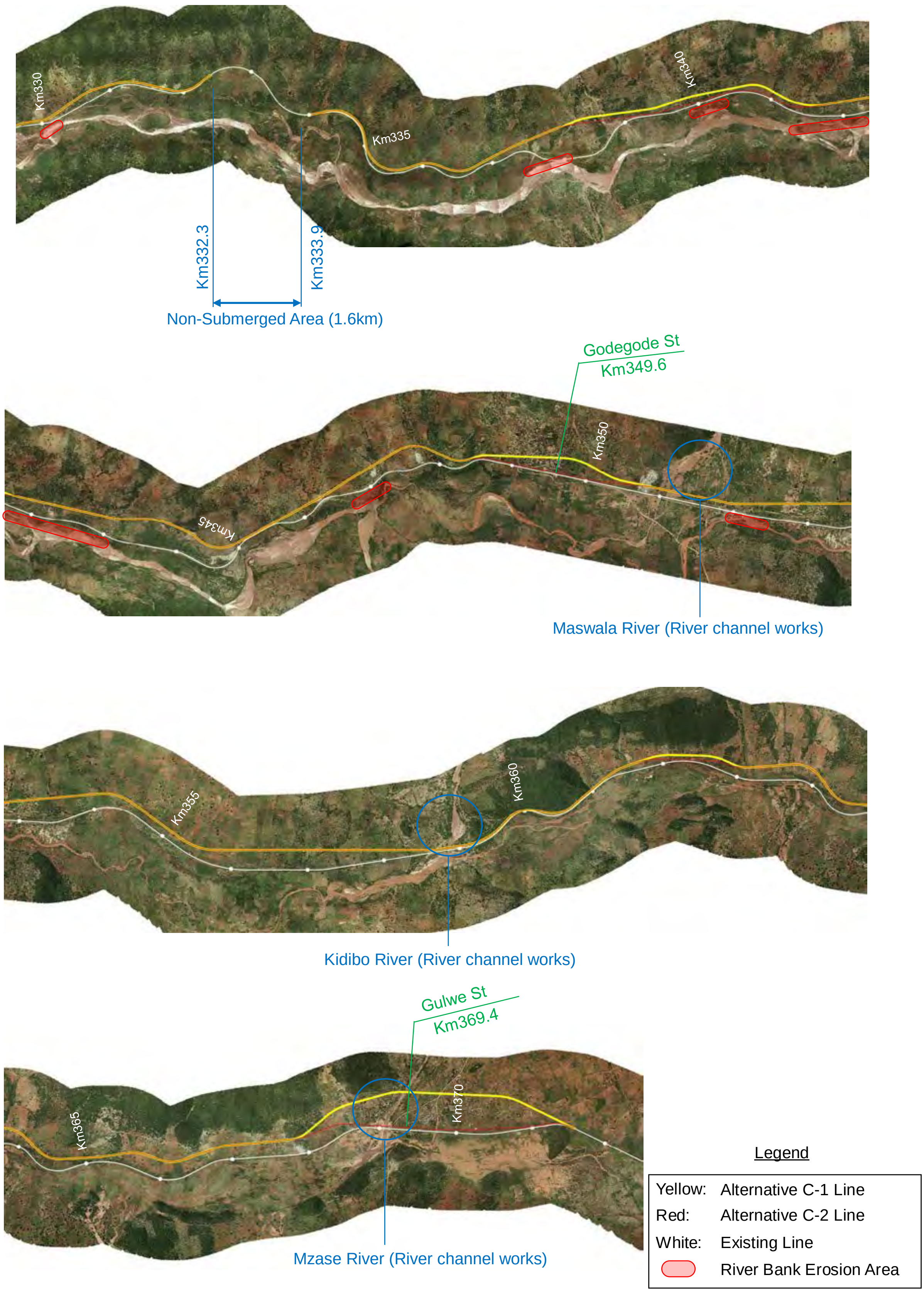
Source: JICA Study Team

Figure 8.38: An Example of Alternative C-2

(4) Study Results

Based on the considerations made above, the alignment of the Alternative C is drawn in Figure 8.39, and the quantity and costs of Alternatives C-1 and C-2 are summarized in Table 8.38 and Table 8.39 respectively.


Kilosa St
Km282.7
Km285
Km290
Bridge at Km 293 (New Bridge)
Km287.0
Flood Wall
Non-Submerged Area
Flood Wall
Munisagara St
Km298.8
Km295
Km300
Km305
Mzaganza St
Km311.2
Km310
Km315
Kidete St
Km326.0
Km320
Km325
Km330
Km321.5
Flood Embankment
Non-Submerged Area (7.8km)
Legend
Yellow: Alternative C-1 Line
Red: Alternative C-2 Line
White: Existing Line
River Bank Erosion Area



Source: JICA Study Team

Figure 8.39: Study Results of Alternative

Table 8.38: Quantity and Cost of Alternative C-1

	Quantity	Unit	Cost (TZS mil)
Riverbank erosion measure			
Embankment work	1,804,000	m^3	86,525
Embankment protection work	684,000	m^3	50,903
Cutting work	62,000	m^2	21,326
Cutting protection work	198,000	m^2	66,392
Riverbank protection work	50	km	313,699
Bridge work	90	m	2,853
Culvert work	333	site	36,758
Measure at Maswala River			
River work	See Subsection 7.6.6		61,766
Bridge work	150	M	4,137
Measure at Kidibo River			
River work	See Subsection 7.6.7		10,367
Bridge work	60	M	1,814
Measure at Mzase River			
River work	See Subsection 7.6.8		13,467
Bridge work	45	m	1,427
Bridge measure at Km 293			
Bridge work	100	m	2,915
Bank protection work	1	set	35
Others			
Temporary road (river structure)	14.0	km	2,293
Temporary road (railway structure)	92.7	km	15,180
Procurement of track materials	0	km	0
Installation of track	66.0	km	49,322
1)Subtotal (railway structure)			**339,551**
2)Mobilization (10% for railway structure)			**33,955**
3)Subtotal (river structure)			**401,627**
4)Mobilization (10% for river structure)			**40,163**
5)Direct cost 1)+2)+3)+4)			**815,296**
6)Indirect cost (35% of direct cost)			**285,354**
Total 5)+6)			**1,100,649**
Total of railway structure (including direct and indirect costs)			**504,233**
Total of river structure (including direct and indirect costs)			**596,416**

Source: JICA Study Team

Table 8.39: Quantity and Cost of Alternative C-2

	Quantity	Unit	Cost (TZS mil)
Riverbank erosion measure			
Embankment work	1,897,000	m^3	90,986
Embankment protection work	525,000	m^3	39,071
Cutting work	100,000	m^2	34,397
Cutting protection work	155,000	m^2	51,973
Riverbank protection work	50	km	313,699
Bridge work	90	m	2,853
Culvert work	333	site	36,758
Measure at Maswala River			
River work	See Subsection 7.6.6		61,766
Bridge work	150	M	4,137
Measure at Kidibo River			
River work	See Subsection 7.6.7		10,367
Bridge work	60	M	1,814
Measure at Mzase River			
River work	See Subsection 7.6.8		13,467
Bridge work	45	M	1,427
Bridge measure at Km 293			
Bridge work	100	M	2,915
Bank protection work	1	set	35
Others			
Temporary road (river structure)	14.0	km	2,293
Temporary road (railway structure)	92.7	km	15,180
Procurement of track materials	0	km	0
Installation of track	66.0	km	49,322
1)Subtotal (railway structure)			**330,831**
2)Mobilization (10% for railway structure)			**33,083**
3)Subtotal (river structure)			**401,627**
4)Mobilization (10% for river structure)			**40,163**
5)Direct cost 1)+2)+3)+4)			**805,704**
6)Indirect cost (35% of direct cost)			**281,996**
Total 5)+6)			**1,087,700**
Total of railway structure (including direct and indirect costs)			**491,284**
Total of river structure (including direct and indirect costs)			**596,416**

Source: JICA Study Team

8.7 Evaluation of Alternatives

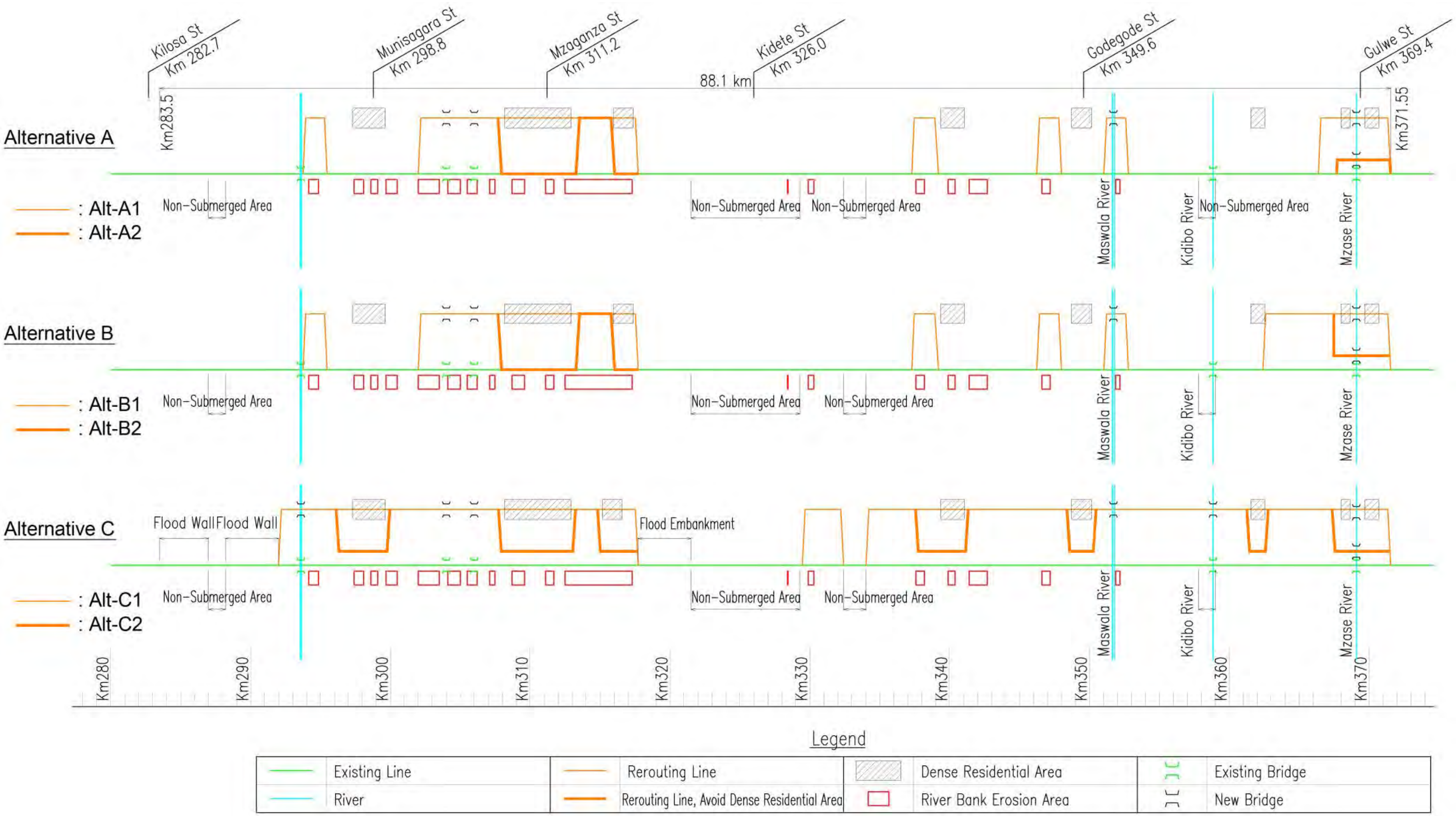
Figure 8.40 shows schematic drawing of the alternatives, and Table 8.40 compares major elements of the alternatives. The major points are summarized as follows:

- Alternative A-2 shows the lowest cost, followed by Alternative B-2 in a narrow margin with only 5.4% difference, and further Alternatives A-1 and B-1. The costs of alternatives C-1 and C-2 are nearly 2.6 times higher than the lowest cost.
- Alternative C reduces danger of flood damages to the largest extent through the provision of hard measures. The project effectiveness of Alternative B ranks second, and that of Alternative A third, indicating that the reliability of railway transport will be the highest in Alternative C, followed by Alternative B, and further to Alternative A. It is noted that transport capacity is equal among the alternatives.
- It is also noted that Alternative-2 has disadvantage over Alternative-1 (for Alternative A, B, and C respectively) in terms of safety of train operations when floods occur or expected to occur due to its lower track level and proximity to the river. In this regard, consideration is given to keeping the same safety level by implementing soft measures including speed restrictions and suspension of train services (assistance in soft aspects will be provided as part of the consulting services to be carried out during the Project).
- With respect to technical difficulty, Alternative A requires the shortest construction period with 66 months, while Alternatives B and C require 70 months and 74 months, respectively. Although construction during rainy seasons is not planned, Alternatives A and B have a low hurdle to do so if necessary. It is noted that the bank protection length of Alternatives A-2 and B-2 is 14.3 km, much longer than that of Alternatives A-1 and B-1 of 8.6 km.
- In terms of environmental and social impact, Alternatives A-1, B-1, and C-1 are not desirable due to the large requirement for cutting, embankment, and resettlement, as well as the large impact on noise and vibration. There are some villages in which the majority of residents need to be relocated. Among the remaining alternatives, Alternative A-2 requires the smallest number of buildings and cultivation land area for relocation. However, the difference between A-2 and B-2 is not large in terms of number of buildings for relocation, with 124 in Alternative A-2 and 164 in Alternative B-2.
- In an economic analysis, a conclusion is drawn as “economically feasible” when the estimated value of economic internal rate of return (EIRR) is above the opportunity cost of capital. Suppose the opportunity cost being 12%, the result of preliminary economic analysis indicates that Alternatives A-1, A-2, B-1, and B-2 are all economically viable, and the implementation of any of these alternatives is justified.

From above points, Alternatives A-2 and B-2 are the most advantageous and well-balanced, but considering that Alternative B-2 is able to reduce danger of flood damages more than Alternative A-2, the Study Team recommends Alternative B-2 as the optimal alternative, and be used for preliminary design.

Alternatives	A-1	A-2	B-1	B-2	C-1	C-2
Cost	◎-	◎	○	◎-	×	×
Reduction in danger	△+	△-	○+	○-	◎+	◎-
Technical	○	○	○	○	◎	◎
Env. and Social	×	◎	×	◎	×	△
Economic Feasibility	○	○	○	○	×	×
Overall Evaluation		○		◎		

Note: ◎=Best, ○=good, △=fair, ×=not good



Note: The Kilometrage above is re-calculated from “Km 282.7”, not the Kilometrage along the railway.
Source: JICA Study Team

Figure 8.40: Schematic Drawing of the Alternatives A, B, and C

Table 8.40: Comparison of Alternatives for Preliminary Economic Analysis

	Alternatives	**A-1**	**A-2**	**B-1**	B-2	**C-1**	**C-2**
Cost (TZS mil.)	Railway construction 1/	272,188	212,604	287,956	232,858	494,958	472,026
	River construction	98,405	136,453	98,405	136,453	594,416	594,416
	Miscellaneous 2/	26,021	26,021	26,021	26,021	26,021	26,021
	Consultants	39,661	37,508	41,238	39,533	55,770	54,623
	Contingency	21,814	20,629	22,681	21,744	58,558	57,354
	Price escalation	169,056	159,877	175,778	168,510	453,826	444,497
	1) Subtotal above	627,145	593,092	652,079	625,119	1,683,549	1,648,937
	2) Maintenance costs 3/	42,721	40,460	44,377	42,587	1,077	1,077
	3) Total of 1)+2)	669,866	633,552	696,456	667,706	1,684,626	1,650,014
	4) Land acquisition cost	172	95	179	105	301	230
	5) Total of 3)+4)	670,038	633,647	696,635	667,811	1,684,927	1,650,244
	Total of 3)+4) in Yen (mil.)	44,805	42,372	46,584	44,656	112,671	110,352
Reduction in danger of flood damages by hard measures		Low	Low	Middle	Middle	High	High
	Length of existing railway to be relocated (km)	28.1	19.7	32.0	25.0	66.2	66.2
	Length of river bank protection (km)	8.6	14.3	8.6	14.3	49.8	49.8
Degree of technical difficulty	Construction period (months)	66	66	70	70	74	74
	Construction in rainy season	Low	Low	Low	Low	Middle	Middle
	Bank protection	In terms of bank protection length, Alternative B's protection area is three times that of Alternative A.				Most rigid and durable type of bank protection works (steel sheet pile and steel pipe pile) to meet planning scale for the entire target areas are applied.	
		Flexible type of bank protection works with periodical recovery against some extent of flood damages is applied.					
Environmental and social considerations	Natural environment						
	Deforestation (ha)	16	15	16	15	31	31
	Volume of cutting soil (m^3)	385,000	281,000	387,000	284,000	683,702	525,110
	Volume of embankment (m^3)	788,000	594,000	891,000	729,000	1,803,996	1,896,764
	Social environment						
	Number of buildings for relocation	552	124	573	164	1,132	489

Alternatives	**A-1**	**A-2**	**B-1**	B-2	**C-1**	**C-2**
Land acquisition area (ha)	140	83	163	116	342	283
Cultivation land area (ha)	42	22	56	41	104	86
Disruption of community	Significant. The railway separates the populated area (Gulwe) into two parts. Large portion of populated area (Mzaganza) needs to be relocated.	Some extent but not significant comparing with A1.	Significant. The railway separates the populated area (Gulwe) into two parts. Large portion of populated area (Mzaganza) needs to be relocated.	Some extent but not significant comparing with B1.	Significant. The railway separates the populated area (Gulwe and Godegode) into two parts. Large portion of populated area (Mzaganza and Munisagara) needs to be relocated.	Some extent but not significant comparing with C1.
Convenient location of station	Stations become closer to the communities (Gulwe and Mzaganza).	Access road to the station is required at Gulwe.	Stations become closer to the communities (Gulwe and Mzaganza).	Access road to the station is required at Gulwe.	Stations become closer to the communities (Gulwe, Godegode, Mzaganza and Munisagara).	Access road to the station is required at Gulwe.
Impact of noise and vibration	Impact becomes larger than the present as the railway is relocated within the community (Gulwe and Mzaganza).	Same with the present condition.	Impact becomes larger than the present as the railway is relocated within the community (Gulwe and Mzaganza).	Same with the present condition.	Impact becomes larger than the present as the railway is relocated within the community (Gulwe, Godegode, Mzaganza and Munisagara).	Same with the present condition.
Provisional Economic Feasibility (EIRR)	Feasible (12.5%)	Feasible (13.1%)	Feasible (12.1%)	Feasible (12.5%)	Not feasible (4.0%)	Not feasible (4.1%)
Overall Evaluation		○		◎		

Notes:
1/ Including track materials for renewal of 60 lbs/yard rails by 80 lbs/yard rails.
2/ Including new station buildings and siding tracks on the rerouted sections, small machinery and equipment for track renewals, and supply of track materials for the existing 80 lbs/yard track section.
3/ Including recovery costs from flood disasters.
Source: JICA Study Tea

9. Railway System

9.1 General

(1) Basic Concept

The Study Team does not consider gauge conversion into a 1,067 mm or a 1,435 mm gauge, but rather adopts the 1,000 mm-gauge, as track conversion while continuing to run trains entails some technical difficulties, and provides little benefit to justify the long period and cost required for the gauge conversion work. During the period of track conversion work, the vast amount of transshipment work occurs at the junction of different gauges. Regarding the transportation capacity, the influence of the gauge difference is quite small as proven in the example that Japanese 1,067mm gauge railways transport almost equal volume to 1,435 mm gauge railways in other countries. Additionally, the axle load should be set at 16 tons. With this, freights of approximately 1,000 tons can be hauled by a locomotive having a weight of 100 tons. For such tonnage, therefore, the Study Team proposes a 6-axle locomotive with an axle load of 16 tons. In case freights are heavier, or are on sharp gradients, a double-heading operation can cope with this.

A maximum speed of 80 km/h is guaranteed for train operation in meter-gauge sections when tracks have appropriate cant and transition curves. In short sections, however, the Study Team maintains an immediate target of train speed at the current level of approximately 50 km/h, even in the rerouted section, as speedups in short sections do not cut much of the total travel time between Dar es Salaam and Kigoma. To facilitate speedups up to 80 km/h or more in the future, the Study Team designs the minimum radius of curves as 400 m, in general, sections, while adopting line profiles to guarantee easy extension of transition curves.

(2) Train Operation

Blocking the sections between stations is indispensable for the safety of train operation. However, the existing wired transmission system between stations is not practical, as it is often subject to vandalism/pilfering. As a communication means between stations, therefore, the Study Team adopts in principle a cellular phone system through lines for public telephone services, with train handling solely resorted to human attention, even though some stations in poor radio wave area are forced to close.

The installation of wireless satellite telephones on locomotives and stations seems useful not only for the blocking of the section but also for the countermeasures against natural disasters. However, it costs around 20 thousand USD[1] a year for one transmitter-receiver. Therefore, it is more practical to use the messenger system by gangs deployed in each 8 km section. After the recent flood disaster in Gulwe, Tanzania Railways Limited (TRL) reviewed the messenger system and decided the procedure to stop the train operation by the gang's information.

Regarding the future communication system, the optical fiber cable without any copper wire plays the leading role as it is not a target of thieves. When it combines with the automatic signaling and the disaster detecting instrument, the train operation becomes safer dramatically. The key is the electric power supply along the railway.

The effective track length in the station yard, which is approximately 420 m, governs the length of train composition. Extension of the effective track length is not practical, as enormous costs are involved. Therefore, the Study Team assumes a scenario to operate trains having a load of

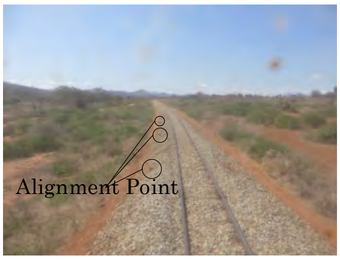
[1] This is the cost in Japan communicating 30 minutes per day. The availability of a satellite wireless transmission system in Tanzania is not confirmed.

approximately 1,000 tons hauled by a single locomotive. The 1,000 tons hauling system can implement the transportation volume of 1.4 million tons per year.

In case transport demand increases beyond the line capacity in the future, not only the quantity but also the quality of the transportation, such as frequency and punctuality required by customers, should be considered. From this point of view, high-frequency operation by a single locomotive should be the focus, rather than a long train by double locomotives for the time being. Because of long train operations, it is hard to recover a level of normalcy of train operations, in the case of a train disorder. Additionally, the Study Team proposes installation of signal stations one-by-one in bottleneck sections, while considering partial double-tracking simultaneously, thereby aiming at reinforcing transport capacity in addition to the usage of long trains.

(3) Track

As the frequency of train operation increases, track deterioration progresses to augment the volume of track maintenance work. Despite that, the next left Figure shows ballast spreading and raising, and right Figure indicates alignment markers for curve adjusting by TRL. Thus, the track maintenance progresses steadily with a good technical capacity. Therefore, TRL does not need to change the method of track maintenance for the Central Railway Line for the time being, as the volume of transport has decreased from the levels seen in the past.



Source: JICA Study Team

Figure 9.1: Track Maintenance by TRL

In the section of flood protection work, track maintenance machines are introduced for line rerouting work. After completion of the work, it is conceivable that those machines would be re-appropriated for a mechanized track maintenance system, to change maintenance work from the current manpower-intensive method to one oriented around track maintenance machines. In discussing changes in track maintenance methods, consideration for social conditions and cost performance is required.

(4) Rolling Stock Maintenance

Locomotive rehabilitation work now in progress and new locomotive procurement plans suggest that the number of active locomotives is expected to increase for the time being. In this opportunity, it is desirable for TRL to switch its rolling stock maintenance from breakdown maintenance to preventive maintenance.

(5) Stations and Related Facilities

As a part of flood protection work, stations are relocated together with their facilities (such as buildings and passing tracks). In general, the basic concept of the relocation is to maintain the present condition. However, it is important to consider the volume and function of the relocating facilities. Because they affect the future railway service and investment cost. The concrete plan should be drawn out through discussions with TRL and RAHCO on the train operating system, the loading and unloading facilities at terminal stations, and the freight information system.

9.2 Basic Concept

(1) Gauge

East-African railways use the 1,000 mm gauge widely, including the Central Railway Line. The UK constructed 1,000 mm gauge railways in Kenya and Uganda, and Germany constructed a railway having a gauge of the same dimension in Tanzania, which later connected into one international rail system. Although no trains are currently running from Tanzania to Kenya or Uganda at present, the tracks are still connected from Dar es Salaam to Mombasa and further to Kampala.

Although some people hold a view to converting the Central Railway Line into a 1,435 mm standard-gauge railway, the Study Team cannot find advantages. Because the difference of speed and transportation capacity between 1,000 mm gauge and 1,435 mm gauge is small and gauge conversion entails some technical and operational difficulties under the condition of running trains. A compromise is to run a mixture of standard and meter gauge trains on three-rail tracks, an application of which is not seen for long-section railways in any country, however. Based on the above, the Study Team concludes that it is appropriate to adopt the existing 1,000 mm gauge intact, to promote flood protection measures along the Central Railway Line.

(2) Axle Load

A diesel locomotive, which can haul a freight train of approximately 1,000 tons on 1% gradients, normally weighs 100 tons, which makes the axle load 16 tons when the locomotive weight is born with six axles. A freight train of 1,000 tons in weight is normally approximately 400 m long, which means that the single locomotive haulage of a 1,000-ton freight train balances with the effective track lengths (approximately 420 m) at different stations along the Central Railway Line.

Some people hold a view to deploying heavier locomotives, thereby aiming at increasing the number of freight cars in a train composition hauled by a locomotive. This idea, however, necessitates the extension of the effective track length at stations, which requires an enormous amount of station remolding cost.

For the reinforcement of the transport capacity, therefore, it is appropriate to increase the frequency of train operations and implement double-heading operation with locomotives (100 tons in weight). Increasing the frequency of train operation is on the right track to satisfy the requirement of shippers though it necessitates more train drivers. From the above viewpoint, it is reasonable to adopt an axle load of 18.5 tons.

(3) Train Speed

It is possible to realize a maximum train speed of 80 km/h for 1,000 mm gauge trains on tracks having appropriate cant and transition curves. As the scheduled train speed is approximately 70% or less of the maximum speed, however, speedups on short sections do not sufficiently cut the travel time to the destination.

If we run a mixture of trains at different speeds, we cannot help but to adopt cant to accommodate trains of any speed. It would result in excessive or insufficient cant for running trains as a consequence. As excessive cant are not desirable for low-speed freight trains, it is appropriate for TRL to determine the dimensions of track facilities based on the Civil Engineering Manual of TRC, while assuming the train speed at the current level about 50 km/h.

(4) Curve Radius

Assuming a maximum train speed of 80 km/h in the future, the Study Team adopts a minimum curve radius of 400 m, in general, sections, or 250 m when 400 m is impractical for various reasons, such as geographic considerations. For the time being, however, the Study Team used cant and lengths of transition curves for the tentatively assumed maximum train speed of 50 km/h. For the possible future speedups, however, the Study Team shall design line profiles to allow necessary correction of cant and extension of transition curves.

9.3 Train Operation

9.3.1 Train Timetable

(1) Current Situation of Train Operation

According to TRL, two to seven trains per day, or an average of 3.8 trains per day in a month (May 2015), are operated between Dar es Salaam and Dodoma. The one-way travel time is around 50 hours from Dar es Salaam to Kigoma (1,251 km) on the Central Line. It is 45 hours from Dar es Salaam to Mwanza (1,218 km), which gives a scheduled speed of 25–27 km/h and a dwell-time disregarding average speed of 29–31 km/h between stations. Regarding train operation diagrams, the Study Team learned the followings from TRL:

1) TRL does not have a master train operation diagram to cover TRL's entire railway network.
2) TRL has two fixed weekly round-trip diagrams for passenger trains.
3) TRL does not have fixed daily operation diagrams for freight trains but uses those drawn up the previous day.

(2) Method of Drawing Train Operation Diagrams for the Next Day

As TRL does not have a master train operation diagram, it draws up a diagram from 15:00 to 17:00 every day by controllers for the next day's operations. Information required for drawing up the train operation diagram reach through voice communication on the telephone to the controller office. After the completion of drawing, the controller office informs related organizations (including station masters) of the train operation diagram for the next day.

(3) Traffic Controller

Controller Offices, i.e., a Headquarters Controller Office and Division Controller Offices functioning thereunder, supervise drawing and implementation of train operation diagrams. Division Controller offices are at Dar es Salaam and Tabora. The former is in charge of the Dar es Salaam–Tabora section, and the latter is in charge of the Tabora–Kigoma and Tabora–Mwanza sections. Controllers assigned to these offices are on duty on a 3-shift/8-hour shift rotation. Refer to Table 9.1 and Table 9.2 for the lineups at these controller offices.

Table 9.1: Number of Staff in Chief Controller Office at Dar es Salaam

Person	Number
Chief Controller	1
Stock Controller	3
Desk Controller[2]	3
Locomotive utilization	1

Source: TRL

Table 9.2: Number of Staff in Division Controller Office

Person	Number	Role
Division Controller	1	
Stock Controller	3	
Desk Controller	4	Traces the movement of trains
Data Recorder	3	Recorder

Source: TRL

Source: JICA Study Team

Figure 9.2: Chief Controller Office at Dar es Salaam, 30 June 2015

9.3.2 Line Capacity

This Section compares and discusses the line capacities before and after reinstatement of the stations currently out of service between Kilosa and Dodoma. "Line capacity" means the number of trains operable on the relevant section per unit time length, or normally per day, which roughly gives the number of trains that can run on that section. See the defining equation for line capacity in the footnote[3].

As suggested by the defining equation, the line capacity is not an exact value, but depends on the time required for trains awaiting others running in the opposite direction to cross at midway stations and reflects ample time lengths calculated and set by different methods to adjust train operation in case trains have delayed. The line utilization factor and block establishing time in the defining equation are values deduced by empirical rules. The line capacity also depends on the train running time between stations selected for calculation out of those of so many trains

[2] Signal and Telecommunication Engineer in RAHCO is called a "Line Controller," which means a person who records the actual diagrams.
[3] Line Capacity = Line utilization factor × (24 hours / Travel time between stations)
= Line utilization factor × {24 hours / (Average running time between stations+ Block establishing time)}

running at different speeds. Therefore, the value of line capacity calculated by the defining equation does not give an exact value of the number of operable trains. Despite that, however, it is an index conveniently used to assess the status of relevant sections, when applied with its real meaning duly born in mind.

Whereas the object of flood protection measures in this Study is the Kilosa-Dodoma section, below discussed is the line capacity between Dar es Salaam and Isaka, where TIRP plans the operation of block trains. For the railway station map of Central line and Mwanza line, see Figure 9.3.

(1) Present Line Capacity

Between Dar es Salaam and Isaka, the longest section between stations is the 60 km-long Gulwe–Kikombo section, in between which there were two stations Msagali and Igandu. Both stations are now out of service, as the frequency of train operations does not warrant their usage.

The longest distance between stations in a section determines the line capacity of the whole section, which is calculated to be 11 trains per day in two directions in the present case, as shown below.

Here, the assumption of the line utilization factor is 0.8 (used by the World Bank) and average running time bases on actual data of 1.58h, and block establishing time under a train ticket blocking system as 5 min. The running time bases on the Working Timetable, published by TRC (Tanzanian Railways Corporation) on 16 July 2001.

Line capacity = 0.8 × (24 hours / travel time between stations)
= 0.8 × {24 hours / (average running time between stations+ block establishing time)}
= 0.8 × 1,440 min. / (1.58 h + 5 min.)
= 0.8 × 1,440 min. / (94.8 min. + 5 min.)
= 11.5

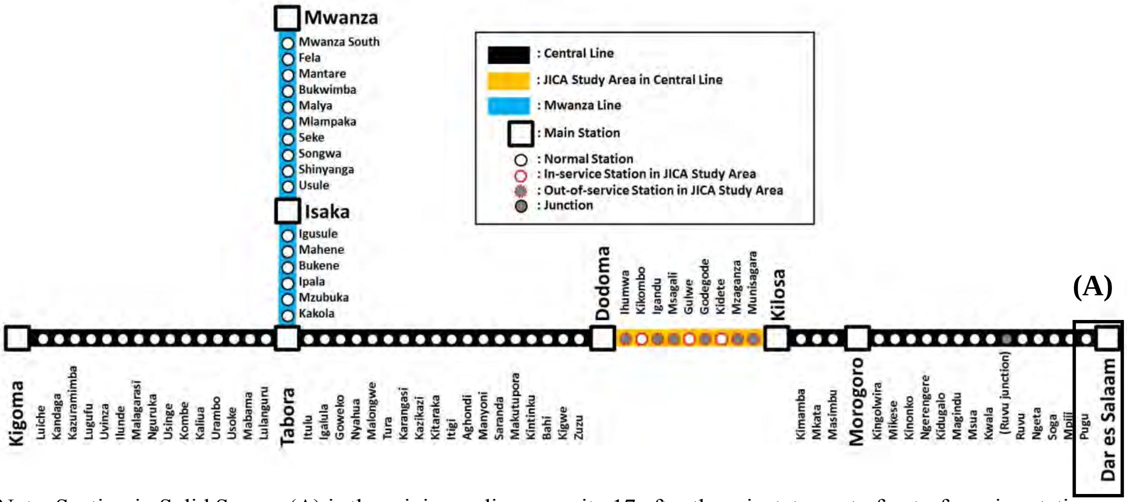
In actuality, however, only 2 to 7 trains are operated per day in two directions as of October 2014. Even though there are stations out of service, therefore, the line capacity is sufficient enough to suggest that there is no need to raise immediately train speed through improvement of tracks or block systems.

(2) Line Capacity after Reinstatement of Stations Out of Service

There are six stations in the section of the JICA Study between Kilosa and Dodoma, which are now out of service: Munisagara, Mzaganza, Godegode, Msagali, Igandu, and Ihumwa.

After the reinstatement of Mzaganza, Godegode, Igandu and Ihumwa stations, Dar es Salaam - Pugu section settles into the minimum line capacity of 17 between Dar es Salaam and Isaka.

The line capacity is estimated using average train speed and time for blocking that are taken as the same as those applied in the above calculation for the Kikombo–Gulwe section. The small line capacity at Dar es Salaam - Pugu comes from the long running time of 1 hour even the distance between stations is only 20 km.



Note: Section in Solid Square (A) is the minimum line capacity 17 after the reinstatement of out-of-service stations.
Source: JICA Study Team

Figure 9.3: Railway Stations Map of Central line and Mwanza line

Thus, line capacity is influenced by the running time between the stations, and the running time is the consequence of the station distance, train speed and block establishing time. If the block system were improved to cut the block establishing time, line capacity would also increase. In this manner, reinstatement of dormant stations increases the line capacity from 11 to 17 trains/day as shown in Table 9.3.

9.3.3 Freight Transport Capacity

(1) Volume of Freight Transport Capacity under the Present Line Capacity

In this section, the Study Team calculates the volume of freight transport capacity based on Subsection 9.3.2 for the 970 km Dar es Salaam–Isaka section, which aims at running block trains under the Tanzania Intermodal and Rail Development Project (TIRP).

According to TRL, the loading weight of a container car operated in TRL is 40 ton/wagon (tare weight 16.8 ton/wagon). As a locomotive is currently hauling 20 container cars, the volume of freight transport capacity (payload) of one train-set is 800 ton/train-set or 40 ton 20 wagon/train-set. The Study Team takes the ratio of passenger trains to freight trains as 1 to 6, the same value as TRC's timetable in 2001. See Table 9.3 for the results of the calculation. The average running speed between Dar es Salaam and Isaka is 33.3 km/h, dividing the distance by the running time excluding stoppage time at stations.

If TRL transports freight every day for a year (365 days) from Dar es Salaam to Isaka, the volume of cargo capacity amounts to 890,000 tons under the current line capacity, which is roughly the same as the record of 833,000 tons achieved by TRL in 2007. If the dormant stations reopen as signal stations, the volume of freight transport capacity reaches 1,350,000 tons per year, which is close to TRL's maximum record of 1,570,000 tons in the past. It means that the early restoration of dormant stations, by itself, is effective as a first step to increasing the potential capacity of freight transport.

The assumptions are as follows;

1) Empty wagon ratio = 0.1 (Number of empty wagon/ Number of total wagon)
2) Load efficiency = 0.85 (Load/Payload of wagon)

Next table shows the line capacity and the freight capacity after the reopening of the dormant stations and the speed up to 50km/h as well.

Table 9.3: Estimation of Freight Capacity from Dar es Salaam to Isaka

	Average running Speed	Line Capacity	All Train Number per day	Freight Train Number per day	Freight Capacity per day	Freight Capacity per year
		Total of two-way	Outward	Outward	Outward	Outward
Unit	km/h	trains/day	trains/day	trains/day	ton/day	ton/year
Present (TRC's timetable in 2001)	33.3	11	5	4	2,448	893,520
After Reinstatement of Dormant Stations	33.3	17	8	6	3,672	1,340,280
After Operational Speed Advancement	50.0	23	11	9	5,508	2,010,420

Assumed value: Carrying capacity per Container is 40 ton/wagon, Ratio of Freight to Passenger is 6.0,
Empty wagon ratio is 0.1, and Load efficiency is 0.85.
Source: JICA Study Team

(2) Foresight and Subjects in TIRP's Long Trains

In the prioritized policy "Big Results Now," Tanzania aims at transporting three million tons per year of freight. The Study Team discusses below, therefore, the number of trains required to attain this target. The concept of TIRP is to run long freight trains on a regular basis between Dar es Salaam and Isaka. In concrete terms, TRL is expected to implement a double-heading operation of freight trains, each hauling 40 wagons by two locomotives. In this regard, TIRP states that the payload of a freight train set amounts to 1,200 tons.

For the wagons used for this purpose, TIRP assumes an axle load of 15 tons and a loading capacity of 2 TEU. From these Figures, the Study Team can surmise that the payload per wagon is 30 (or 1,200/40) tons. The term 2 TEU suggests that the maximum volume of freight transport is 56.160 tons (two sets of 20 ft. containers, each having a loading capacity of 28.080 tons, according to ISO668 Amendment 1). It seems to have been suppressed to 30 tons (one of 40 ft. containers) to cope with the regulated axle load.

TIRP proposes the freight transportation system as follows;

1) Two tandem locomotives haul 40 wagons.
2) One wagon has a payload of 30 tons.

It means that nine freight trains shall run every day in each direction for the whole year (365 days) to transport three millions tons.[4] In the estimation, the empty wagon ratio and the load efficiency is assumed 0.1 and 0.85 respectably, as well.

If passenger and freight trains ran at the ratio of 1 to 6, two additional passenger trains per day would make their debut in each direction (decimals are all rounded to the nearest whole number). In total, therefore, 11 passenger/freight trains shall run in each direction, which requires a line capacity of 22 trains/day or over when both the up and down trains run. Therefore, the Study Team discusses a line capacity of 22 trains/day.

According to the assumptions in TIRP, each trainset is 620 m long, including 40 wagons (580 m in length) and two locomotives, which is longer than the effective refuge track length (about

[4] (3,000,000 ton/365 days)/(1,200 ton/train)/{0.85/(1-0.1)}=8.9≒9 trains/day

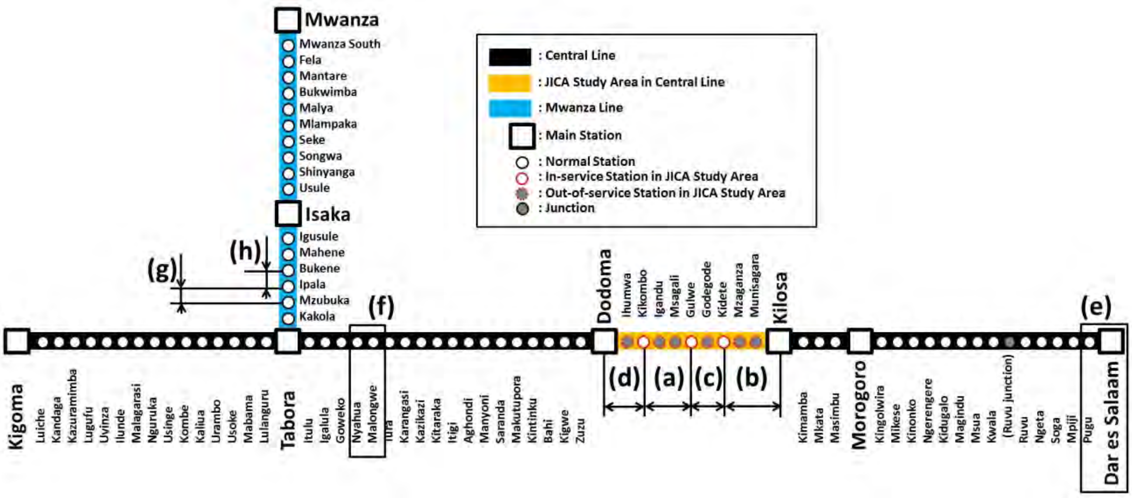
420 m) of the current TRL stations. According to TRL, TIRP requires the extension of effective track length as refuge tracks for the long trains at some ten major stations among the 56 stations from Dar es Salaam to Isaka.

The following assumptions/plans are necessary under TIRP concept:

1) The following eight sections require a signal station or double tracking to obtain the line capacity of 22 trains/day.

   (a) Gulwe–Kikombo, (b) Kilosa-Kidete, (c) Kidete–Gulwe, (d) Kikombo–Dodoma,
   (e) Dar es Salaam-Pugu, (f) Malongwe–Nyahua, (g) Mzubuka–Ipala, (h) Ipala–Bukene
   Note: The Alphabets (a)-(h) are arranged in ascending order of the line capacity.

   i. The reason the line capacity is low, except in sections (e), (f), (g), and (h), is that midway stations are out of service. If these stations begin service for train operation, the line capacity increases to 22 trains/day or more. The bottleneck sections are the Dar es Salaam-Pugu section in (e), the Malongwe–Nyahua section in (f) above existing between Dodoma and Tabora, and the Mzubuka–Ipala section in (g), and the Ipala–Bukene section in (h) above existing between Tabora and Isaka.
   ii. When trains of 20 wagons go into operation, the refuge track length is 420 m for each station. In this case, a total 1,680 m of additional refuge track is required for the bottleneck as mentioned above sections, excluding additional turnouts and curves needed to connect to the mainline.
   iii. In case that the average speed is 50 km/h on each section, a line capacity less than 22 trains/day is only in the section of Gulwe–Kikombo in (a), Kilosa-Kidete in (b), and Kidete-Gulwe in (c). These bottlenecks are wiped off, however, by reinstating dormant stations.



Note: Sections in (a)-(h) are with Line Capacity Less than 22 trains/day.
The Alphabets show the line capacity in ascending order.
Source: JICA Study Team

Figure 9.4: Location of Stations with Line Capacity Less than 22 Trains/Day

2) When the TIRP's long trains of 40 wagons run, the refuge track length must be extended up to 620 m for at least 10 stations. Therefore, the total length of refuge track is 2,000 m in total.[5] As other trains cannot refuge from long trains at stations remaining intact, the recovery of normal train operation is delayed, in the case that the train operation diagram has been disturbed.

3) In total, the construction of an additional 1,680 m track is required for 20 wagon sets, and 2,000 m for 40 wagon sets, at the current train speed. When the average speed is 50km/h, the total refuge track length is zero for 20 wagons and 2,000 m for 40 wagons except for in addition to turnouts and curves to connect to the mainline.

(3) Subjects in Operation of Non-Long Trains

To attain the target of transporting freights of three million tons per year under the current operational formation (hauling 20 wagons, each having a payload of 40 tons, by a single locomotive), 14 freight trains[6] shall run every day in each direction for the whole year (365 days). Here, Empty wagon ratio and Load efficiency are assumed 0.1 and 0.85 respectably as is the case with 9.3.3(1).

If passenger and freight trains ran at the ratio of 1 to 6, three additional passenger trains per day would make their debut in each direction (decimals are all rounded to the nearest whole number). In total, therefore, 17 passenger/freight trains shall run in each direction, which requires a line capacity of 34 trains/day or more for both up and down direction.

Therefore, the improvements are necessary such as the installation of signal stations or double-tracking for the sections where the line capacity is less than 34 trains/day that corresponds to 3 million tons per year. Currently, the line capacity between Dar es Salaam and Isaka is 11 trains/day and the reinstatement of the dormant stations increases up to 17 trains/day that correspond to 1.34 million tons per year. The upper right cell of Table 9.4 shows the present 33 sections that require improvement. The top left cell indicates the 35 sections that have priority next to the reopening of the dormant stations. The reason for the increase of sections is that the reinstatement of the stations adds the number of stations. In Table 9.4, sections are arranged in ascending order that indicates the priority of the improvement.

Above estimation bases on the assumption that the train speed, indicated in the TRC's timetable in 2001, doesn't change and the average speed between Dar es Salaam and Isaka settles into 33 km/h. When the running speed increases up to 50 km/h in every section, the number of low line capacity sections decrease as shown in the lower cells in Table 9.4. It indicates that high-speed train operation increases the line capacity as well.

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5 (620−420) m/station × 10 stations =2,000 m

6 (3,000,000 ton/365 day) /(800 ton/train)/{0.85/(1-0.1)) = 13.4≒14 trains/day

Table 9.4: List of Sections between Stations with Line Capacity Less than 34 Trains/Day

Running Speed	Section between Stations (Reinstatement of dormant stations)	Section between Stations (Present situation)
33 km/h (average between Dar es Salaam and Isaka)	Dar es Salaam-Pugu, Malongwe–Nyahua, Mzubuka–Ipala, Ipala–Bukene, Makutupora–Saranda, Morogoro–Masimbu, Masimbu–Mikata, Mikata-Kimamba, *Kidete–Godegode, Igandu–Kikombo, Ihumwa–Dodoma,* Saranda–Manyoni, *Kilosa–Munisagara,* Zuzu–Kigwe, Kigwe–Bahi, Aghondi–Itigi, Tura–Malongwe, Bukene–Mahene, Kimamba–Kilosa, Ngeta–Ruvu, Ruvu–Kwala, Kwala–Msua, Ngerengere–Kinonko, Kinonko–Mikese, Mikese–Kingoleira, *Godegode–Gulwe, Msagali–Igandu,* Kitaraka–Kazikazi, Kazikazi–Karangasi, Karangasi–Tura, Nyahua–Goweko, Goweko–Igalula, Igalula–Itulu, Tabora–Kakola, Msua–Magindu (35sections)	(Gulwe–Kikombo), (Kilosa–Kidete), (Kidete–Gulwe), (Kikombo–Dodoma), Dar es Salaam–Pugu, Malongwe–Nyahua, Mzubuka–Ipala, Ipala–Bukene, Makutupora–Saranda, Morogoro–Masimbu, Masimbu–Mikata, Mikata–Kimamba, Saranda–Manyoni, Zuzu–Kigwe, Kigwe–Bahi, Aghondi–Itigi, Tura–Malongwe, Bukene–Mahene, Kimamba–Kilosa, Ngeta–Ruvu, Ruvu–Kwala, Kwala–Msua, Ngerengere–Kinonko, Kinonko–Mikese, Mikese–Kingoleira, Kitaraka–Kazikazi, Kazikazi–Karangasi, Karangasi–Tura, Nyahua–Goweko, Goweko–Igalula, Igalula–Itulu, Tabora–Kakola, Msua–Magindu (33 Sections)
50 km/h (in every section)	Malongwe–Nyahua, Mzubuka–Ipala, Ipala–Bukene, Kigwe–Bahi (4 Sections)	(Gulwe–Kikombo), (Kilosa–Kidete), (Kidete–Gulwe), Malongwe–Nyahua, (Kikombo–Dodoma), Mzubuka–Ipala, Ipala–Bukene, Kigwe–Bahi (8 Sections)

Note: The sections in parentheses show closed mid-stations.
The sections are in ascending order of Line Capacity.
The sections in italics show the section emerges after the reinstatement of the dormant stations.
Source: JICA Study Team

The train operation plan has the following features when the current operational formation continues.

1) The necessity of double-tracking or installation of the signal station for sections where the line capacity is less than 34 trains/day.
   (1) 35 sections require such measures to reinforce the transport capacity under the following conditions (The line utilization factor 0.8; Same average train speed as present; 5 minutes of block establishing time; Reinstatement of dormant stations). The extension length of refuge track is 14,700 m in total[7].
   (2) Four sections require such measures to reinforce the transport capacity when the average train speed is 50 km/h. The extension length of refuge track is 1,680 m in total[8].
   (3) In the case of a 20 wagon train: the total refuge track length is 14,700 m for the current train speed, and 1,680 m for the speed of 50 km/h, excluding additional track required for turnouts and curves to connect to the mainline.

[7] 420 m/station × 35 stations =14,700 m
[8] 420 m/station × 4 stations = 1,680 m

2) As there are no long trains, however, the train operation diagrams can be adjusted in the same way as before. Therefore, this operational formation is strong against transport disturbance, with train operations planned without restrictions.

When the volume of cargo capacity is 1.3 million tons or less per year, as shown in Table 9.3 above, a line capacity of about 17 trains/day is sufficient enough. Investment into equipment/ facilities is not necessary as far as the volume of freight transport capacity per year is equal to or less than the above-quoted Figure.

When the volume of cargo capacity per year is two million tons, the line capacity shall be nearly 22 trains/day under the same assumption as that used for calculation when TRL shall transport of three million tons per year. In this scenario, signal stations shall be constructed in four sections between stations, i.e., Dar es Salaam-Pugu, Malongwe–Nyahua, Mzubuka–Ipala, and Ipala–Bukene sections, at the current train speed, with the services at dormant stations resumed. When the average train speed is 50 km/h, new signal stations do not need to be constructed, if dormant stations reopen.

(4) A Draft Transport Plan for the Future

As explained above, a capacity to transport freights of 890,000 tons per year is guaranteed under the current operational formation of hauling 20 wagons by a single locomotive, even without installing new signal stations or implementing measures to increase train speed. If dormant stations were reinstated further in train operation services, the volume of freight transport capacity would potentially reach 1.3 million tons per year. Only in the case where the volume of freight transport further increases, the installation of signal stations and other measures become inevitable.

Whereas the option to run long trains as envisaged in TIRP enables massive cargo capacity (despite that the line capacity is not yet sufficient for this), it is indispensable for 10 stations to be expanded to allow trains of shorter length refuge from long trains. This option cannot be introduced before the expansion of refuge tracks, because the number of conventional short trains is limited even after that, and it may be prone to cause confusion in train operation diagrams. Delay in transport, both in passenger and freight services, breaks the confidence of customers, which potentially lead to adverse effect on transport demand.

Different transport systems have merits and demerits at the same time. It seems appropriate to increase transport capacity stepwise while seeing the trend of transport demand. The Study Team does not stick to the operation of long trains in actuality, but rather, keeps an eye on reinforcing transport capacity at early stages and stepwise implementation through different policies.

1) In phase 1, the Study Team targets cargo of 1.3 million tons per year and reinstates stations currently out of service as signal stations, in particular, Igandu, Munisagara, Godegode, and Ihumwa, thereby aiming at increasing freight transport capacity as a key to invite further transport demand.
2) In phase 2, the Study Team targets cargo of 2.0 million tons per year or more and proposes to consider utilizing long trains for operation. In this context, demand for passenger trains may have increased, as well as the need for regular operation. The Study Team believes, therefore, that it is desirable while seeing through this tendency, to construct new signal stations and implement partial double-tracking stepwise in different sections, starting with bottleneck sections.

3) It is recommended to consider the future policy repeatedly until the time limit comes because there is a big demand risk for the railway investment. The practical way is to increase transportation capacity by adopting, after discussions, a preferable policy to select either (1) operation of long trains or (2) high-frequency operation of standard train length, considering the capacity and stability of transport.

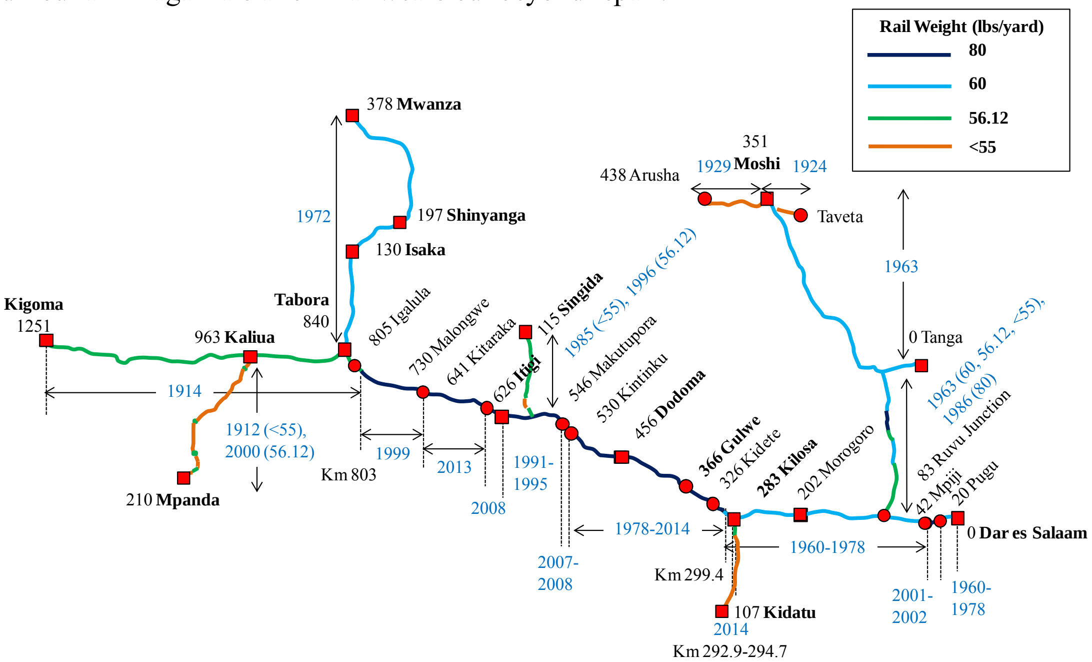
9.4 Track Maintenance

9.4.1 Track Condition

(1) Rail

Figure 9.5 shows the distribution of rail weight and installed year on the Central Railway Line. The track from Km 299.4 to Gulwe (Km 366.0) and Dodoma (Km 457.0) re-laid with 80 lb/yd rail between 2001 and 2002 as part of a project to replace 60 lb/yd rail. The track between Km 292.9 and Km 294.7 re-laid with 80 lb/yd as in 2013 as part of a project to construct a new bridge at km 293. The two sections of Kilosa (Km 282.7) to Km 292.9 and Km 294.7 to Km 299.4 remain with 60 lb/yd rail that laid in the 1970s. All 80 lb/yd rails had pandrol compatible sleepers and fastened with pandrol clips while the old 60 lb/yd rails have clip bolt-and-nut type fasteners on K-type sleepers.

Mainline turnouts between Kilosa and Gulwe are of 1:12 dimensions. There are no siding turnouts. There are six 80 lb/yd turnouts between Kilosa and Gulwe while seven similar turnouts are between Gulwe and Dodoma. The intention was to replace all 60 lb/yd turnouts with 80 lb/yd turnouts, but the latter were not in sufficient numbers. Therefore, there are still two 60 lb/yd turnouts between Kilosa and Gulwe and three similar turnouts between Gulwe and Dodoma. All 60 lb/yd turnouts are overdue for replacement due to wear and tear. Turnouts of density 80 lb/yd have some wear but are still in fair condition, except for one monoblock-type turnout at Mzaganza station that wears out beyond repair.



Source: JICA Study Team

Figure 9.5: Types of the Rails Used on the Central Railway Line

(2) Sleepers

The Central Line adopts iron sleepers except at turnouts and in ballast-less bridge sections. On 80 lb/yd rail, there are 17 sleepers per 12 meter of rail or 2,244 sleepers per mile. In the section with "Short Welded Rails," the rails are welded in panels of 40 m length. In general, the distance between sleepers is 30 cm. Sleepers are at closer intervals near joints.
Some iron sleepers bear buckling scars at their center, presumably because train loads are directed mostly to the center of the rails, due to insufficient ballast thickness underneath, as shown in Figure 9.6.

Source: JICA Study Team

Figure 9.6: Iron Sleepers

(3) Ballast

The formation level is unclear, with rails laid at a level almost the same level as the ground surface. It means that the ballast thickness is not enough. Track sides change as a walking pass. Ballast and roadbeds are washed away to expose sleeper ends and generate gaps underneath. Ballast should be spread at sleeper shoulders and arranged properly to secure the ballast layer section. Furthermore, sleepers should be protected at the bottom against erosion from rainwater.

At some places, the ballast is left unattended after spreading in excessive volumes within the track gauge, making it impossible to check the conditions of fish bolts or fishplates (Figure 9.7). The ballast within the track gauge is meaningless for tracks. For the purpose of mechanical maintenance work possible in the future, it is necessary to make sleeper positions clear to determine the tamping points.

The densely grown grass on the track proves that ballast contains large volumes of sand and soil, with the loss of bearing capacity apprehended when floodwaters stay on the roadbed. The Study Team visually confirmed the existence of track irregularities due to ballast subsidence at the joints between bridges and ground-level tracks, presumably because abutments installed on soft grounds had laterally displaced or roadbeds/ballast behind abutments runoff. It is conceivable that reinforcing work is necessary for the future for such civil engineering structures that cannot support ballast track.

Exposed Sleeper Ends

Ballast Covered with Grass

Source: JICA Study Team

Figure 9.7: Ballast

9.4.2 Track Maintenance

(1) Heavy Machine and Maintenance Structure

The introduction of heavy maintenance machines is inevitable by increasing destruction of track caused by frequent train operations in the future. TRL owns five tamping machines. One of them is usable of which capacity is 500 m/day. The other four machines do not work because of problems in procuring spare parts.

Source: JICA Study Team

Figure 9.8: Tamping Machine

The heavy maintenance machine requires a reform of track maintenance structure to match with the future big machine performance. Therefore, TRL introduced the "Mobile Gang" concept in the sections Tabora–Kigoma and Tabora–Muwansa. One mobile gang party of 15 workers covers nearly 60 km of track under a ganger and several key men. One key man inspects nearly 8 km of his territory. A ganger controls movements by trolley. These introductions of heavy machinery and the organization reform are right steps taken by TRL.

Table 9.5: Ordinary and Mobile Gang Man

	Ordinary Gang (person)	Mobile Gang (person)	Role
Ganger	1	1	Foreman of a gang of laborers
Key man	1	8	Track inspection
Gang man	8	15	Manual laborers
Walk	8 km	60 km	

Source: JICA Study Team

(2) Subjects

Heavy machine maintenance becomes more important than now, and following viewpoints should be examined:

Separation of Inspection from Maintenance Work

The current track inspection regime relies mainly on human/visual assessment rather than measuring instruments. However, it becomes more necessary to schedule the maintenance work quickly based on the numerical information, such as track irregularity. For this purpose, the introduction of efficient inspection machines, such as a track inspection trolley car is useful. When the track inspection system is changed to use these efficient machines, the organization of inspection party should be independent of the maintenance work party.

Improvement of Maintenance Technology

TRL has multiple manuals on track maintenance, even though TRL sets them aside. However, when the train speed is up, the track maintenance must obey the technical standards strictly. Before the speedup, the technological level/competency of the workers should be improved as well. It refers to not only track maintenance but also to roadbed and structures.

Other

TRL seems to have enough potential to adapt to the future, judging from the manuals as shown in Figure 9.9, an extraction from Civil Engineering Manual 1998 and the morale of workers. Additionally, a constructive approach is already taken, as seen in the mobile gang organization and procurement of heavy track maintenance machine from Austria. Therefore, Japanese assistance does not seem necessary, except the material supply for exchanging to 80 lb/yd rails.

2.2.3 SAFETY TOLERANCES

Safety tolerances establish the maximum deviation from the design track geometry that can be permitted for each "Speed Class" of track.

Should any non-complying track geometry (deviations which exceed the limits for each "Speed Class" as stated in the following table) be detected by the track recording car or by hand measurement. train movements must be protected by imposing speed restrictions. The track defect must then be repaired at the earliest opportunity and the speed restriction removed.

Figure 2-2 - Track Geometry Safety Tolerances

Track Geometry Parameter	Class of Track				
	1	2	3	4	5
	Maximum Permissible Speed (km/hr)				
	15	35	55	75	90
Wide Gauge (mm)					
• on straight track	35	25	15	15	15
• in curves & transition curves	35	25	15	15	15
Tight Gauge (mm)	-10 mm	-7 mm	-6	-5	-4
Change in Gauge (per sleeper)	7 mm	6 mm	4	3	2
Cross Level (mm)					
• on straight track	40	30	25	20	15
• in curves	40	30	25	20	15
Twist (mm/m)	10	8	6	5	4
Alignment (mm)	35	30	25	25	20
Unevenness (mm)	40	30	25	24	20
Acceleration (g)					
• vertical	0.4	0.3	0.28	0.25	0.25
• lateral	0.35	0.3	0.28	0.26	0.25

Source: TRC, Civil Engineering Manual, 1998

Figure 9.9: Safety Tolerances

9.5 Rolling Stock Maintenance

As locomotive rehabilitation work is in progress, with a new locomotive procurement plan envisaged simultaneously, the availability of locomotives increases in the immediate future. However, despite that locomotives shall be overhauled once per eight years, which is equivalent to the general inspection schedule in Japan, TRL has not yet implemented this most significant renewal work in recent years, as spare parts are in short supply. It means that the preventive maintenance system disrupts in TRL. When newly manufactured or rehabilitated locomotives have superannuated, the once-decreased frequency locomotive accidents increase again.

While the maintenance work is not so busy because of the procurement of new locomotives, it is desirable for TRL to secure required spare parts and switchover the rolling stock maintenance from the current system breakdown maintenance to one of preventive maintenance.

9.5.1 Locomotive Situation

(1) New Purchase and Rehabilitation of Locomotive

Newly-Built Class 90 Locomotives

TRL has procured 13 newly-built Class 90 locomotives (Table 9.6).

1) Out of the 13 locomotives, four were already delivered to the Morogoro workshop, of which two have already been in service. (See the following photo for a Class 90 locomotive.) Of the other nine locomotives, three are on the ship moored at the Dar es Salaam Port and six are now under assembling in South Africa.
2) Electro-Motive Diesel Africa (EMD Africa) assembled the locomotives, mounting engines made by GE (from the US), with the contract awarded to EMD Africa after a competitive bidding. The warranty period is two years, which is common to all TRL locomotives of different classes. The procurement price is US$ 3.6 million per locomotive.
3) The Class 90 locomotive is a mainline diesel electric locomotive, having a total weight of 82.2 tons and an axle load of 13.7 tons. Table 9.7 summarizes the detailed specifications of all TRL locomotives, including Class 90 locomotives.
4) Class 90 locomotives equip with DC main motors that are the same as those used for other locomotives. TRL explains that it does not use AC motors for the reason that they are expensive though it acknowledges their manpower saving features in maintenance services.

Table 9.6: TRL Locomotive Holding as of 25 June 2015

Type		Class	Country of Car body manufacturer	Year purchased	Registered on Book	Active Holding	Under Maintenance in Workshop	Actual Outage for Today's Operation
Locomotive	Main Line	90	South Africa	2015	13*	**2**	0	2
		89	German	1992, 1993	9	**3**	2	1
		88U	Tanzania (supported by Malaysia)	2014, 2015	8	**8**	3	5
		88	Canada, India	1972, 1979	27	**9**	2	7
		73	India	1975, 1976	10	**5**	4	1
			Subtotal		67	**27**	11	16
	Shunting	65	German	1991, 1992	4	**2**	0	2
		64	German	1978, 1979	24	**2**	2	0
		37	German	1985	5	**2**	0	2
			Subtotal		33	**6**	2	4
			Total		87	**33**	13	20

Note: * 4 Locos are now at the Morogoro workshop, 3 at Dar es Salaam Port, 6 are under assembly in South Africa.
Source: TRL

Table 9.7: Locomotive Specifications

Class	Weight			Engine			Max. Tractive Effort (kN)
	Total weight (ton)	Axle load (ton)	Wheel arrangement	Type	Manufacturer	Horse Power (PS)	
90*	82.2	13.7	Co-Co	DE	GE	2,000	N/A
89	74	12.3	Co-Co	DE	MTU	2,130	252
88U**	96	13.7	1Co-Co1	DE	GE	2,150	234.5
88	103.446	13.5	1Co-Co1	DE	ALCo	1,880	239.5
73	72	12.6	Co-Co	DE	ALCo	1,380	124
65	38.4	10.1	B-B	DH	MTU	760	124
64	38.6	10.3	B-B	DH	MTU	740	120
37	36.2	13.2	C	DH	N/A	***401	107.9

Notes: *Class 90 is the newest locomotive. **Class 88U is a remanufactured locomotive of Class 88. ***: converted from 295[kW] to metric horsepower [PS]
Abbreviations: DE = Diesel Electric, DH = Diesel Hydraulic
Source: TRL

<u>Rehabilitated Class 88U Locomotives</u>

1) Regarding the rehabilitation of Class 88 locomotives that a Malaysian enterprise, SMH Rail undertakes, the Study Team witnessed five locomotives under rehabilitation work at the Morogoro workshop on 6 June 2015. Locomotives for which rehabilitation has finished put affixing “U” at the end of the designation, such as “Class 88U.”

2) The Study Team heard that the rehabilitation cost is approximate US$ 2.0 million per locomotive.

3) Twenty Malaysian engineers stay at the Morogoro workshop, with workers employed by these engineers working in the workshop yard. Six TRL employees are being educated on locomotive maintenance through OJT, included as part of the procurement contract terms, with manuals and technical documents provided by SMH Rail.

<u>Procurement in the Future</u>

1) TIRP states its expectation that the acquisition of three more locomotives, each having an axle load of 25 tons and engine power of 2,000 HP, is probable in the future.

(2) Number of Active Locomotives

As it has procured the new Class 90 locomotives, TRL now has 33 active locomotives, 27 for mainline and six for shunting services, as of 25 June 2015. Table 9.6 above summarizes the number of active locomotives at the time of this Study.

(3) Number of Locomotive Failures

1) According to TRL, a locomotive failure occurred almost every day in the past on average. In recent years, however, they have dropped by half (for example, only 11 failures were recorded for the month of June 2015), presumably thanks to the introduction of new Class 90 locomotive and the rehabilitation of old Class 88 locomotives.

2) TRL states that failures, mostly occurring in diesel engines, do not concentrate on any particular Class of locomotives.

Source: JICA Study Team

Figure 9.10: The Newest Locomotive, Class 90

9.5.2 Locomotive Maintenance

(1) Inspection

Inspection Cycles

1) Mainline locomotives have different inspection cycles, which depend on each class based on the running times and working days. The specified inspection cycles are different for different classes for the reason that different manufacturers fabricate them. However, the specified cycles are not those offered by manufacturers, but they TRL determined based on the recommendation of manufacturers by reviewing the records of failure occurrence of different locomotives. TRL's activities to evaluate the frequency of failure occurrence and review inspection cycles by itself is praiseworthy from the viewpoint of productivity and improvement of locomotive quality.

2) Regarding the rehabilitated locomotive, Class 88U, five service categories have been adopted and put into trial application. They are (i) weekly service, (ii) monthly service, (iii) quarterly service, (iv) one-year service and (v) 4-year service. The Study Team hears that TRL is now discussing the inspection cycles for new locomotives Class 90.

3) The overhaul or heavy maintenance of locomotives (8-year cycles) has not been implemented in recent years, as spare parts are in short supply, as explained below.

Status of Spare Parts in Stock

1) Major spare parts in short supply are those used for engines, air compressors and main motors, all related to the propulsion and braking function of locomotives to directly govern their availability. TRL remarks that engines for the overhaul are in short supply, in particular.

2) As a result, the structure of preventive maintenance has virtually collapsed. For instance, shop-in locomotives for overhaul cannot be provided with repair services due to a shortage of spare parts. Therefore, they cannot be returned to revenue service operation again. Consequently, locomotives on the verge of the overhaul are degraded to a valuable fountain of spare parts for other locomotives, thus terminating their service life. In the workshop yard, the Study Team witnessed many such defunct locomotives. (See Figure 9.13 below for a defunct locomotive.)

3) According to TRL, the shortage of spare parts stems from the shortage of funding. TRL explains that they are procuring new locomotives and undertaking rehabilitation work as a measure of expensive spare parts required for repair services. Therefore, because TRL could purchase the new locomotives, it does not have an overall fund shortage, but rather a budget shortage for repairs. The Study Team suggests that the shift of the emphasis on budget allocations from new purchases toward maintenance is favorable while scrapping the old-type locomotives.

(2) Workshop

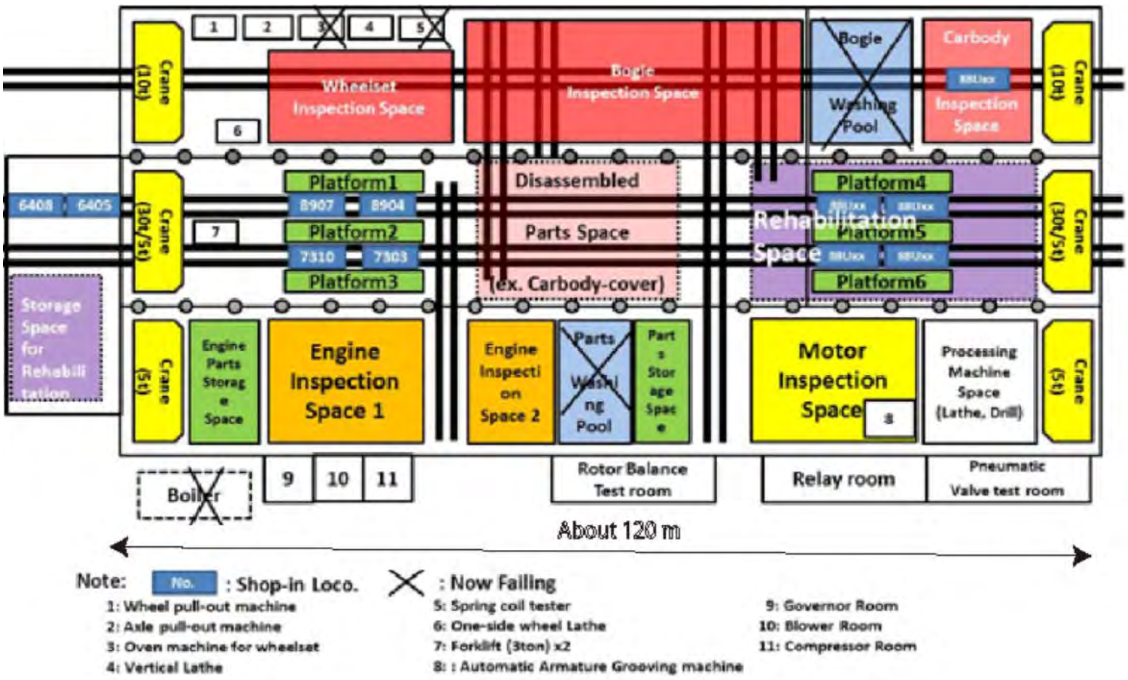
Workshop Organization

1) At the workshop, 120 TRL employees are working. The workshop organization consists of works manager and assistant works manager, under which there are seven inspection sections separately for different fields of inspection, i.e., power units, traction motors, machining tools, fabrication, superstructures (assembling/disassembling), bogies, and wheels.
2) Disassembling and cleaning of engines/DC motors are not outsourced but are implemented under its direct management, proving that TRL has the skills required for inspection.

Outline of Workshop Equipment/Facilities

Figure 9.11 shows the layout of the inspection shop at Morogoro Workshop.

1) At the center, there are two sets of main inspection line for an overhaul. Four locomotives can enter the accommodation tracks on the left-hand side platform in the Figure.
2) The platform on the right-hand side, having the same locomotive accommodation capacity, is now used for rehabilitation work. Therefore, the site can accommodate eight locomotives in total, after completion of rehabilitation work.
3) Among the inspection and repair facilities, wheel lathes and processing machines are functioning well, but some machines and a boiler are out of order. Before the completion of boiler repair work, machine parts cannot be subject to hot-water washing and now dealt with cold-water washing. Figure 9.12 shows a parts washing pool.
4) Figure 9.13 displays the situation of old locomotives in the Morogoro Workshop Yard. The remains of old-type locomotives are left in the Morogoro Workshop yard after some parts were removed from and appropriated to repairing other locomotives.



Source: JICA Study Team

Figure 9.11: Layout of Inspection Shop in Morogoro Workshop

Source: JICA Study Team

Figure 9.12: Parts Washing Pool in Inspection Shop

Source: JICA Study Team

Figure 9.13: Situation of Dilapidated Locomotives in the Morogoro Workshop Yard

9.5.3 Subjects in the Future

(1) Save of Spare Parts

1) A priority subject for TRL is to remedy the situation where it cannot implement preventive maintenance due to the shortage of spare parts, which makes the old-type locomotives terminate their service life virtually in eight years. For several years from now, however, there are no problems, as the frequency of train operation is not very high, with active locomotives increasing as new locomotives are coming and rehabilitated ones are coming back to the frontlines. Despite that, however, given the fact that the number of rolling stock increases in the future, with procured and rehabilitated locomotives, superannuated simultaneously, it is a matter of the highest priority for TRL to discuss how to have enough spare parts for maintenance services.

2) Under the circumstances where new locomotives are arriving and rehabilitated ones coming back to revenue service, TRL engineers may, fortunately, have chances to be in direct contact with those from manufacturers. On this occasion, they shall discuss measures to make sure the procurement of spare parts, while studying the technique of regular inspections within the two-year warranty period. In concrete terms, TRL shall negotiate with manufacturers and take budgetary procedures within TRL's organization and to the Tanzanian government. TRL shall secure parts on a prioritized basis, at least for new Class 90 locomotives, or the principal mainline locomotives and rehabilitated Class 88U locomotives.

3) Although TRL explains that new or rehabilitated locomotives are cheaper than spare parts, it is not conceivable that parts are more expensive than locomotives, unless they are special parts customized and manufactured on a small-lot production line. The Study Team thinks this implies that manufacturers are not cooperative for after-sales services.

   (1) As a solution to this problem, the Study Team recommends TRL to discuss a method to purchase the substitute parts from manufacturers other than the supplier of the original piece. Although it depends on the status of the development of manufacturers in Tanzania, it is an attempt to order an alternative part equivalent to the original one conveniently from a domestic part manufacturer, use it on a trial basis, and formally procure more after verification. Although it may be difficult to apply this idea to

important parts, the Study Team recommends TRL to start joint development of substitute parts from simple consumables (such as motor brushes).

(2) As TRL prepares tender documents by itself in placing orders for procurement or rehabilitation of locomotives, it may be possible for TRL to add a stable supply of spare parts for two years or over in the contract terms in the future. The supplier shall introduce similar products as alternatives if the original parts go out of production. Not to make all bidders bow out. However, a practical and reasonable warranty period shall desirably be set for that purpose.

(2) Consideration of the Standardization of Equipment and Parts

Non-unification of parts may be cited as one of the factors to have made their procurement difficult.

At the moment, TRL is procuring parts by itself. Through a competitive bidding process, the bidder who has offered the lowest price obtains the letter of award. As a result, different spare parts shall be procured from various suppliers featuring different car body/engine manufacturers, though their engine outputs, axle loads, and other basic specifications are the same.

The Study Team recommends TRL to screen one to two suppliers who would be able to supply high-quality parts constantly in the future, unify parts to improve maintainability, and maintain a structure to procure spare parts at lower costs. However, TRL shall pay attention to the transparency of procurement and perform a total cost evaluation, such as not to induce high-cost procurement unexpectedly as a result of negotiated contracts with specially-designated suppliers.

(3) Consideration of the Installation of High Maintainability Equipment

The diesel-electric locomotives currently owned by TRL are all installed with DC motors. TRL explains that DC motors are cheaper than induction motors. Nowadays, however, induction motors are the mainstream of electric railway cars from the technical viewpoint and are superior to DC motors regarding maintainability, robustness, and the ratio of outside dimensions on output (smaller outside dimensions at the same output). The Study Team recommends, therefore, for TRL to consider the procurement of induction motors while taking into account the technical progress and the market prices, continuously

9.6 Signaling System and Telecommunication

The Study Team surveyed the signal and telecommunication systems/facilities in the section between the Kilosa and Dodoma stations as detailed below.

9.6.1 Block Systems and Signals

(1) Block Systems

For the safety of train operations, there are several types of block systems. The Study Team surveyed the paper ticket block system used by TRL. Under this system, train operation over the whole section is controlled by a controller, and between stations by stationmasters. Each stationmaster communicates through block telephones (portable telephones on public telephone networks) with the stationmaster of the adjacent station (to which the train in question is proceeding) to check whether a train exists in the section up to that station. After the confirmation of the non-existence of a train, the station master issues and hands over a paper ticket to the train driver who is going to pass the station to permit entry into the section up to the adjacent station. The train driver provided with the paper ticket runs the train up to the station specified on the ticket.

The authority of stationmaster at large stations is different from that at small stations. At large stations, (i) a foreman has the power to issue the ticket on behalf of the stationmaster and (ii) a point man manipulates points, confirms their status and reports it to the foreman. At small stations, on the other hand, such procedures are all implemented by the stationmaster.

There was a tablet block system in the past, but it damaged and is now out of use.

Source: JICA Study Team

Figure 9.14: A Ticket Used under the Paper Ticket Block System

Source: JICA Study Team

Figure 9.15: Devices Used under the Tablet Block System (Now Destroyed and Out of Use)

Source: JICA Study Team

Figure 9.16: Block Telephone Sets (Out of Use with Copper Cables Broken)

(2) Signals and Points

Signals

There are semaphore signals as home and departure signals but damaged and not in use (Figure 9.17).

Source: JICA Study Team

Figure 9.17: Semaphore Signals (Destroyed and Not in Use)

Shunting Signals

There are no shunting signals

Points

All stations equipped with manually turned padlock-locking type points (Figure 9.18). To turn the point, the point man unlocks the padlock first and re-locks it again after manipulation.

Source: JICA Study Team

Figure 9.18: Manually-turned Point (Locked with a Padlock)

Interlocking System

There is no interlocking system in any station.

(3) Power Source for Signals

TRL introduced a power supply system of solar panels for signals and telecommunication devices (Figure 9.19). Due to the pilfering of telecommunication lines or breakage of cables by floods, however, the power source has not served its intended purpose thus far.

Source: JICA Study Team

Figure 9.19: Solar Energy Source Power Supply System (Not in Use)

9.6.2 Telecommunication System

(1) Trunk Telecommunication Lines

Optical fiber cables laid along the 840 km long section between the Dar es Salaam and Tabora Stations.

(2) Optical Fiber Cables

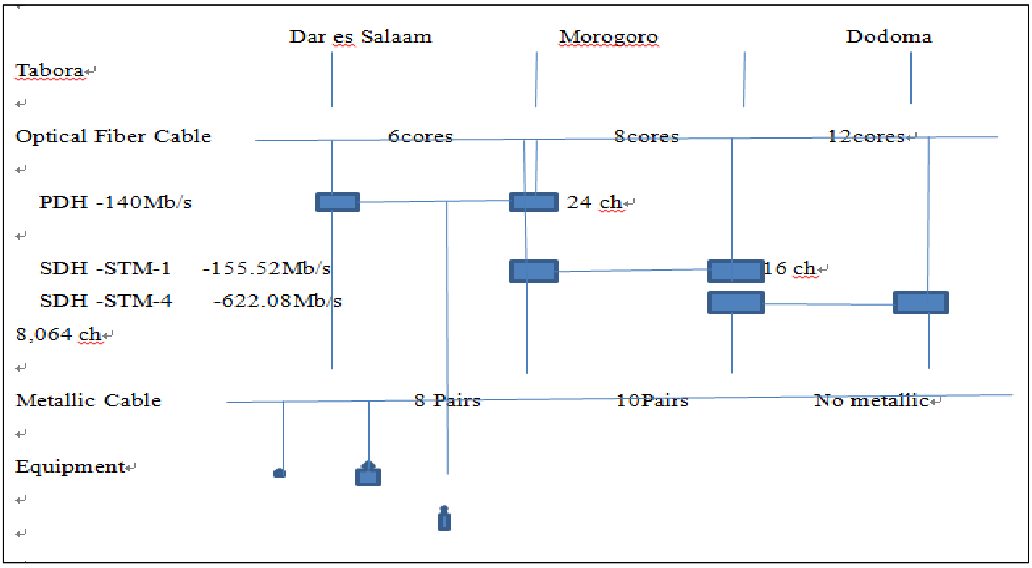
Regarding optical fiber cables, the Study Team has learned from TRL the following:

1) There is a six-core optical fiber cable between Dar es Salaam and Morogoro, with multiplexers connected to the optical fiber cables, one each for every three to four stations. Telephones at each railway station link to the copper cables extended from a multiplexer. The copper cables are victimized, however, by burglary or floods and out of use now.
2) There is eight-core optical fiber cable between Morogoro and Dodoma, of which only two cores are now active. However, TRL intended to lease the rest to outside subscribers, which has not yet been licensed, by the government. The allocation of active two core cables is the five-channel telephone circuits, with one for up-direction circuit and the other in the down-direction circuit. The copper cables are victimized, however, by burglary or floods and out of use now.
3) There is twelve-core optical fiber cable in the Dodoma and Tabora section, with a multiplexer installed at each station. Telephones at each railway station directly connect to the multiplexer without using copper cable wire. VHF wireless telecommunication units (in the 150 MHz band) are also installed to enable communication to/from relevant organizations.

Source: JICA Study Team

Figure 9.20: Multiplexer

Figure 9.21 shows a circuit diagram of the trunk transmission line:



Source: RAHCO

Figure 9.21: Diagram of Communication Line

(3) Block Telephones

TRL's stations equipped with block telephones, which are out of use, however, as copper cables are stolen or broken by floods. As a means of communication between stations, therefore, portable telephones sets for public use are deployed (Figure 9.22), with which stationmasters establish a block section between stations.

Source: JICA Study Team

Figure 9.22: A Portable Public Telephone Set
(Used as a Block Telephone Set)

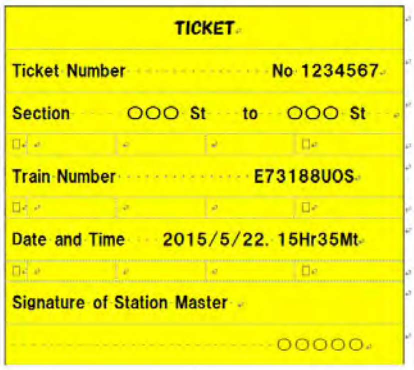
9.6.3 Signal and Telecommunication Systems in the Future (Viable Block Systems)

The Study Team has clarified through this Study that TRL's signal facilities and telecommunication lines are devastatingly robbed and damaged such that block telephones and signals can no longer serve their original purpose. In such vandalism, investment into TRL's signals and telecommunication facilities would end their futileness. It may be a far more practical way of thinking to avoid a renewal of signal and telecommunication equipment/ facilities at this juncture.

The Study Team recommends TRL, therefore, to operate trains by the following method instead, while using existing signals and telecommunication lines that have survived wrongdoings. If TRL were required to perform speedups or increase the frequency of train operation in the future, TRL should introduce high-level signal and telecommunication systems to cope with the new situation accordingly.

The Study Team recommends adoption of the paper ticket block system to run trains by following the procedures bellow.

1) To make a train depart from an adjacent station (a recipient station), the station master shall establish a block section (protected section) up to the receiving station after confirming that no trains exist in the section up to the receiving station with its stationmaster through a portable telephone set.
2) When there are no trains in the protected section, the stationmaster shall turn the relevant point where necessary, confirm its status whether it is in the normal or reverse position (closed or opened) and shall mechanically lock it.
3) To start the train, the station master shall issue a ticket (to allow entry into the protected section) and hand it over to the locomotive driver.
4) Figure 9.23 shows the sample of the ticket.



TICKET

Ticket Number	No 1234567
Section	○○○ St to ○○○ St
Train Number	E73188UOS
Date and Time	2015/5/22. 15Hr35Mt
Signature of Station Master	
	○○○○○

Source: JICA Study Team

Figure 9.23: An Example a Specimen of the Ticket Used under the Ticket Block System

5) The ticket consists of duplicated sheets (carbon copies).
6) The stationmaster shall prepare a recording book on his/her desk, into which he/she shall enter the train handling records.
7) The stationmaster shall keep the recording book and tickets at a safe place for three months.
8) The stationmaster shall prepare hand lamps (Figure 9.24) and spare lamps to use for departure and other signals at night.

Source: JICA Study Team

Figure 9.24: Hand Lamps

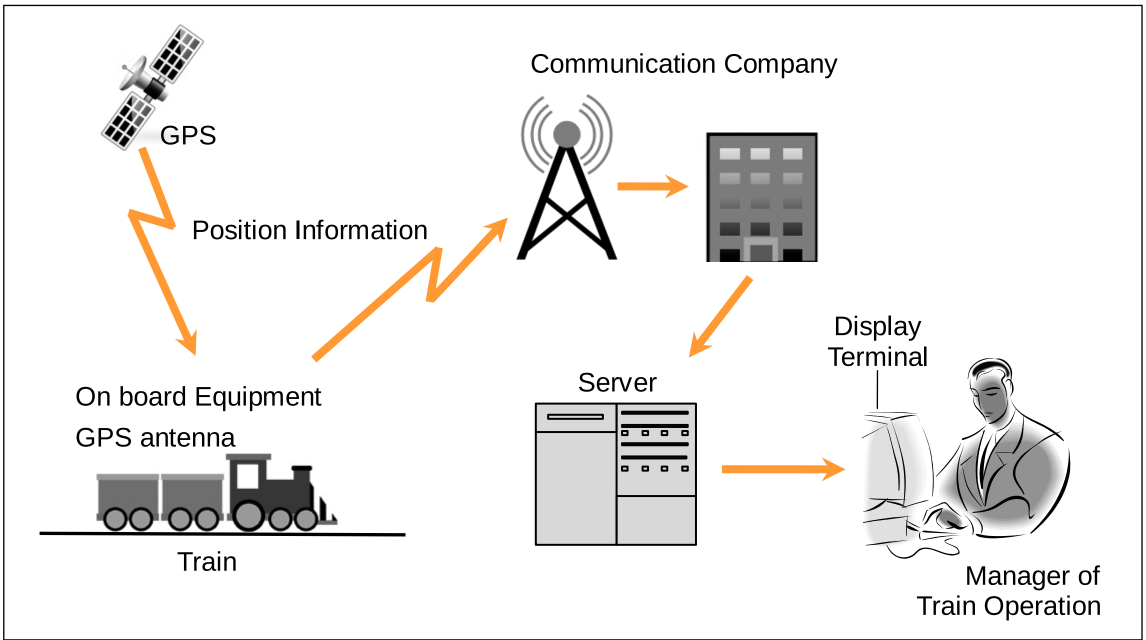
9.6.4 Ideal Train Operation Control in the Future

An ideal system for the future train operation control may be as follows:

1) The system combines a global positioning system (GPS) and the normal public portable telephone network to compose a train operation control system.
2) The driving cab of each train equips with (i) a display terminal for monitors and (ii) two antennas, one for GPS and one for the normal public portable telephone network.
3) Trains acquire their positions information through GPS and transmit it to the operation control center via the antenna for the mobile telephone network. Thus, the operation control center grasps the position of all trains on a real-time basis.
4) In case an accident or other abnormal situations have occurred, communications are made between stations and train dispatchers, between train drivers and dispatchers, and between

different stations through the portable telephone network to promptly and appropriately recover normal train operations.

Figure 9.25 gives an image of this train operation control system.



Source: JICA Study Team

Figure 9.25: Diagram of the Train Operation Control System in the Future

9.7 Stations and Related Facilities

Attempting to offer the core passenger and freight services is a meaningless endeavor without first ensuring safe and regular train operations to meet transport demand. After that is ensured, the next step is to provide improvements in users' convenience, by designing stations and terminals to allow for fluidity in the movements of passengers and freight. Furthermore, provisions shall be made to facilitate transfers to other transport modes at station plazas. The Study Team recommends that consideration is given to the improvement of equipment/facilities to guarantee mobility of physically handicapped people (barrier-free access/movement).

A subject of focus for freight terminals is the ability to control information on the location of containers, and implement a system to notify consignees of the arrival times of their freight.

Requirements for passenger and freight services frequently change according to social conditions, and the measures cited above cannot be adjusted/realized overnight. Therefore, TRL must constantly make efforts to grasp what is required for the Central Railway Line, by observing other global railways examples improving its own services step-by-step while considering cost performance at all times.

9.8 Flood Protection

9.8.1 General

The purpose of flood protection measures is to guarantee a transport capacity, approximately equal to the maximum levels seen in the past. As a first step toward this goal, Section 9.8.2

below explains an image of train operations after the implementation of the flood protection measures.

After that, Section 9.8.3 describes the policy of relocating railway facilities as a basis for flood protection works, with specifics for the objects of relocation, truck structures, tracks and station facilities, and relevant standards. Following this, Section 9.8.4 describes track relocation work, one of the largest components of the railway facilities relocating project for flood protection; Section 9.8.5 describes track strengthening after flood protection measures; Section 9.8.6 describes track materials used for facilities relocating work; and Section 9.8.7 contains some general remarks/conclusions for after the implementation of the flood protection measures.

9.8.2 Train Operation after Flood Protection

(1) Effect of Relocation of Equipment/Facilities

The line capacity between Kilosa and Gulwe, the object section for flood protection, remains unchanged even after completion of the flood protection project, as the track relocation for flood protection does not change the distances between stations in a major way (a maximum of 0.1 km, or 100 m).

As stated in Section 9.3.2, the line capacity is an index used to calculate, roughly, the number of operable trains, by using the values of (i) line utilization factor, (ii) block establishing time, and (iii) running time between stations averaged over different trains. Although it is a mere index, therefore, it shall be applied by bearing in mind the fact that some preconditions are involved.

Table 9.8 compares distances between stations and line capacities before and after the relocation of tracks from flood protection measures, with line capacities calculated under the same conditions as those in Chapter 9.3. The line capacity between Kilosa and Munisagara after relocation is 1 train/day less than before, because of the rounding factor (from 26.9 to 26.0).

Table 9.8: Distances between Stations before and after Relocation of Tracks

		Kilometrage of Starting Station (km)	Kilometrage of Arrival Station (km)	Distance between Stations (km)	Increase/ Decrease (km)	Line Capacity (trains/day)
Kilosa–Munisagara	**Before relocation**	282.7	298.8	16.1	-	27
	After relocation	282.7	298.9	16.2	+0.1	26
Munisagara–Mzaganza	**Before relocation**	298.8	311.2	12.4	-	39
	After relocation	298.9	311.3	12.4	±0	39
Mzaganza–Kidete	**Before relocation**	311.2	326.0	14.8	-	34
	After relocation	311.3	326.1	14.8	±0	34
Kidete–Godegode	**Before relocation**	326.0	349.6	23.6	-	22
	After relocation	326.1	349.7	23.6	±0	22
Godegode–Gulwe	**Before relocation**	349.6	369.4	19.8	-	36
	After relocation	349.7	369.4	19.7	-0.1	36

Source: JICA Study Team

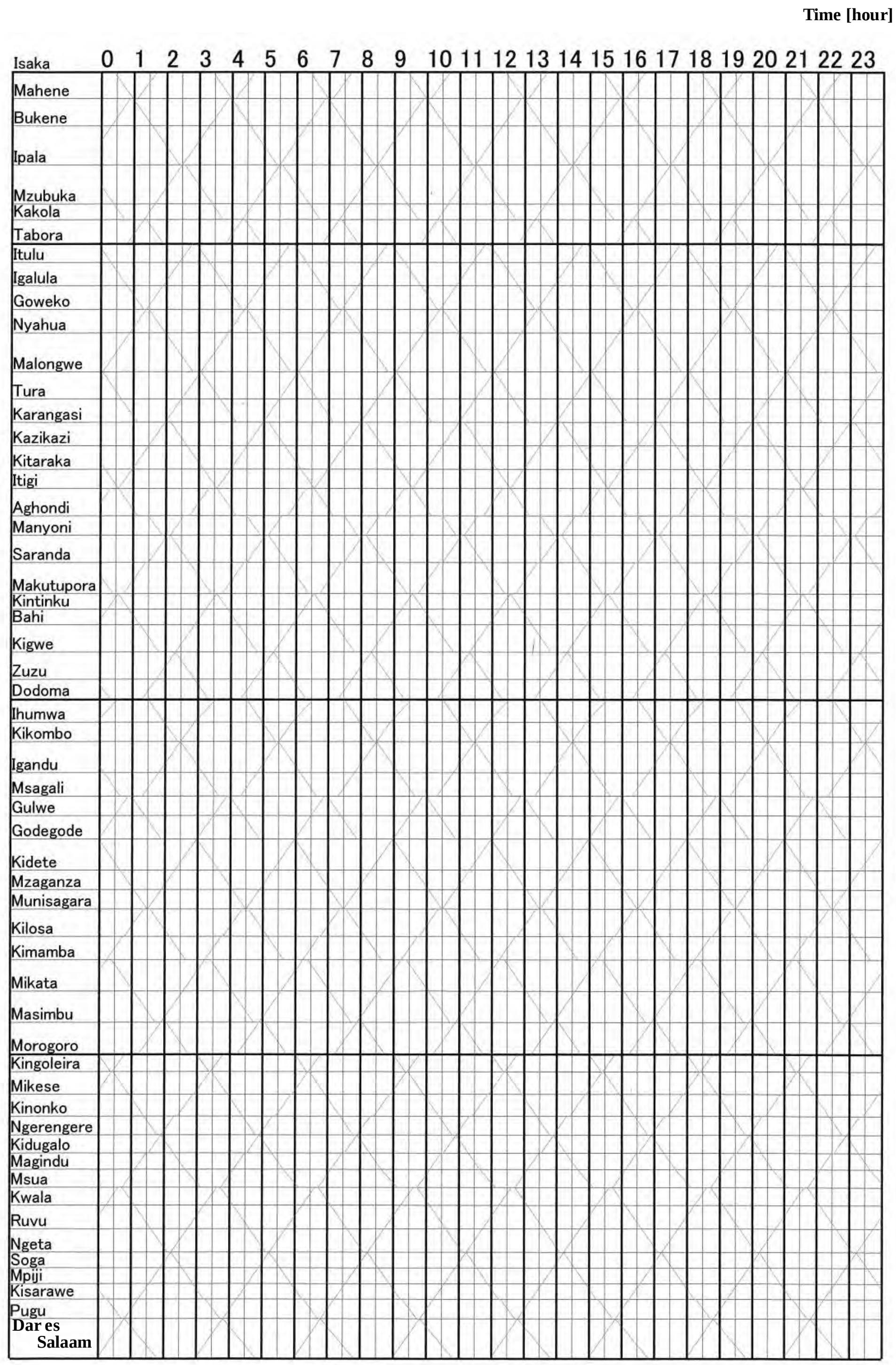
(2) Train Operation Diagram

Whereas the object section of flood protection in this Study is the Kilosa–Dodoma section, Figure 9.26 shows a train operation diagram assumed for the section between Dar es Salaam and Isaka, the area scope of TIRP plans. In drawing the train operation diagram, the Study Team set eight round-trip trains per day, in consideration of the minimum line capacity of 17 trains/day given in Table 9.3.

In this trial calculation, the Study Team set a line utilization factor 0.8 and a block establishing time 5 minutes, while adopting for calculation the train running time between stations of the maximum-speed freight train in the Tanzania Railways Corporation Working Timetable, dated July 16, 2001. For reference, five or so trains were operated in each direction in those days.

The train operation diagram is what is called a "parallel diagram", to run trains at equal three-hour intervals with a minimum dwell time of five minutes at each station. In principle, the up-train has priority for starting from/entering into stations at up- and down-train crossings. The reason for this priority comes from the fact that the demand for up trains from Dar es Salaam Port to Isaka located in an inland area is larger than that of down trains. Therefore, the punctuality of up trains is more important than that of down trains. The Study Team also assumes that down trains are more likely to transport empty containers than up trains, which naturally are of a lower priority.

This train operation diagram is applicable irrespective of whether a flood protection project is in progress, as the project does not change the line capacity. Therefore, in order to put this train operation diagram into effect, all that is required is to reinstate the currently-dormant stations as signal stations to enable two trains running in the opposite directions to cross each other at such signal stations. Additionally, the volume of freight transport capacity would potentially reach 1.3 million tons or less per year, as shown in Table 9.3 above.



Source: JICA Study Team

Figure 9.26: A Sample Timetable between Dar es Salaam and Isaka

9.8.3 Relocation Plan of Railway facility

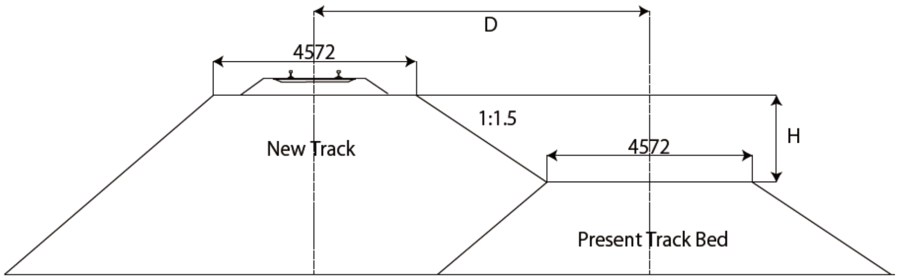
(1) Track Structure

Between Kilosa and Gulwe, 25 km of the line is to be rerouted under the flood protection project. The typical patterns of disaster are as follows:

- Pattern 1: Flood damages from the mainstream river (Kinyasungwe River).
- Pattern 2: Flood damages from the tributaries and slopes of mountains along the railway, due to inadequate cross-drainage.
- Pattern 3: Submergence of the track by the floodwaters from the mainstream and tributaries/slopes of mountains, due to inadequate drainage along the railway.

For each of the above patterns, the fundamental countermeasure is to relocate the track to a higher area where the disaster risk is lower. The concept of the relocation is to construct a higher bank along the existing track bed. When the safe elevation of the new bank is H mm higher than existing track, the distance D between the present and new track is estimated by the next equation, assuming a slope of 1.5 for the bank slope ratio and 4,572 mm for the formation level width, as shown in Figure 9.27.

D (mm) = H x 1.5 + 4,572



Source: JICA Study Team

Figure 9.27: Concept of Route Relocation

The Study Team is estimating the safety height *H*, and this is one of the most important points of the project. If *H* is assumed to be 5,000 mm, the distance between the track centers is 12,072 mm,[9] indicating that the new route runs along the mountain-side of the existing line.

(2) Railway Standards

Table 9.9 shows the proposed railway standards for the track relocating section which the Study Team deems to be appropriate. The standards comply with TRL manuals and current railway conditions.

Table 9.9: Railway Standards

Item		Remarks
Gauge (mm)	1,000	Gauge conversion not considered
Axle load (ton)	18.5	Double heading operation for steep gradients or larger hauling tonnage
Length of train composition (m)	Approx. 420	Current track layout in yard taken into account
Max. train speed (km/h)	50	Immediate target, with 80 km/h operation enabled in the future
Min. curve radius (m)	400	Adoption of line profiles to facilitate extension of transition curves
	250	Where 400 m is impractical
No. of turnout	Main: No. 10 Siding: No. 8	Mainly single and double-curve turnouts of the same type are used to avoid unsymmetrical double-curve turnouts in the same or opposite directions

Source: JICA Study Team

9 5,000 mm x 1.5 + 4,572 mm = 12,072 mm

Length of the Straight Line between Curves

The length of the straight line between curves shall be larger than the maximum length determined based on the safety limit (prevention of derailment caused by three-point rolling stock support) and ride comfort (in consideration of the change in cant over time and excessive centrifugal force due to cant deficiency).

Minimum Length of Curve

Trains are prone to roll at the point of entering and exiting from a circular curve, through the same process described in the previous paragraph. To prevent an accumulation of this rolling motion, it is important to ensure a circular curve longer than at least than a car length.

Cant/Superelevation

Trains running on a curve are subject to an outward centrifugal force. This (i) causes potential danger of outward overturn, (ii) affects the lateral force on the outer rail and wears on the tracks, increasing the volume of track maintenance work, and (iii) pulls passengers outward, reducing ride comfort. Therefore, tracks are to be furnished with cant on the outer rail in curved sections to prevent these effects.

In actuality, however, there is a speed difference between passenger and freight trains. This means any single cant does cannot satisfy both train speeds. To address this, the cant is set as the average speed obtained by the root-mean-square method.

For the non-relocated sections, the correction of cant is not necessary since the train speeds do not change.

Others

1) Track section length between adjoining curves or turnouts

A straight track section length equivalent to the maximum car length is necessary between adjoining curves and turnouts. Moreover, the same curve length between the adjoining straight section is required as well. The purpose of the minimum section length is to prevent the cumulative car body vibration.

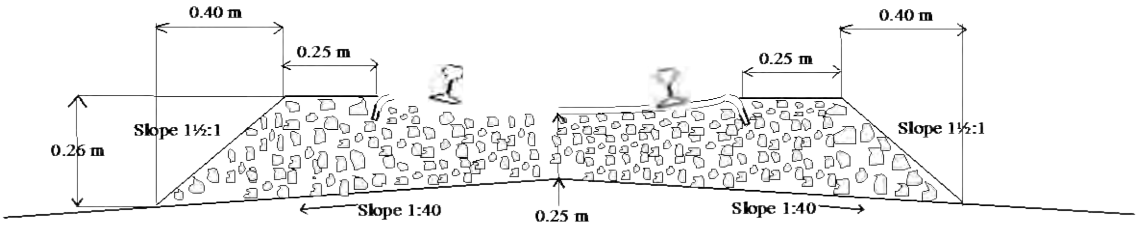
In the case that the insertion of a straight section as specified above is difficult for various constraints, such as in station yards or other places, the minimum section length is reduced to 5 m or more in length, in consideration of the car wheelbase.

2) Joints between curves, structures

Trains are normally subject to rolling at curve joints (BTC, BCC, ECC, ETC), crossings, abutments, and turnouts. The track requires a damping distance longer than the maximum car length between curves to reduce the collective car body vibration caused by such curve joints. This issue becomes serious considering the plans for speeds up to 80 km/h in the future. Therefore, it is better to consider it now, at the planning stage of track alignment.

(3) Track

Tracks are subject to be replaced in not just the re-routed sections, but sections that are presently equipped with 60 lb/yd rails as well. The new tracks shall be a meter-gauge ballasted structure composed of 80 lb/yd rails and steel sleepers as a standard. See Figure 9.28 for a track sectional drawing.



Source: TRC, Civil Engineering Manual, 1998

Figure 9.28: Track Sectional Drawing

(4) Stations

As a part of the flood protection project, some sections of railway track transfer together with stations and related facilities. The concrete objects of the relocation are:

- The facilities in service
- The facilities that have an established plan, even if they are unserviceable at this moment.

Examples of the relocated facilities/objects are as follows:

- Track (main line and refuge track)
- Station main buildings

(5) Summary

Table 9.10 summarizes railway facilities subject to relocation.

Table 9.10: Railway Facilities Subject to Relocation

	Object of Relocation		Remarks
Track structure	Section of track relocation		Length: 25.1 km (after relocation)
Track	Section of track relocation		Length: 25.1 km (after relocation)
Station facilities	Gulwe station	Station building	
		Sub-mainline for up- and down-train crossings 1 set	Effective track length: 450 m

Source: JICA Study Team

9.8.4 Relocation of Track

(1) Track Structure

Figure 9.28 and Table 9.11 summarize track structures applicable to sections subject to track relocation.

Table 9.11: Track Structure

Track structure			
	Ballasted track		
	Joint	Standard size	
	Distribution of joints	Supported joint	
	Joint supporting method	Parallel joint	
Track materials			
	Rail	Rail type Length of rail Rail steel	80 lb/yd over Standard size: 24.0 m or over Ordinary rail
	Rail Fastening	Composition Fastening spring Fastening method	Double elastic fastening Wire spring, spring crip No-screw fastening
	Sleeper	Sleeper type Sleeper interval	Steel Sleeper 1477 Units/km, (33 Units/24 m) A=229mm, B=610mm, C=686mm, D=748mm
	Ballast	Ballast Thickness of Ballast Width of Ballast shoulder Volume of Ballast	Crushed Stone 250 mm 250 mm 885.0 m^3/km

Source: TRC, Civil Engineering Manual, 1998

(2) Transport of Materials

Track materials are heavy, long, and bulky. Their bulk transportation requires appropriate vehicles and equipment for work sites, temporary storage yards, and main stock yards at the construction base. For the transportation of equipment, dedicated freight cars on the rail and trailers on the road play an active part.

The transportation of rail, sleepers, and track ballast pose some challenges. The availability of sufficient spaces for loading/unloading and equipment to be transported governs the capacity of the carriage. See Table 9.12 for methods to transport track materials.

Table 9.12: Methods to Transport Track Materials

Track material for transport	Transport route	Methods to transport and unload track materials
Rail	By a revenue service line	Unload rails from rail-transporting freight cars with a rail unloader at the main stock yard in the construction base.
		Unload rails from track motor-cars with a rail unloader at the work site.
	By land	Unload rails from trailers with a crane at the work site.
Sleeper	By a revenue service line	Unload sleepers from sleeper-transporting freight cars and track motor-cars at the main stock yard in the construction base.
	By land	Unload sleepers from trucks with a crane at the work site.
Track ballast	By a revenue service line	Transport track ballast by a ballast-transporting freight cars from the factory at the quarry to the main stock yard in the construction base and unload.
	By land	Load track ballast on dump trucks at the main stock yard in the base and transport to and unload at the work site.
		Transport track ballast from the factory at the quarry directly to the work site by dump trucks and unload.

Source: JICA Study Team

For carrying-in, storage, and loading of track materials, and storage of construction machines/tools, the process is to prepare the main stock yard in the base adjacent to the work site and equip it with gantry cranes and other loading/unloading machines. Where necessary, a temporary storage yard is established close to the work site.

	Rail	Sleeper	Track ballast
Transport by Land	 Website: yoyogiall	 Website: nikko	 Website: matsuikido
Transport by a revenue service line	 Website: hokuju	 Website: daitetsu	 Website: mjk21

Source: JICA Study Team

Figure 9.29: Typical Equipment for Transport of Track Materials

(3) Track Construction

After constructing a track bed, ballast is manually or mechanically spread and leveled on the track bed up to the height of sleeper bottom and compacted with a vibration compactor. Next, a track panel is set up on the compacted ballast and replenishing ballast is spread to form an appropriate ballast layer section. Below, a method is explained for performing track construction work for a length of 500 m in a time period of two weeks.

Spreading/leveling ballast on the track bed to the height of sleeper bottom

Transport track ballast directly up to the construction site by dump trucks. See the method explained in sub-section (2). For a 250 m-long track construction project, ballast of 150 m^3 is required (on the assumption that ballast of 0.6 m^3 is necessary for a track length of 1 m). Transporting ballast up to a volume of 150 m^3 necessitates deploying five times a fleet of six 5 m^3 10 ton dump trucks (5 m^3/track x 6 tracks x 5 times). Spread and level the ballast unloaded with power shovels to form a ballast layer to the height of sleeper bottom and compact it with a vibrating compactor. See Table 9.13 for machines required for a 250 m-long track construction task.

Table 9.13: Important Track Maintenance Machines Required for Ballast spreading/Leveling work

Machine	Quantity	Purpose
Road-rail power shovel	2	Ballast spreading and leveling

Source: JICA Study Team

Setting up of Track Panel

After unloading sleepers to the side of formation level, uniformly arrange them on the track bed with power shovels and cranes. Use over-raise rail shifters to manually adjust spaces between sleepers. Use 360 sleepers for a track length of approximately 244 m.

After that, laterally or longitudinally move and arrange rails on the sleepers. Adjust joint gaps and fix rails with rail fasteners to set up a track panel. A 240 m-long track consists of 20 24 m-long standard-size rails on the left and right sides. See Table 9.14 for track maintenance machines required for 240 m-long track fabrication task.

Table 9.14: Major Track Maintenance Machined Required for a Track Panel Setting up

Machine/Tool	Quantity	Purpose
Road-rail power shovel	2	Unloading rails and sleepers
Attachment (gripper)	2	Unloading and arranging sleepers
Road-rail 8-t crawler crane	2	Unloading of heavy articles and shifting of track panels in lateral directions

Source: JICA Study Team

<u>Replenishment of Ballast</u>
After setting up a track panel, deliver replenishing ballast with road-rail power shovels. On the assumption that ballast of 0.3 m^3 is necessary for a 1 m-long track, replenish ballast of 48 m^3 for a 160 m-long track, by deploying twice a fleet of six road-rail 8 ton dump trucks, each having a capacity of 4 m^3. In parallel with ballast replenishing operation, carry ballast with road-rail power shovels; tamp the ballast with a 16-tool tie tamper and compact with a vibration compactor. See Table 9.15 for the machines used to complete the above operations in a day.

Table 9.15: Important Track Maintenance Machines used for Ballast Replenishing

Machine/Tool	Quantity	Purpose
Road-rail 8t dump truck	6	Transport of replenishing ballast
Road-rail power shovel	2	Formation of ballast section
Road-rail 16-tool tie tamper	1	Tamping of track ballast

Source: JICA Study Team

(4) Realignment of Track

There are two kinds of the realignment of the track. One is the preparing of track switchover, and the other is immediately after the switchover. The former is to tamp track ballast and realign track panels by using hand tie tampers or multi-tool road-rail power shovels while the latter to deploy multiple tie tampers and multi-tool road-rail tie tampers to adjust track irregularities caused by trains running for construction work trains and revenue service. Local track irregularities tend to occur before and after bridges and culverts, for which hand tie tampers are useful. After starting a revenue service operation, attention shall be paid to track settlements near switchover points, structures, and abutments, from the viewpoint of track maintenance. Such points require more careful tamping work than for other sections.

As newly constructed tracks are deformable by train loads, they need several times of tamping and compacting work repeatedly. Perform track inspection and measurement with a simplified track inspecting instrument to check their finishing conditions. See Table 9.16 for the machines required for track correction and ballast tamping for an approximately 500 m-long track per day.

Table 9.16: Main Machines for Realignment of Track

Machine/Tool	Quantity	Purpose
16-tool road-rail tie tamper	1	Track ballast tamping
Simplified track inspecting instrument	1	Track inspection

Source: JICA Study Team

Composition of Track Machines and Schedule

See Table 9.17 for the composition of track machines used to construct and realign a 480 m-long track, which includes the descriptions from the preceding Subsections (3) and (4), respectively. Also, see Figure 9.30 for a work schedule for an approximately 500 m-long track realignment conducted in a two week period.

Table 9.17: Composition of Main Track Machines

Machine/Tool	Quantity	Purpose
Road-rail 8-t dump truck	6	Transport of replenishing ballast
Road-rail 8-t crawler crane	2	Unloading of heavy articles and shifting of track panels in lateral directions
Road-rail power shovel (16 tool tie tamper attachment)	1	Tamping of tracks
Road-rail power shovel	2	Forming of track sections
tie tamper attachment	2	Tamping of tracks
gripper attachment	2	Arranging of sleepers
Simplified track inspecting instrument	1	Inspection of tracks

Source: JICA Study Team

Item		Details	Deployed Machine: Name of machine	Deployed Machine: Quantity	Deployed Machine: Implementing speed per track length	1st Week: M	T	W	Th	F	Sa	Su	2nd Week: M	T	W	Th	F	Sa	Su
Realignment of track	Spreading/leveling ballast up to the height of sleeper bottom	Transporting bottom ballast	10 t dump truck	6 sets	250m/day	■	■												
		Spreading/levelling	Road-rail power shovel	2 sets	250m/day	■	■												
		Tamping	Compacting machine	2 sets	250m/day	■	■												
	Setting up of Track Panel	Arranging sleepers	Road-rail power shovel Road-rail crane	2 sets 2 sets	244m/day			■	■										
		Arranging rails	Road-rail crane Road-rail power shovel	2 sets 2 sets	240m/day					■			■						
		Adjusting rail joint gaps								■			■						
		Tightening fasteners								■			■						
	Replenishing of ballast	Transport of replenishing ballast	Road-rail dump truck	6 sets	160m/day									■	■	■			
		Forming ballast layer sections	Road-rail power shovel	2 sets	160m/day									■	■	■			
Correction of track	Tamping (including compacting)		Road-rail power shovel (16-tool tie tamper)	1 set	500m/day												■		

Source: JICA Study Team

Figure 9.30: Work Schedule

(5) Track Switchover

After completing track construction works for the relocating section, the next step is to switch the tracks. Track switching work often reveals some problems, such as insufficiency of construction gauge or adverse effects on a train running performance due to an improper track profile caused in track connecting work. In planning a track switchover, therefore, it is important to check the site conditions in advance, guarantee sufficient working time, and prudently pay attention to recruitment of workers and procurement of tools/machines in a reliable manner.

Track Switching Operation and Train Operation Diagram

As the track switchover works require a long train interval, it often requires a change in the train operation diagrams. In particular, large-scale switchover works often require cancelation of train operations. On such occasions, notify passengers and freight consignees/shippers in advance of changes in the timetable or cancelation of train operations.

Working Time Required for Track Switchover

The work site conditions govern the working time necessary for track switchover. It is essential to implement preparatory work before the switchover. Consider dividing the switchover work into several phases and shorten the working hours to complete the track switchover work within a limited train interval.

Track Switchover Work and Low-Speed Train Operation

There are two types of slowdown patterns of train speed during a track switchover work. One pattern is to run several trains at low speeds at the switchover point and scrape out track ballast as a preparatory work before track closure. The other pattern is to run trains at reduced speeds to ensure running safety until the track exerts a sufficient strength at the switchover point after completion of a track switchover work. Discuss the timing of the lifting of the speed restriction while correcting and measuring the track deformation, as it gradually stabilizes by running trains.

9.8.5 Track Strengthening

In Tanzania, 60 lb/yd rail sections are not subject to track relocation. TRL plans to replace the 60 lb/yd rails in these sections with 80 lb/yd rails by itself. In this regard, the Study Team wishes to avail itself of this opportunity to provide the information below on what TRL should observe in promoting the 60 lb/yd rails replacing scheme.

(1) Switching to Heavy Rails

Iron sleepers currently in use for 60 lb/yd rails cannot fasten 80 lb/yd rails, as their width of rail sheet is too small. Therefore, they shall be replaced by the introduction of new rails or whole track panels.

Prior replacement of sleepers requires several repetitive works at the same points, which prolongs the period of rail replacing work and is hardly-applicable to the sections where a rail switching scheme is also planned. Therefore, the discussions below focus on the way to replace whole track panels.

Such big track renewal work can result in times where trains do not run. As cancelation of train operations is by no means appropriate from the viewpoint of customer service/satisfaction, switching to heavy rails is implemented, with daily train operation maintained under the following preconditions:

- The planned sections switching to heavy rails do not include the section of the flood protection.
- In parallel with switching to heavy rails, iron sleepers shall be replaced with new iron sleepers, with ballast layer sections corrected simultaneously.
- Switching to heavy rails with simple machines and facilities.
- Switching to heavy rails during the regular track closure times as much as possible.

The work to switch to heavy rails includes transport of materials, removal of track, laying of track, correction of track, and carrying-out of waste produced during the rail switching work. To execute the work to switch to heavy rails, discuss the method of execution while considering methods to procure materials, working environments, operation period, cost, and other factors.

(2) Transport of Materials

Methods for Transport and Unload Track Materials

Among track materials, those which are difficult to transport are rails, sleepers, and track ballast. In particular, the method to transport track ballast governs the whole period and cost of the construction work, as its quantity is enormous.

Table 9.18 summarizes different methods to transport track materials. There are two transport ways: one is with a carriage on the road, and the other is on the revenue service lines. To transport track materials by a service revenue line, use freight cars and unloaders both dedicated to material transport. As trains run on the service revenue line back and forth, in this case, the volume of ballast is governed by the capacity of freight cars and the transport time between the loading and unloading bases.

Table 9.18: Methods to Transport and Unload Track Materials

Track material for transport	Section of constructing tracks	Route of Transport	Methods to transport and unload track materials
Rail	Levee widening of an existing track	By a revenue service line	Unload rails from rail transporting freight cars with a rail unloader at the work site.
			Unload rails from track motor cars with a rail unloader.
		By land	Unload rails from trailers with a crane.
Sleeper	Levee widening of an existing track	By a revenue service line	Unload sleepers from track motor cars with a crane at the work site.
		By land	Unload sleepers from trucks with a crane at the work site.
	Separate line	By land	Unload sleepers from trucks with a crane at the work site.
Track ballast	Levee widening of an existing track	By a revenue service line	Spread ballast from ballast transporting freight cars.
		By land	Transport ballast by dump trucks from the factory at the quarry and unload at the work site.
	Separate line	By a revenue service line By land	Transport ballast by dedicated ballast transporting freight cars from up to the nearest station; transship to dump trucks there; forward to the work site and unload to spread.
		By land	Transport by a dump truck from the factory at the quarry to the work site and unload to spread.

Source: JICA Study Team

After unloading rails and sleepers at the work site, place them in parallel with the existing track to facilitate fabrication of track panels.

(3) Preparation for Track Construction and Removal

The track construction process explained below consists of spreading/leveling work of bottom ballast, compaction work, and fabricating/laying work of track panel.

The meaning of “the spreading/leveling work of bottom ballast” is to spread/level ballast up to the level of the new sleeper bottom by manually or mechanically. “The compaction work” means the lifting, tamping, and compacting with a vibration compactor. “The fabricating/laying work of track panel” is the forming of track panel by manually relocating the materials that were sent to and stored in the vicinity of the work site beforehand.

After completing the preparatory work for track construction, remove the existing track after cutting it into pieces of a constant length, and move them a small distance to the side of the formation level with a crane or an over-raise rail shifter.

(4) Construction of Track

When broadly classified, there are two kinds of track constructing methods featuring different process sequences:

Track Constructing Method 1

After temporarily placing a newly fabricated track panel, lift it while spreading replenishing ballast to suffice the necessary volume and tamp it to finish.

Track Constructing Method 2

After spreading/leveling track ballast up to the height of sleeper bottom and compacting it with a vibration compactor or by other means, place the track panel on it and replenish the required volume of ballast to finish.

Select one of the above two methods according to the purpose, whether it is levee widening or not, manual or mechanical track laying, transport of materials by land or by a service revenue line, and so forth.

The work to laterally shift a track panel assumes the use of a special over-raise rail shifter for heavy articles as shown in Figure 9.31, which has a simple structure and is readily applicable to rail/turnout replacing and track maintenance work for different lines.

To transport materials and execute track construction work, large vehicles, such as those to transport track panels or for track renewal work, running on revenue service lines, are sometimes deployed. However, these vehicles are omitted from the discussions below, as they entail enormous amounts of initial investment and maintenance costs and are applicable only to the limited scope of track maintenance work.

Source : To-Ko-Sangyo Website

Figure 9.31: Special Over-Raise Rail Shifter for Heavy Articles

A unit track panel is one composed of two 24 m-rails. Assuming that a track panel has two 24 m-long 80 lb/yd rails, 70 kg steel sleepers, and 5 kg rail fasteners per sleeper, the weight of a track panel amounts to approximately 3.5 tons. As the lifting capacity of a special over-raise-rail-shifter is approximately 1.5 to 2 tons, 3-4 sets of special over-raise rail shifters shall be used to shift a 3.5-ton track panel laterally.

Table 9.19: Weight of Track Panel

Item	Quantity	Unit weight	Weight
Rail	24.0 m	40 kg/m	960 kg
Sleeper	33 pieces	70 kg/piece	2,310 kg
Fastener, pad	33 pieces	5 kg/piece	165 kg
		Total	3,435 kg

Source: JICA Study Team

After installing a track panel, refill ballast to form track ballast sections. This workload is so heavy that it governs the speed of track renewal work as a whole. After track panel laying work has progressed to the extent that construction cars are allowed to run thereon, it is efficient, from that point, to being spreading ballast by using ballast spreading cars. Figure 9.32 shows photos of typical ballast spreading cars, which can spread ballast within and outside of the track gauge.

Source: MJK Website

Figure 9.32: Typical Ballast Spreading Cars

(5) Correction of Track

After completing the construction of track, refill the ballast to correct the track irregularities. Procedures to correct the track are different depending on the selected track constructing method. In the case of track construction method 1, lift the track panel with jacks up to the specified height and tamp. In construction method 2, spread and tamp the rest of the ballast over the already spread/leveled bottom ballast, the height of which is under the sleeper bottom.

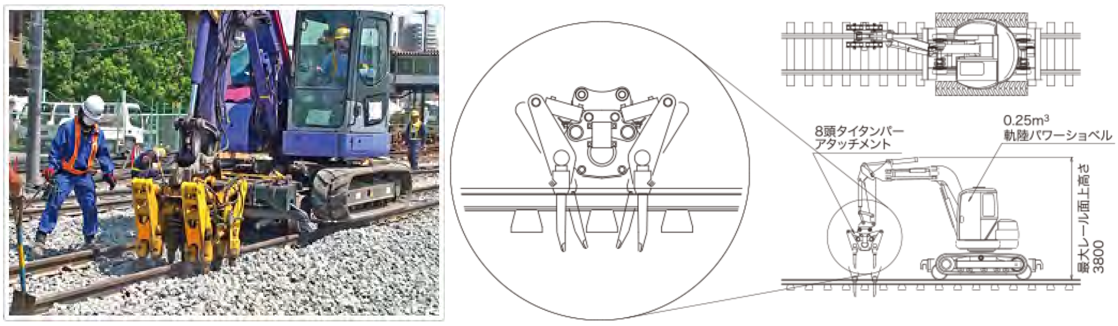
Correct the track as per the criteria stipulated in the Civil Engineering Manual 2.2.2, “Construction and Maintenance Tolerances”. There are three ballast tamping methods. The first is to tamp ballast seamlessly with a multiple tie tamper; the second is to rely on manual means; the third to use road-rail power shovels attached with tamping attachments. Select one according to the volume of workload and required functions therefor. The features of these methods are described below:

<u>Multiple Tie Tamper</u>

It is a machine, basically a unit of rolling stock, used to tamp track ballast seamlessly and also to correct alignment irregularities. With one dedicated to the site, even large-scale construction work can efficiently be implemented at a high quality. However, note that as Multiple Tie Tampers run on the track itself, they must start from and return to the same point before/after track closure time, and thus their production time on sites is limited.

<u>Road-Rail Power Shovel</u>

It is a machine, smaller than a Multiple Tie Tamper in size, capable of running both on roads and tracks and used to tamp track ballast successively. Before tamping ballast, lift the track panel with jacks, as it does not have a lifting function. It does not have the alignment correcting function, either. It is highly mobile, however, in that it can enter and exit from a track anywhere as far as the work site is plain. This machine can also be used for track ballast excavation/adjustment, sleeper replacement and other categories of track maintenance work when fixed with an attachment dedicated to it.



Source: matsui-kidou Website

Figure 9.33: Road-Rail Power Shovel (with 8-Tool Tie Tamper Attachment)

Bucket type

16-Tool Tie Tamper

Source: matsui-kidou Website

Figure 9.34: Road-Rail Power Shovel (Exchanging Attachment)

<u>Manual Operation</u>

This process involves raking in track ballast under the sleepers manually with hand tie tampers. As this operation necessitates carrying-in/out of hand tampers and jacks to lift track panels, it is not suitable for long-range track correcting work, but is useful for track spot reworking operations.

(6) Track Stamping

There are two methods of track stamping. One is to stamp tracks by stamping trains, and the other is by track stabilizing cars.

Stamping Trains (Test-Run Trains)

As track ballast sometimes loosens during a track correcting work, track ballast may sink to a large extent and cause track distortion when a revenue service train runs on it the next day. To prevent this track settlement beforehand, run test trains to stamp the ballast after correcting the overall-rail-level, cross level, track gauge and alignment on the newly constructed track. As the track sinks to a large extent at the first test run, tamp it for correction. After that, repeat a stamping test run and track correction. As the required frequency of tamping is largely dependent on the track bed conditions, determine the number of required iterations by observing the changes in the settlement depth at stamping test runs.

Track Ballast Stabilizing Cars

It is useful to deploy track ballast stabilizing cars in place of trains to stamp the track. After a tamping operation, track stabilizing cars transmit vibration to the ballast through rails and sleepers, expediting the initial settlement of the ballast and stabilizing track conditions to produce the results summarized below:

Facilitates start of normal train operation:
- Recovery of lateral ballast resistance force
  - → Elimination of low-speed operation
  - → Cutting the operation time

Extension of maintenance period:
- Expediting of initial track settlement
  - → Suppression of the progress of track irregularities

(7) Low-Speed Train Operation

After completing the series of heavy-rail introducing works, review whether low-speed train operation is necessary, and if required at what speed, in parallel with track irregularity correcting work while observing the progress of the track stamping operations.

Judge the progress of the track stamping operations based on the degree of track settlement at train entry. Carefully watch the sections before and after bridges or culverts, as they are particularly prone to settlement.

9.8.6 Track Materials

(1) Role of Track Materials

Considering the track maintenance work and economic efficiency, the Study Team adopted ballasted tracks (track bed tracks) composed of rails, sleepers, track beds, and other components. The Study Team explains the concept to determine the specifications based on the role of each component.

Rail

1) Role

Rails provide a safe and smooth running surface for rolling stock and shall have functions to support directly and distribute large axle/wheel loads, thereby facilitating reduced maintenance requirements and control of tracks. The section and profile of rails shall:

(i) Withstand external train loads and longitudinal loads caused by temperature changes without yielding large-degree deformation,
(ii) Not change much due to wear in service for long years,

(iii) Ensure smooth running for rolling stock, and
(iv) Have a sufficient level of durability.

In other words, it is important to discuss track structures that minimize the dynamic force caused by running trains and ensure efficient track maintenance work. The introduction of heavy track panels is helpful to raise the rigidity of tracks, as it is possible to improve the resistance of tracks against displacement due to train loads.

2) Length

Dynamic loads work at rail joints, requiring significant manpower for track maintenance. Therefore, it is desirable to minimize rail joints in number as far as possible. On the other hand, however, long rails necessitate control of rail axial force against temperature changes and affect the easiness of rail transport and workability in replacement. Despite that the introduction of long rails is helpful, rails of standard length are usually used in consideration of the track maintenance structure, where the standard length is determined to reflect environmental conditions.

<u>Rail Fastener</u>

1) Role

The roles of rail fasteners are:

(i) Fasten the left- and right-side rails to sleepers, thereby correctly maintaining the track gauge and resist rail creeping, and
(ii) Withstand the load and vibration on tracks in lateral directions when a train runs and transmits the force/vibration to substructures such as sleepers, track beds, and subgrades.

2) Fastening Structure and Materials

The selection of fastening structure comes from the viewpoint of ensuring the easiness of maintenance and satisfying the function of rail fasteners. In concrete terms, bolts are not used for rail fastening, with attention paid to the easiness of judgment of the rail pressing conditions by a component member (adoption of wire springs). Furthermore, prevention of vandalism/pilfering, a concern in Tanzania, is an object of consideration. Figure 9.35 illustrates a rail fastener designed with a vandalism-free profile. In this rail fastener, a projection at the tip of wire spring is hooked at a point inside the shoulder, which cannot be unhooked easily with a crowbar. Instead, a special tool is used to install or uninstall the fastener.

Source: PANDOROL's website

Figure 9.35: Rail Fastener

<u>Sleepers</u>

1) Role

Sleepers play a role in fixing rails, correctly maintaining the track gauge, and widely distributing the train load through the rails and onto the track bed.

2) Sleeper Types

Figure 9.36 illustrates iron sleepers. They have a hollow space under the main frame, allowing ease of transport thanks to their small volume when piled up on top of each other. They also feature a thickness smaller than that of PC sleepers that easily ensures a sufficient track bed thickness, are more lightweight than PC sleepers, law-shaped frame ends with a great withstanding force into lateral directions, and have the possibility of recycling after use. However, they have demerits in their workability and maintainability, in that the sleeper ends bent downward like a claw, precluding the ability to easily install them and insert ballast using a compacting operation. They are now widely used in TRL for the reason that they can reduce the thickness of track beds compared to other sleepers. From the viewpoint of track maintainability, it is required to discuss the possibility of PC sleepers introduced below.

Source: Website of Nippon Steel & Sumikin Texeng and Kitakyushu Innovation Gallery

Figure 9.36: Iron Sleepers

PC sleepers feature the heavyweight, stability, significant buckling resistance of track panels, the low-speed progress of track irregularities, and savings in maintenance cost. However, because of these features, they are harder to transport and require larger track bed thicknesses when compared with iron sleepers.

3) Standards for Use

The points for the selection of sleepers are maintainability responding to the degree of creeping and the lateral force in steep gradient sections. The number of sleepers depends on the categories of sleepers and rail fasteners, curve radii in the installation object section, and train running conditions.

<u>Track Bed</u>

1) Ballast

The places of production and transport conditions are essential in the selection of ballast. In manufacturing ballast, efforts shall be made in quality control to make element stones square and sharp to increase the inner friction of ballast when used on tracks. To manufacture and transport massive ballast stones, it in indispensable to construct ballast manufacturing plants and discuss the ballast transporting method.

2) Thickness, Cross-Sectional Profile

It is important to ensure a sufficient track bed thickness in track remodeling work while assuming deterioration of track bed ballast such as consolidation, lateral flow, penetration into subgrades, and grain refining. Also, it is important to design an appropriate sectional profile for the ballast layer for each of different curve radii in curved sections where lateral pressure tends to increase.

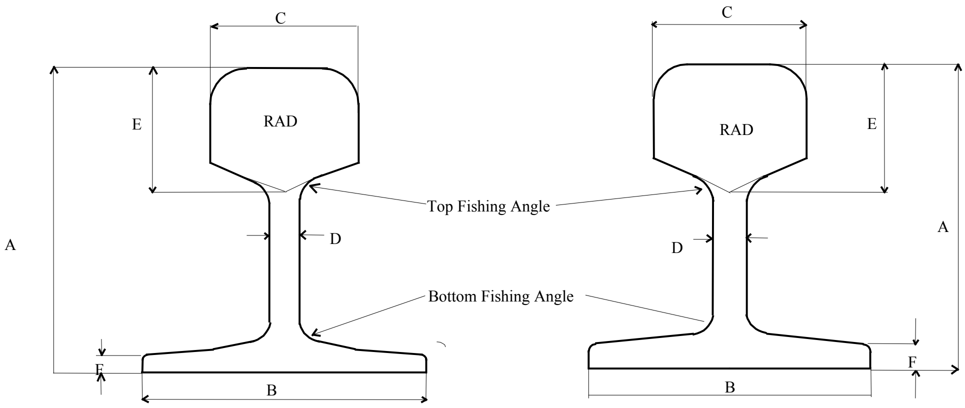
(2) Key Specifications and Standard Drawings of Track Materials

Refer to the following tables and figures for the key specifications and standard drawings of track materials.

Table 9.20: Key Specifications of Tracks

Track Structure			
	Ballasted track		
	Joint	Standard size	
	Distribution of joints	Supported joint	
	Joint supporting method	Parallel joint	
Track material			
	Rail	Rail type	80 lb/yd
		Length of rail	Standard size 24.0 m or over
		Rail steel	Ordinary rail
	Rail Fastening	Composition	Double elastic fastening
		Fastening spring	Wire spring, spring Crip
		Fastening method	No-screw fastening
	Sleeper	Sleeper type	Steel Sleeper
		Sleeper interval	1477 Units/km, (33 Units/24 m)
			A=229 mm, B=610 mm, C=686 mm, D=748 mm
	Ballast	Ballast	Crushed Stone
		Thickness of Ballast	250 mm
		Width of Ballast shoulder	250 mm
		Volume of Ballast	885.0 m^3/km

Source: JICA Study Team

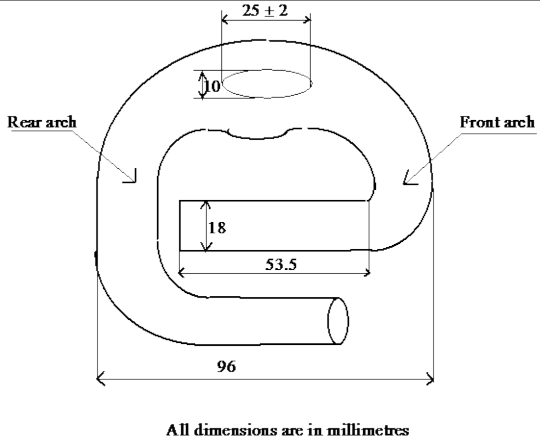


Source: TRC, Civil Engineering Manual, 1998

Figure 9.37: Sectional Drawing of Rail

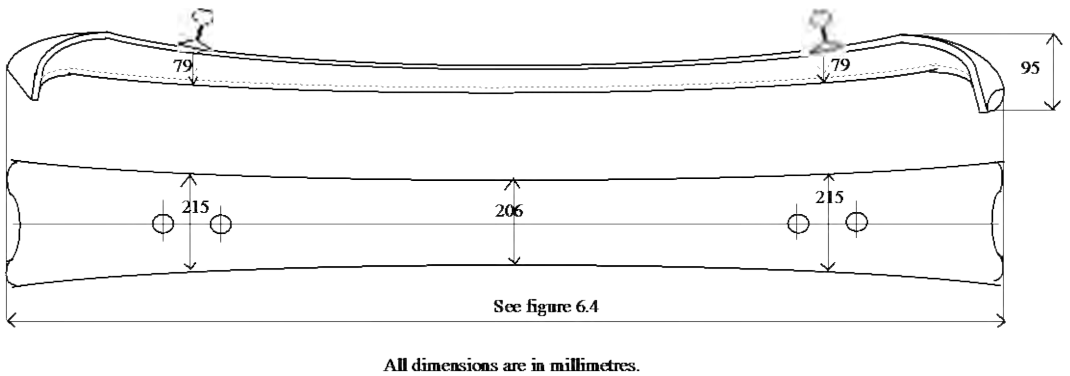
Table 9.21: Dimensions of Rail

Rail Section	Type	Dimensions in millimeters						Fishing Angle		Radius of the Table (mm)
		A	B	C	D	E	F	Top	Bottom	
80A.BS	1	133.4	117.5	63.5	13.1	42.5	25.0	1:2.75	1:2.75	304.8
80R.BS	2	133.4	122.0	63.5	13.5	40.9	19.5	1:3	1:6	229.0



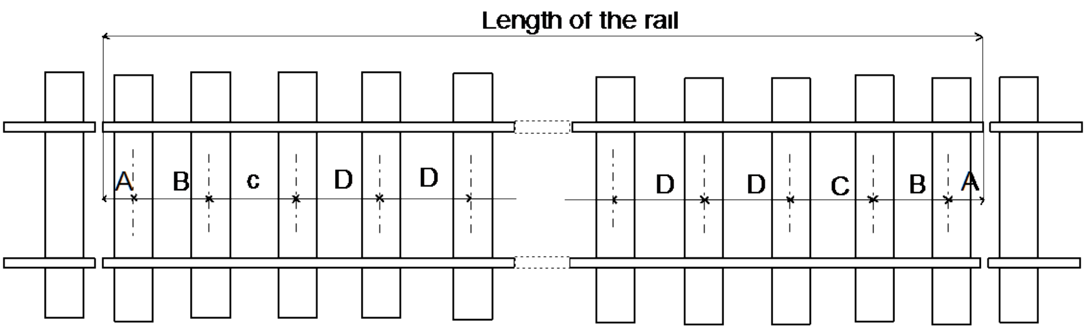
Source: TRC, Civil Engineering Manual, 1998

Figure 9.38: Example of Rail Fastener (e-Crip)



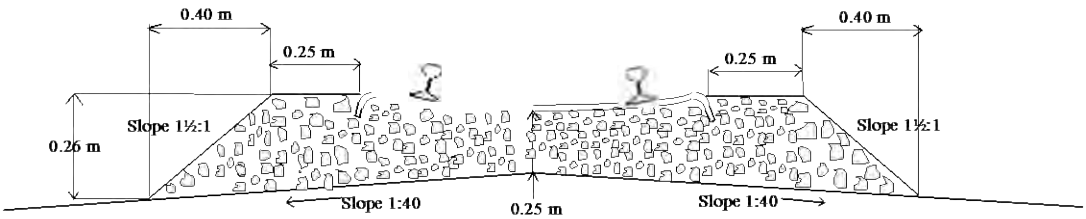
Source: TRC, Civil Engineering Manual, 1998

Figure 9.39: Example of Steel Sleeper



Source: TRC, Civil Engineering Manual, 1998

Figure 9.40: Sleeper Interval



Source: TRC, Civil Engineering Manual, 1998

Figure 9.41: Ballast Layer Sectional Profile

Table 9.22: Volume of Ballast

STANDARD CUSHION					
Type of Ballast	Type of Sleeper	Group	Rail Section	Cubic m/km	
				Jointed Track	SWR & LWR Track
Brocken Stone	Steel Sleeper	-	80 RBS 80 OBS	885.0	941,8

Source: TRC, Civil Engineering Manual, 1998

9.8.7 Conclusion

(1) Train Operation

The current line capacity of the Dar es Salaam–Isaka section is 11 trains/day, as restricted by the bottlenecked Gulwe–Kikombo section.

If the stations in that bottlenecked section reopen as signal stations irrespective of whether there are flood protection measures, the Dar es Salaam–Pugu section becomes the new bottleneck section, but there is nevertheless an overall increase in line capacity of the Dar es Salaam–Isaka section to 17 trains/day.

When 16 trains/day (6 freight trains and 2 passenger trains in each direction) run on the section, the freight transportation capacity increases to 1.3 million tons per year. If average train speed can increase to 50 km/h over the whole section in the future, the freight capacity reaches approximately 2 million tons per year. (see Table 9.3).

(2) Safety Measure

For the railway undertaking, the purpose of flood protection measures is ultimately to provide customers with safe transport opportunities. In this context, railway operators should sense dangers and stop trains at any time. Refer to the descriptions in manuals for concrete methods of how to do so. What is essential for those concerned is to abide by rules with utmost resolve. To attain this end, it is a key to repeat training and exercise.