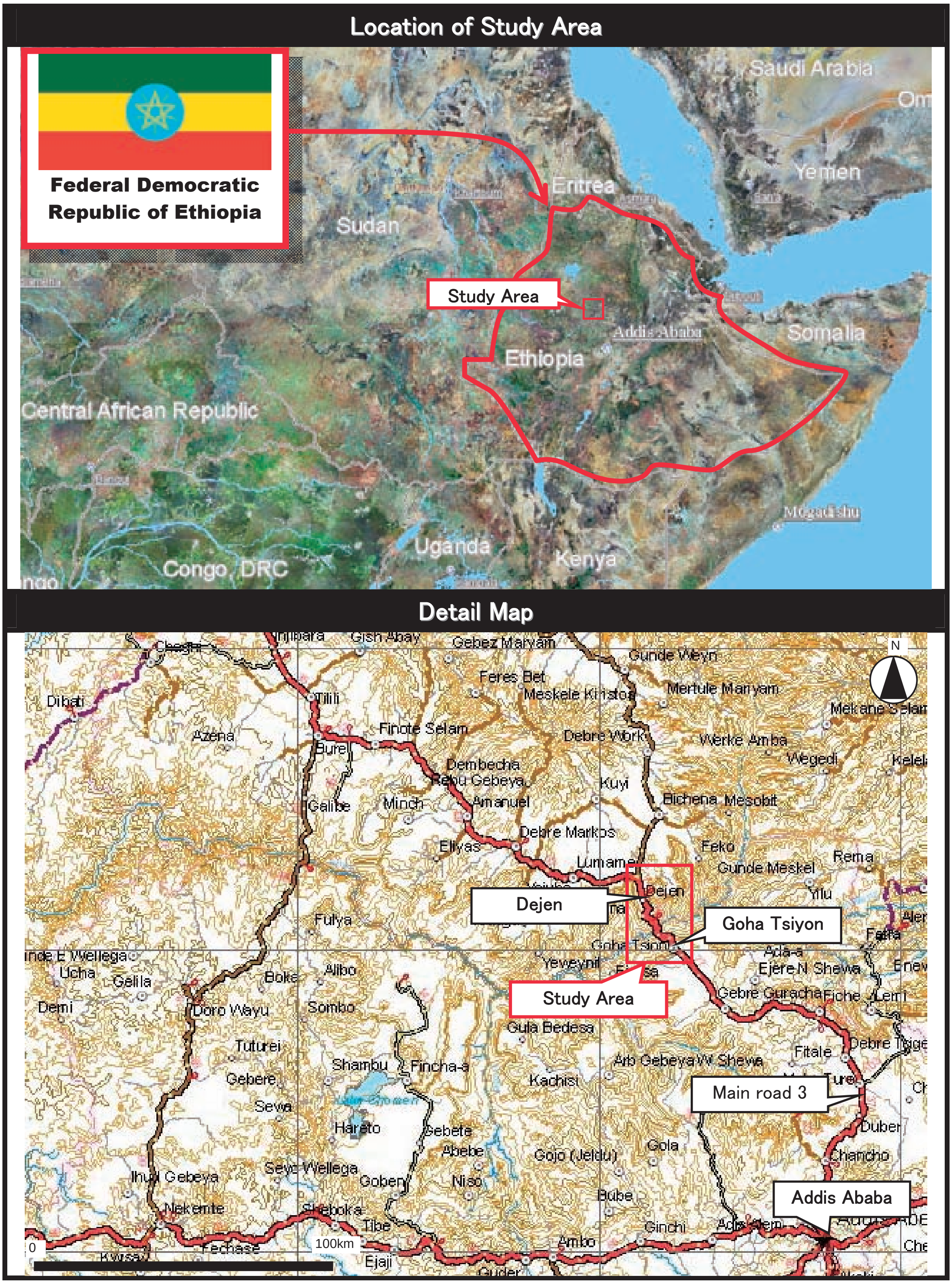
JAPAN INTERNATIONAL COOPERATION AGENCY
GEOLOGICAL SURVEY OF ETHIOPIA

THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDERS IN THE ABAY RIVER GORGE

FINAL REPORT
SUMMARY

January 2012

KOKUSAI KOGYO CO., LTD.
JAPAN CONSERVATION ENGINEERS CO., LTD.



Location Map

Rate of Currency Translation

1 USD	= 17.29 ETB
	= 77.73 JPY
1 ETB	= 0.0578 USD
	= 4.4955 JPY

ETB: Ethiopia Birr

As of December 1st, 2011

Executive Summary

The report describes the results of Project on Developing Countermeasure against Landslides in Abay River Gorge. The project formulated for the technical transfer of landslide mitigation techniques which focused on the investigation, monitoring, analysis and the formulation of comprehensive countermeasures. The project period is from April 2010 to January 2012.

At the initial phase of the project, the drilling work could not be implemented in the proper time period (before rainy season) due to some misunderstanding of the protocol of JICA project. However, through several discussions with stakeholders, major concern was resolved. Since than, the project were smoothly implemented and well managed by JICA Study team and their counter part staff – members of Geo-hazards Investigation Business Process of Ethiopian Geological Survey.

Natural Conditions

The project site of Abay Gorge has the elevation deference of 1,060m within the two major city of Goha Tsiyon and Dejen (distance of 40.45km). There the national road 3 passes this gorge with tremendous winding road along the cliffs and steep slopes. Four major critical landslides observed within the project site namely, L/S00, L/S05, L/S27 and L/S28. The study and the technical transfer have been focused on this four landslide area.

The rainy season of the site is from June to September, with July and August accounting for about 50% of annual precipitation. Annual average rainfall is 1,394mm/year (49 years at Dejen) and 1,195 mm/year (34 years at Filiklik village)

The geology of the site is characterized by the stratified sedimentary rocks capped by the basaltic plateau.

Landslide Survey

The survey entails hydrological, topographic, geomorphologic, geological, drilling survey and geophysical exploration. Those results are compiled into Final Report with GIS and database.

The techniques and measurements used especially for landslide are; new installation of rain gauge (at Abay bridge and Gabrielle church) for detailed observation rainfall to identify the relationship of rainfall and landslide movement. Other four devices installed to detect the landslide movements which are; inclinometer (for detection of slip surface), extensometer (for detection of landslide surface movement), borehole extensometer (for detection of vertical movement of landslide) and water level gauge (accurate groundwater level meter).

The gorge is mainly made by thick Mesozoic sedimentary rocks and overlain by series of basaltic lava flows and pyroclastics. The detailed surveys on the topographic, geological, geophysical and drilling revealed that the most common materials of landslide areas are colluvial deposit, pyroclastc rock, basalt, limestone, silt and shale.

In addition, rock failure and debris flow survey is also conducted at the site. The result of the survey was compiled into the table showing the risks of occurrence by the site.

Landslide Analysis and Interpretation

In combination with the hydrological, topographic and geological analysis, the hazard map was prepared at the project site. The area under the risk of the hazard was indicated on the map in the deferent categories with deferent colors. The assessment of the risk has been made to the general risk and the risk influence to the road. Assessment was conducted using the score of seriousness on A: Causes (topographical and geological conditions), B: History of landslide and C: Effectiveness of current countermeasure. The hazard map and the risk category table has been prepared. Altogether 22 landslides (or slopes) categorized as high risk to the road, and which four landslides was considered to be most serious case. Interpretation of these landslides is as follows;

1. L/S00 (ST.0+200 – 1+100)

Three deferent slip surfaces were predicted by the geological survey, drilling core log and monitoring result. The biggest one is rock slide composed by colluvial deposits. Second landslide is part of former landslide and this is also composed chiefly by colluvial deposits. Most active landslide block is at the part of embankment. Main triggering factor of this landslide is water level rising. The largest surface movement during the rainy season was 42.4mm. Depth of slip surface (at the drilling point) is 16.2m depth (at B00-12) and 10.5m (at B00-22). Water level is between the depths of 20 to 24m.

2. L/S05 (ST.4+800 to 5+600)

Two possible landslide mass can be observed. The one is upper side of the road which are composed of colluvial deposit provided from past landslide residue. The drilling cannot be made to this landslide due to the steep and rough surface, the limestone was initially considered to consist as a part of slip surface. The other is at the lower side of the road and also composed of colluvial deposit. Active portion is the lower one, the slide occur due to the accumulation of several subsurface water way. The largest surface movement during the rainy season was 57.6mm. Depth of slip surface (at the drilling point) is between 7.5 to 17.02m depth (at 4 drilling result). Water level is between the depths of 22 to 32m.

3. L/S27-28 (ST.27+200 to 28+800)

This is the largest landslide block in the area with at least more than 20 sub blocks. Initial landslide occurs at the weathered portion and followed by the debris like material covers the entire block. Active landslide bodies are composed of basaltic and/or limy soil and gravel as colluvial deposit. There seems to be several shallow and deep slip planes with the movement of smaller blocks triggers the instability of entire landslide block. The largest surface movement during the rainy season was 294.9mm. Depth of slip surface (at the drilling point) is between 8.9 to 24.5m depth (at 7 drilling result). Water level is between the depths of 15 to 25m.

The relation between the movement of the landslide and the rainfall is obvious. There are two factors of rainfall to be considered. The one is intensity and the other is accumulation. From the monitoring result, extensometer moves gradually with the rainfall accumulation. But the intensity of the rainfall seems more serious cause for the triggering the movement of the landslide. For example, at L/S27-28, a day maximum movement is 7.7mm recorded on 17/Aug/2011 and this trend extended until 8/Sep/2011 (total movement of 136mm). During this period, intensive rainfall has been recorded including the maximum daily rainfall of 244.5mm.

The stability analysis using the Jambu method was demonstrated. In case of Japan, for the economical and systematic calculation of the countermeasure, the method of calculation is standardized by the government agency. The technical now how of the stability analysis has been transferred by utilizing back calculation of the important parameters of c and φ. The condition of safety (safety factor) was set as 0.98 in accordance with the Japanese standard.

Rock fall and debris flow analysis was also conducted, and the interpretation and measures are indicated using simulation software.

Landslide Countermeasure

There are major two deferent measures commonly used. One is control works and the other is restraint works. The first one is mainly to reduce the triggering factor or causes (such as lowering groundwater table, surface water drainage) and the other is to against the sliding force by using piles, anchors etc. In Ethiopia, the application of control works should come first to prevent the landslide by controlling groundwater.

The first method is drainage of water from the landslide mass using horizontal drilling technique. If the groundwater can be reduced into certain level, the pore pressure of the slip surface will be reduced which lead to prevent the movement of the landslide. Second measure will be the surface drainage system and surface treatment to prevent the rainfall penetrates into the landslide mass. This method also contributes the accumulation of rainfall into the landslide mass, and also reduces the pore pressure.

Consideration of the countermeasure is often setup by the practices of long term try and error. Therefore, the first application in this country shall be follow this step towards the setup of system for the design realistic measures. The drawings of the countermeasure (draft) have been shown in this report.

Technical Transfer

The project is aimed to upgrade the skills of counterpart on landslide protection measure. The step by step approach was applied for the technical transfer. For the phase 1, the on site job training has been applied. In house joint analysis has been done in phase 2 followed by their own demonstration by the counterpart staff.

On demand structure of JICA expert team was requested for the support of above mentioned procedure. During the project period, 3 in house technical seminars, 11 workshops and more than 20 on site technical transfer has been conducted. As the most technology on landslide was mainly transferred on the on site or on demand bases, seminars and workshops are conducted as a mile stone of entire project.

Further more, from 18/June/2011 to 8/July2011, four counterpart members visit Japan to ensure the technical transfer has been successfully operated during phase 1 and 2 of the project and experience and learn the techniques at sites and research institutes of several organizations.

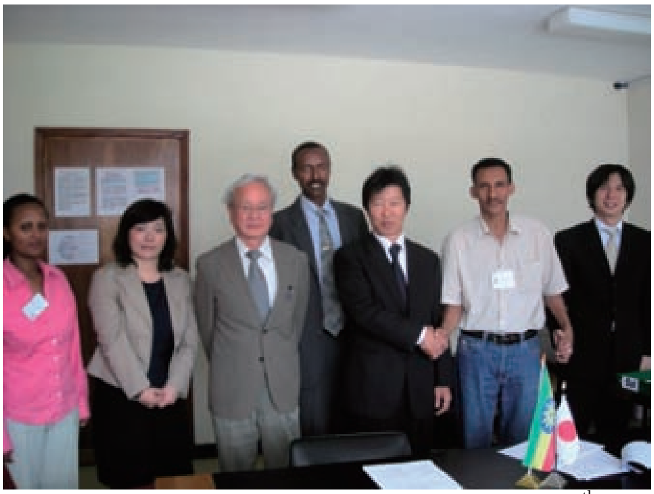
For ensure the progress of their achievement, PDM has been applied to ensure the outcome of the project. The result of review of the output and activities of PDM, the project operation has been implemented successfully.

Capacity assessment is also conducted to review the progress of the counterpart's knowledge on the landslide investigation and analysis. The result indicates the scores on important indicators (project implementation, geomorphological survey, geological survey, landslide monitoring and stability analysis) were upgraded (the skills of counterparts on landslide survey, analysis were advanced).

Total of 5 Joint Coordination Committee (JCC) was held during the project period. The committee has well functioned to understand the policies of JICA and resolve the project problems (such as drilling, budget preparation, etc.) through the discussion among all stakeholders. It should be also mentioned that the involvement of Ethiopian Road Authority (ERA) was the center of the success of this project.

The counterpart (GSE) started the additional drilling by themselves to ensure their earned skills from November 2011, and their continuous challenge for the landslide survey with high motivation makes promising on their sustainability and progress of the landslide investigation/analysis for the future development.

Photos of the Project (1)



After the sign for commencement of the Project, 14th Apr. 2010

Second Joint Coordinating Committee Meeting, 1st Jul. 2010

Seismic exploration at the landslide site

Digging trench for extensometer

Installed extensometer at the landslide

Drilling work at ST.0.800

Photos of the Project (2)

Downloading the rain fall data

Technical transfer on site (Measurement method of cracks), 25th Jan. 2011

Technical transfer on site (Mapping of the location of cracks), 27th Jan. 2011

Technical transfer on site (Data collection of monitoring devices), 18th Feb. 2011

Workshop of the landslide, debris flow and rock fall analysis (Lecture of landslide stability analysis), 25th Feb. 2011

Workshop of the landslide, debris flow and rock fall analysis (Drawing of landslide cross sections), 25th Feb. 2011

Photos of the Project (3)

Workshop of GIS utilization for landslide
18th Mar. 2011

Technical transfer on drilling.
4th Jun. 2011

Technical transfer on drilling. Installation of casing pipes for inclinometer, 12th Jul. 2011

Monitoring data collection of borehole extensometer, 21st Jun. 2011

Monitoring data collection of extensometer
21st Jun. 2011

Technical transfer for connecting casing pipe for inclinometer, 13th Jul. 2011

Photos of the Project (4)

Technical transfer for connecting casing pipe for inclinometer, 13th Jul. 2011

Installation of groundwater level meter, 22nd Jun. 2011

Slip surface on the core at B05-13

Workshop for landslide, debris flow and rock fall analysis, 7th Oct. 2011

Workshop of monitoring and early-warning system, 11th -16th Oct. 2011

Workshop for field survey and integrated analysis, 28th -30th Oct. 2011

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Abbreviations

C/P	Counterpart
CA	Capacity Assessment
DED	District Engineer Division
DEM	Digital Elevation Model
DRMC	District Road Maintenance Contractor
EMA	Ethiopian Mapping Agency
ERA	Ethiopian Roads Authority
GIS	Geographical Information System
GOE	Government of the Federal Democratic Republic of Ethiopia
GOJ	Government of Japan
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
IC/R	Inception Report
ITR(IT/R)	Interim Report
JCC	Joint Coordination Committee
JICA	Japanese International Cooperation Agency
L/S	Landslide
M/M	Minutes of Meeting
MM	Ministry of Mines
MME	Ministry of Mines and Energy
MoFED	Ministry of Finance and Economic Development
NGO	Non Governmental Organizations
NMSA	The Ethiopia National Meteorological Services Agency
PCM	Project Cycle Management
PDM	Project Design Matrix
PR (P/R)	Progress Report
S/C	Steering Committee
S/W	Scope of Work
The Project	Developing Countermeasures against Landslides in the Abay River Gorge
The Study Team	Japanese Study Team organized by JICA
WWIS	World Weather Information Service

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Chapter 1

Introduction

1 Introduction

1.1 General

This Report covers the results for the Project on Developing Countermeasures against Landslides in the Abay River Gorge (hereinafter the Project) according to the Minutes of Meeting (hereinafter M/M) agreed upon between the Geological Survey of Ethiopia (hereinafter GSE), of the Federal Democratic Republic of Ethiopia (hereinafter Ethiopia) and the Japan International Cooperation Agency (hereinafter JICA) witnessed by the Ministry of Finance and Economic Development (hereinafter MoFED) and Ethiopian Roads Authority (hereinafter ERA) of Ethiopia.

JICA organized a Japanese Study Team (hereinafter the Study Team) consisting of 18 experts of the major fields relevant to the landslide investigation and analysis. The Project commenced in April 2010 and was completed at the end of December 2011. Phase 1 of the Project was executed from April to November 2010. Phase 2 was from December 2010 to April 2011. Phase 3 was from May to December 2011. The Project is implemented during this term based on cooperation with the implementation and counterpart (hereinafter C/P) organizations, mostly from GSE.

1.2 Background of the Project

Main road 3, a major arterial road in the Federal Demographic Republic of Ethiopia (hereinafter, Ethiopia), connects the capital Addis Ababa with Sudan, is part of the Trans-African Highway Network, and is vital to its economy and the livelihoods of its citizens. The stretch of main road 3 that passes through the Abay Gorge steeply climbs nearly 1,500 meters over 40 kilometers. It is plagued by landslides in the rainy season from June to September. Some of these are up to two kilometers wide, putting into jeopardy this vital link. To fundamentally solve this problem it is necessary to implement appropriate countermeasures after clarifying the mechanisms that trigger landslides in this stretch of road.

Despite landslides occurring throughout Ethiopia, until now there has been no organization responsible for surveying landslides. In April 2009, the Geo-hazards Investigation Division, specialized in investigating geo-hazard processes, was established in the Geological Survey of Ethiopia, of the Ministry of Mines and Energy (hereinafter, MME). In light of this background, MME made a request to the Government of Japan for the technical and personnel development of this division so that it can undertake geological surveying, mapping, investigating landslide causes and mechanisms, and planning landslide countermeasures.

In response, discussions—based on the detailed planning survey implemented by the Japan International Cooperation Agency in December 2009—were concluded on 12 December, 2009; wherein the Scope of Work (S/W) and Minutes of Meeting (M/M) were signed. This Project is implemented according to this Scope of Work. Furthermore, the countermeasures, based on the outcomes of this Project, is implemented by the organization responsible for maintaining Ethiopia's roads, the Ethiopian Roads Authority (ERA).

1.3 Objectives of the Project

1.3.1 Superior goal

To figure out the mechanisms triggering landslides in the Abay Gorge along main road 3; and to mitigate human suffering and economic losses by implementing appropriate countermeasures.

1.3.2 Project purpose

- To clarify landslide mechanisms in the Abay Gorge
- To assist GSE to acquire skills to analyze and investigate landslides

1.3.3 Project outputs

The implementation of this Project is expected to achieve the following outputs:

- The project implementing system is established.
- The situation of landslides is identified.
- The geomorphological and geological condition of landslides is identified.
- The landslide characteristics due to seasonal changes are identified.
- The landslide mechanisms are figured out.
- The survey and analysis of disasters other than landslides are conducted.
- The counterpart agencies become familiar with landslide survey and analysis work.

1.4 Scope of the Project

1.4.1 Counterpart

Counterpart organization

• Geological Survey of Ethiopia (GSE), Ministry of Mines

Relevant organizations

• Ethiopian Roads Authority (ERA)

• Ethiopian Mapping Agency (EMA) and others

Beneficiary

• Direct beneficiary: ERA

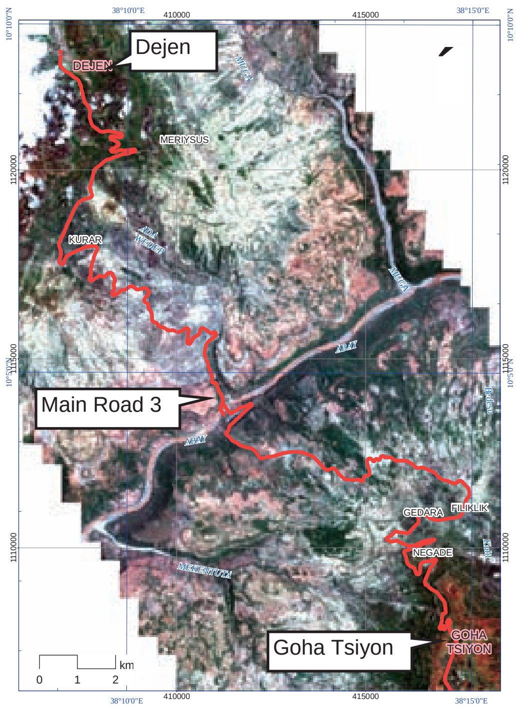

Figure 1.4.1 Project Area Map

1.4.2 Project area

1. L/S00 area
2. L/S05 area
3. L/S22 area
4. L/S27 area
5. L/S28 area

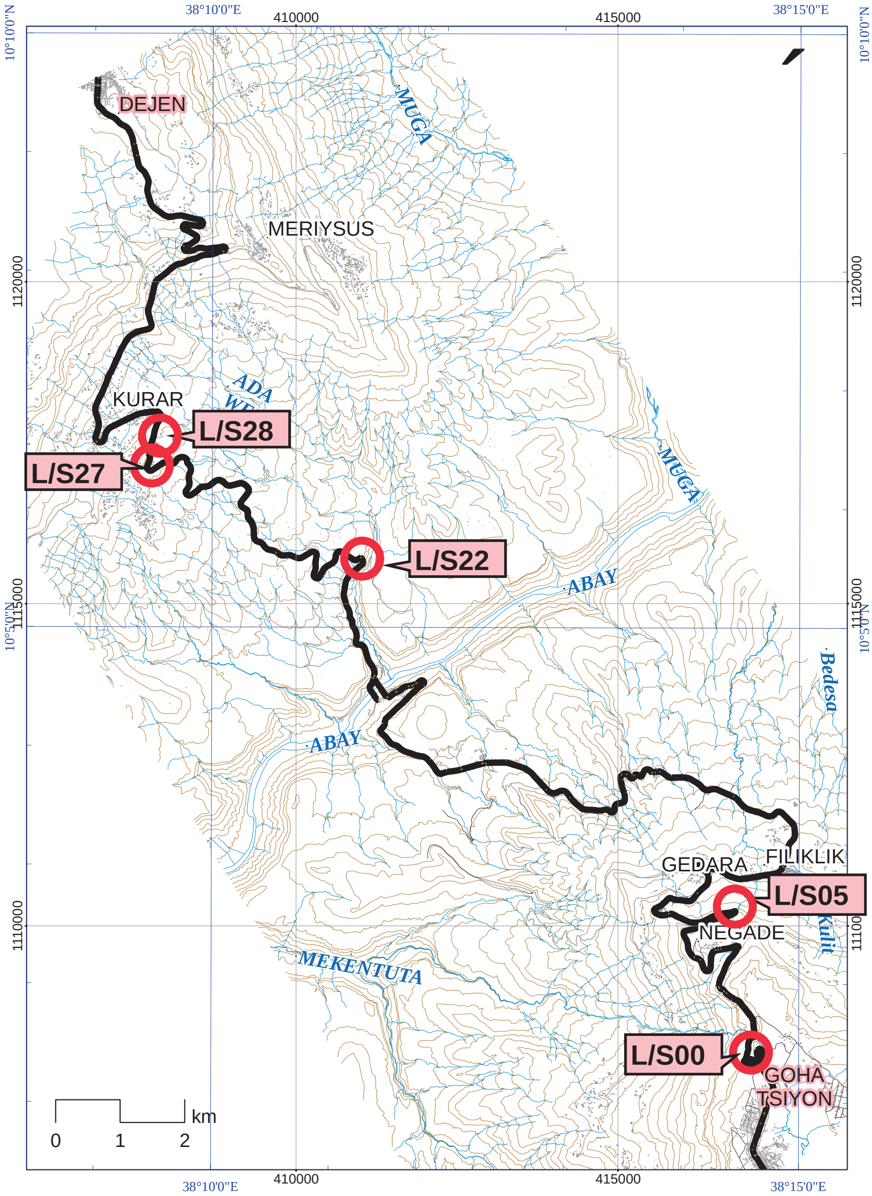

Figure 1.4.2 Location map of the landslide area

1.5 Work plan and schedule

This Project was implemented according to the Scope of Work and Minutes of Meeting agreed upon in Addis Ababa on December 16, 2009; and a method of implementation will be formulated upon fully understanding and considering the content of these documents.

The general work flow of the implementation of the Project for effective and efficient technical transfer, fully taking into account the surveys and analyses for landslides, is summarized in the following Figure 1.5.1. A detailed implementation schedule flowchart based on this is shown in Figure 1.5.2.

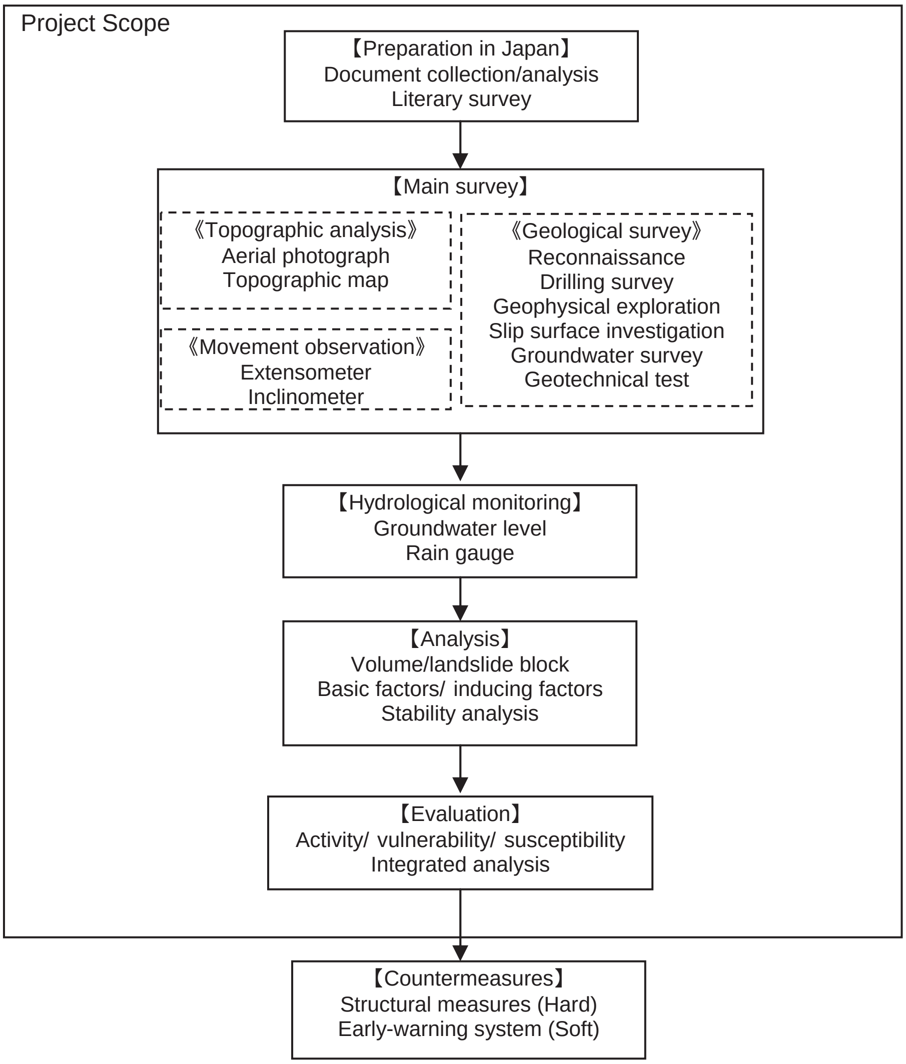

Figure 1.5.1 Flowchart summarizing survey/analysis for landslides

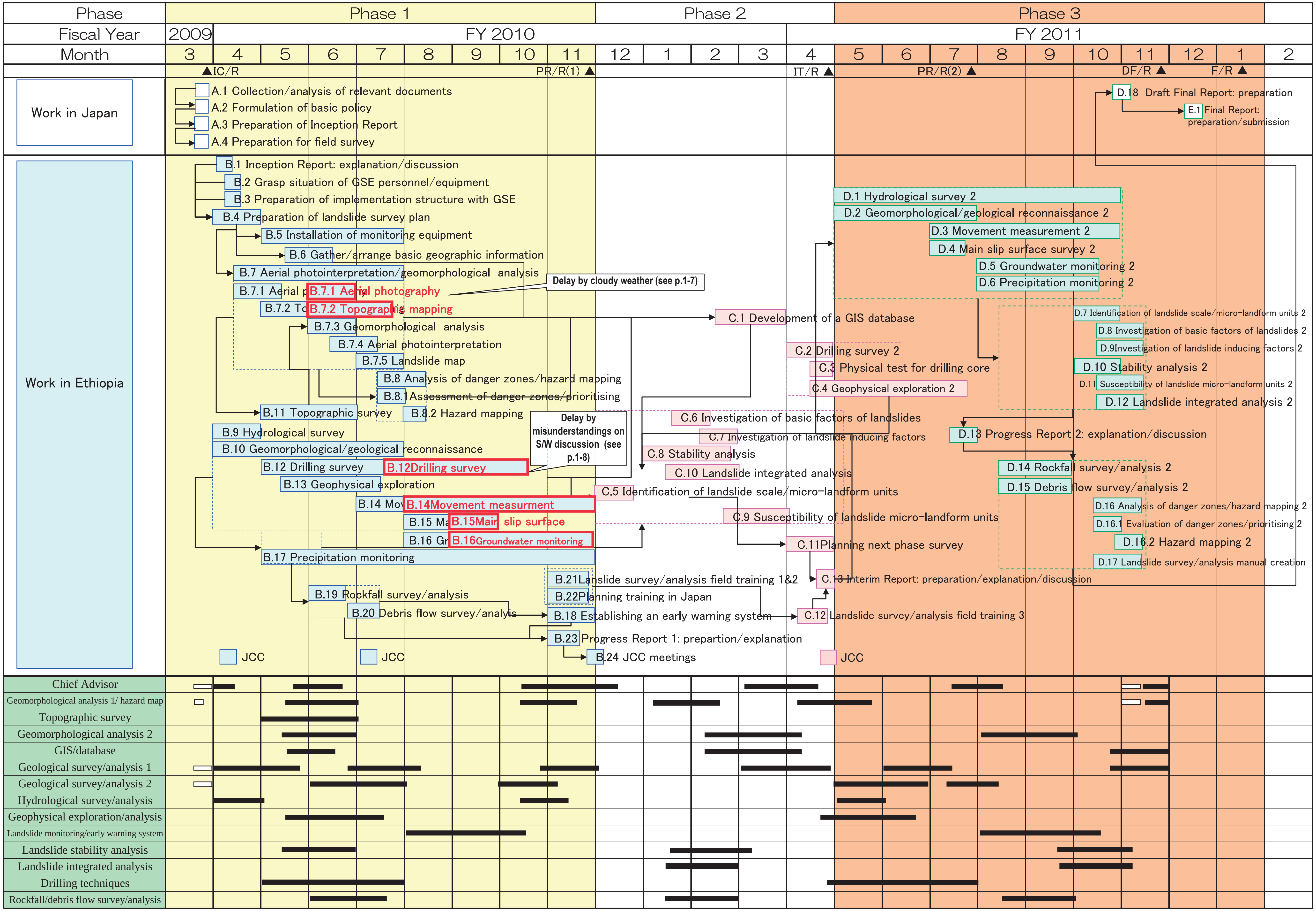

Figure 1.5.2 Detailed implementation schedule flowchart

1.5.1 List of JICA experts and counterparts

The names of the Study Team members and counterparts are listed below. The table indicates the role of each member and their field of expertise.

Table 1.5.1 List of JICA experts and counterparts

No	JICA Experts	Field of Expertise	Counterpart (GSE)	Position
1	Kensuke ICHIKAWA	Team leader (Project Management)	Dr. Getnet Mewa	Senior
2	Satoru TSUKAMOTO	Geomorphological analysis1 /hazard map	Leta Alemayehu	Senior
3	Shozo SHIMODA	Topographic survey	Haile Selassie G/Selassie	Senior
4	Mitsuya ENOKIDA	Geomorphological analysis 2	Melkamu Tegnge	Junior
5	Yoshimizu GONAI	GIS/Database	Yewubnesh Bekele	Junior
6	Takeshi KUWANO	Geological survey/analysis 1	Solomon Gera	Senior
7	Makito NODA	Geological survey/analysis 2	Zulfa Abdurahman	Senior
8	Shoji TSUCHIYAMA	Landslide Monitoring /Early-Waning system	Tesfaye Shewa	Senior
9	Shigekazu FUJISAWA	Hydrological Analysis	Demis Alamerew	Senior
10	Naohiro ISOGAI	Geophysical exploration /analysis	Tadesse Lema Sisay Alemayehu	Senior Junior
11	Shigekazu FUJISAWA*	Landslide stability analysis	Zulfa Abdurahman	Senior
12	Masao YAMADA	Landslide integrated analysis	Yewbnesh Bekele	Junior
13	Takashi SUZUKI	Drilling Techniques	Bayu Wedajo	Senior
14	Yoji KASAHARA	Rockfall/debris flow survey /analysis	Biruk Abel	Junior
15	Kazuo FURUKATA	Project Coordinator	(Tadesse Lema)	
16	Masami TAKAHATA	Project Coordinator	(Leta Alemayehu)	
17	Yosuke YAMAMOTO	Project Coordinator	(Leta Alemayehu)	

** Mr. Fujisawa is assigned to two roles of Hydrogeological Analysis and Landslide Stability Analysis. Therefore, the total number of experts is 17s.*

1.5.2 Notable Events in the Project

Most of the planned schedule and tasks were executed in a satisfactory manner and the technical transfer was implemented smoothly. However, some activities were delayed due to natural conditions and a lack of mutual understanding on aspects written in the M/M and S/W, which were signed in December 2009. These issues are described as follows;

a. Delay in Topographic Mapping.

b. Delay in Drilling Program

c. Budget Allocation for the Fiscal Year 2012

d. Preparation and Execution of Additional Drilling

1.6 Landslide survey/analysis manual preparation

A manual on landslide surveys and analysis, based on the results of the Project will be made. The basic outline of the manual is given in Table 1.6.1.

Table 1.6.1 Content of the landslide survey/analysis

Subject	Manual content
1.Preliminary survey	Summary and purpose of the preliminary survey. Basic survey methods such as documentation research and geomorphological analysis.
2.Planning	Summary and purpose of the planning. Method of determining facilities to be preserved in the field reconnaissance, and confirming scale and extent of landslides and their movement aspect. Also, methods regarding the type and location of monitoring equipment installation.
3.Survey	Summary and purpose of the surveys. Detailed description of the types, methods and purpose of observation equipment for surveys of topography, geology, slip surface, ground movement, groundwater, and soil property testing.
4.Analysis	Method of handling and analyzing the data acquired in the surveys. And overall analysis techniques for the field survey results.
5.Countermeasures	Method of reflecting analysis results in road countermeasures.
6.O & M	Method of operating and maintaining the observation equipment

Chapter 2

Natural Condition of the Abay Gorge

2 Natural Condition of the Abay Gorge

2.1 Topography

Macro landforms consist of a basaltic lava plateau (Eocene period flood lava), with an elevation of about 2,400 m, and slopes that are dissected by the Abay River. The elevation of the valley bottom at Abay Bridge is 1,060m above mean sea level. The width of the valley is approximately 15 to 20 km at the edge of the lava plateau. The average slope angle from the edge of the lava plateau at the narrowest section is about 9 degrees.

Lateral slopes of Abay Gorge consist of several levels of cliffs, colluvial slopes and denudation slopes. There are seven steps of cliffs observed, and those cliffs are highly resistant to erosion. Three cliffs at the top consist of basalt lava, three cliffs in the middle consist of limestone and shale, and two cliffs at the lower part of the valley consist of sandstone. Many denudation terraces have been formed above the cliffs. Very thin soil layers and some debris washed out from the upper slope have deposited on these denudation terraces. At the foot of the cliffs, gentle slopes with fallen rocks from the cliffs form wide colluvial slopes. Though there are a lot of boulders on the slope surface, the size of the debris becomes smaller as the distance from the slope becomes further. Gentle slopes spread out widely mid-way down the Abay Gorge. These gentle slopes develop on the areas of limestone and shale, which are covered by residual soil and colluvial deposits. Several landslides are apparent at these slopes.

Major tributaries on the slope of Goha Tsiyon side are the Mekentuta River and unnamed river. The Mekentuta River crosses the road at ST.1+150 and flows down in another westerly direction. Several small channels cross the road at Filiklik Village. As the whole slope of this area forms a concave slope, most of the small channels disperse and join the Abay River. The unnamed river flows parallel to the road between ST.17km and ST.18km with steep cliffs of sandstone. The main tributary on the slope of Dejen side is the Ado Wedeb River and its branches. From ST.20km to ST.22km the river flows down parallel to the road with steep cliffs of sandstone. From ST.22km to Dejen, small channels are distributed through the catchment area of Wedeb River and cross the road at several points.

2.2 Climate

2.2.1 Rainfall

Ethiopia lies between latitudes 3°00’ to 15°00’ north, and longitudes 33°00’ to 48°00’ east. It is a landlocked country surrounded by five nations (Somalia, Sudan, Kenya, Eritrea, and Djibouti).

Two thirds of the country is alpine, at altitudes over 1,500 m to 4,000 m, and has very steep mountains. The Ethiopian alpine belt could be classified in Koeppen's climate zones (Figure 2.2.1). In a revised version by Trewartha, alp climate (sign H) was added. The alp climate in a low latitude area has a small annual range of temperature, and although it maintains the characteristics of low land tropical climates, the temperature is generally low. Moreover, it is comparatively cool throughout a year for its latitude. This kind of climate is called "eternal spring."

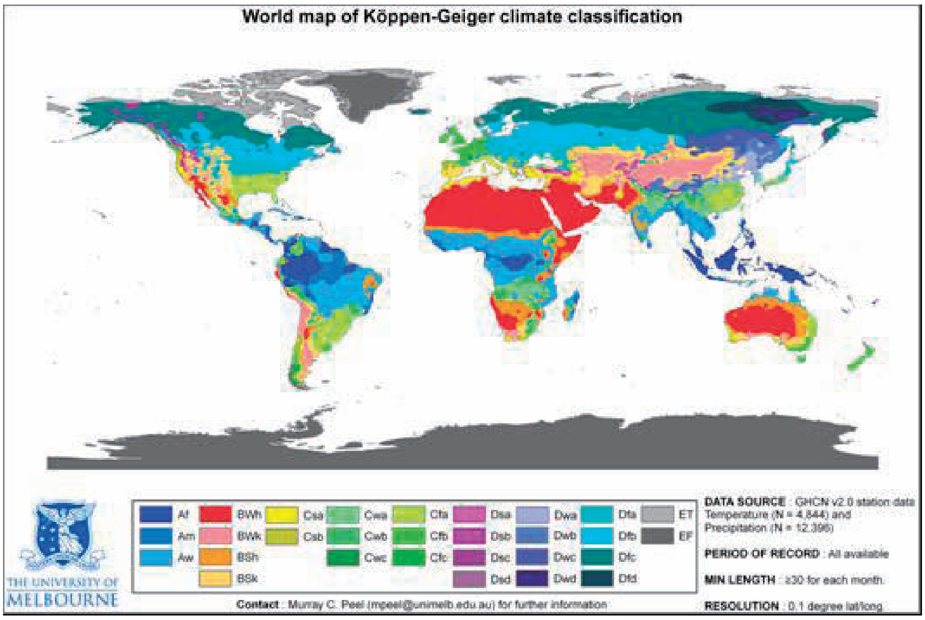

Figure 2.2.1 Köppen-Geiger Climate Classification Map

Abay Gorge, the target area of the Project, is in the upstream of the world's longest river, the Nile, and about 85% of its total volume of water comes from the Blue Nile of Ethiopia. The rainy season in the Abay Gorge is from June to September, with July and August accounting for about 50% of annual precipitation.

Existing rainfall observation records in the Abay Gorge area are 49 years and 34 years for Dejen town and Filiklik village respectively. In addition, the annual average rainfall is 1,394 mm/year and 1,195 mm/year for Dejen and Filiklik respectively (Figure 2.2.2).

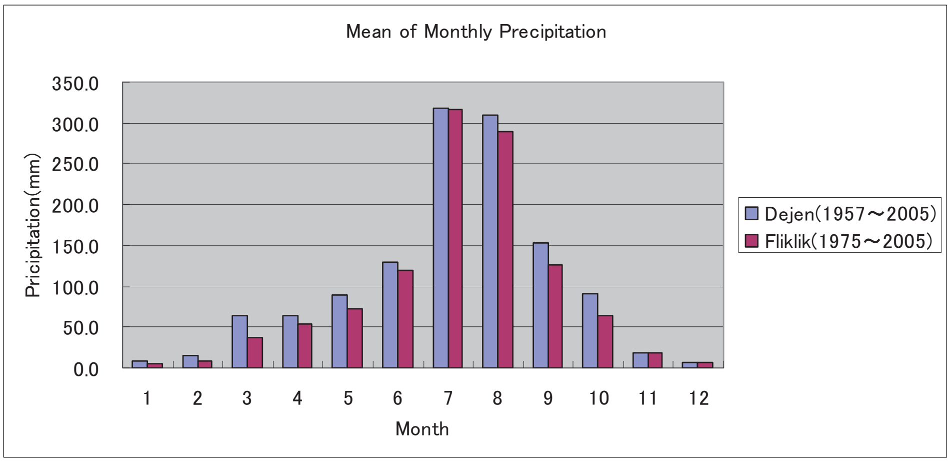

Figure 2.2.2 Mean of Monthly Precipitation

2.2.2 Temperature

According to the data of WWIS (World Weather Information Service), the temperature in Addis Ababa ranges from a minimum of 15℃ and a maximum 25℃ (Figure 2.2.3).

The Abay Gorge has an altitude difference of about 1,000 m from its highlands to lowlands. Given the common calculation of temperature change, 0.6℃ to 0.7℃ per 100m, there will be a difference of 6℃ to 7℃ between high and low lands.

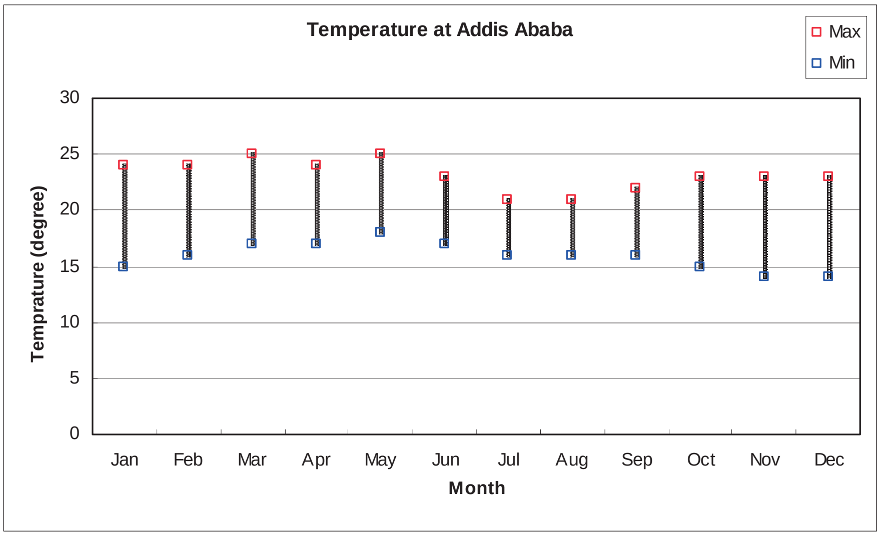

Figure 2.2.3 Annual temperature at variation of the Addis Ababa town

2.3 Geology

The geology of the Abay Gorge area is characterized by stratified sedimentary rocks capped by basaltic plateau. Figure 2.3.1 indicates a general geological map of Ethiopia (Tefera et al., 1996).

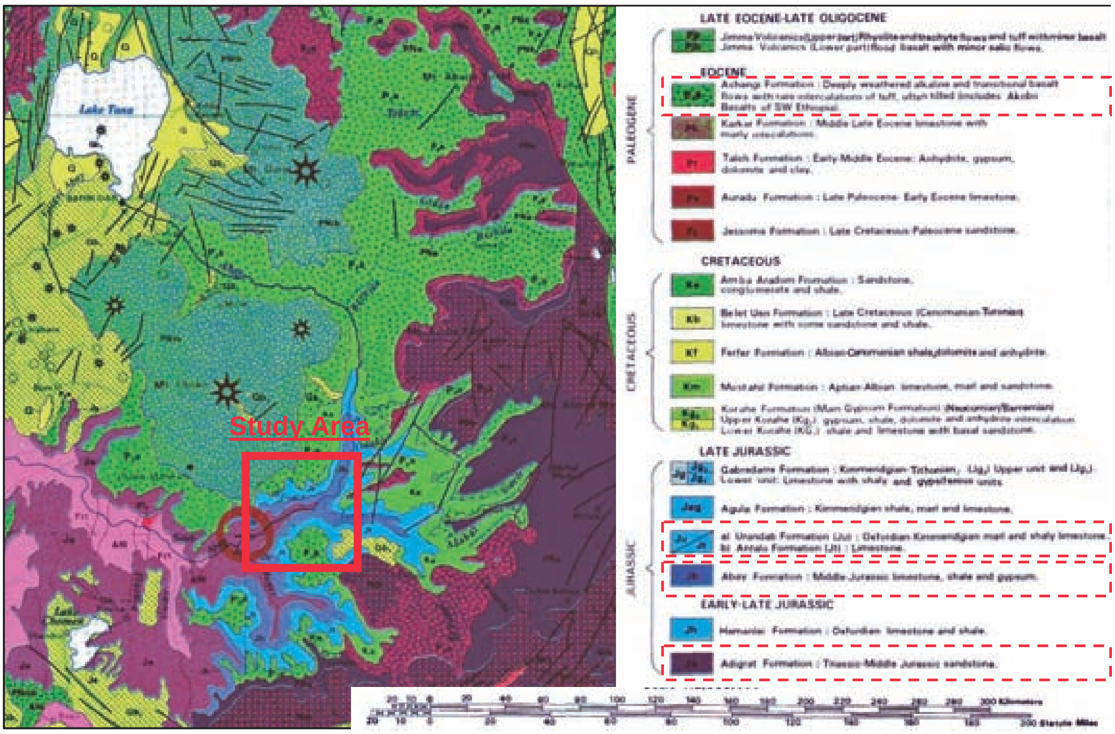

Figure 2.3.1 General geological map of Ethiopia (Tefera et al., 1996)

According to Jepson and Athearn (1961) and Tefera et al. (1996), the geology in the area is mainly classified into four formations. Table 2.3.1 shows the geological classification in the area.

Table 2.3.1 Geological classification in the Abay Gorge (Tefera et al., 1996)

Era	Name	Geology/ Descriptions
Tertiary (Paleogene)	Ashangi Formation	Deeply weathered alkaline and transitional basalt flows with rare intercalations of tuff
Jurassic	Antalo Formation	Limestone
	Abay Formation	Middle Jurassic limestone, shale and gypsum
	Adigrat Formation	Triassic to middle Jurassic sandstone

Although the sedimentary and volcanic rocks in the area are exposed largely as symmetrical stratigraphy on both sides of the Abay River, the detailed sequences are unevenly distributed. The sequence in the area is not disturbed due to major faults and is generally horizontally stratified. However, there are a lot of minor normal faults with a down throw of 1-2 meters. Figure 2.3.2 shows a schematic geological cross section of the Abay area (Ayalew and Yamagishi, 2003). The characteristics of the stratigraphy on the major sequences are also described by Almaz and Tadesse (1994).

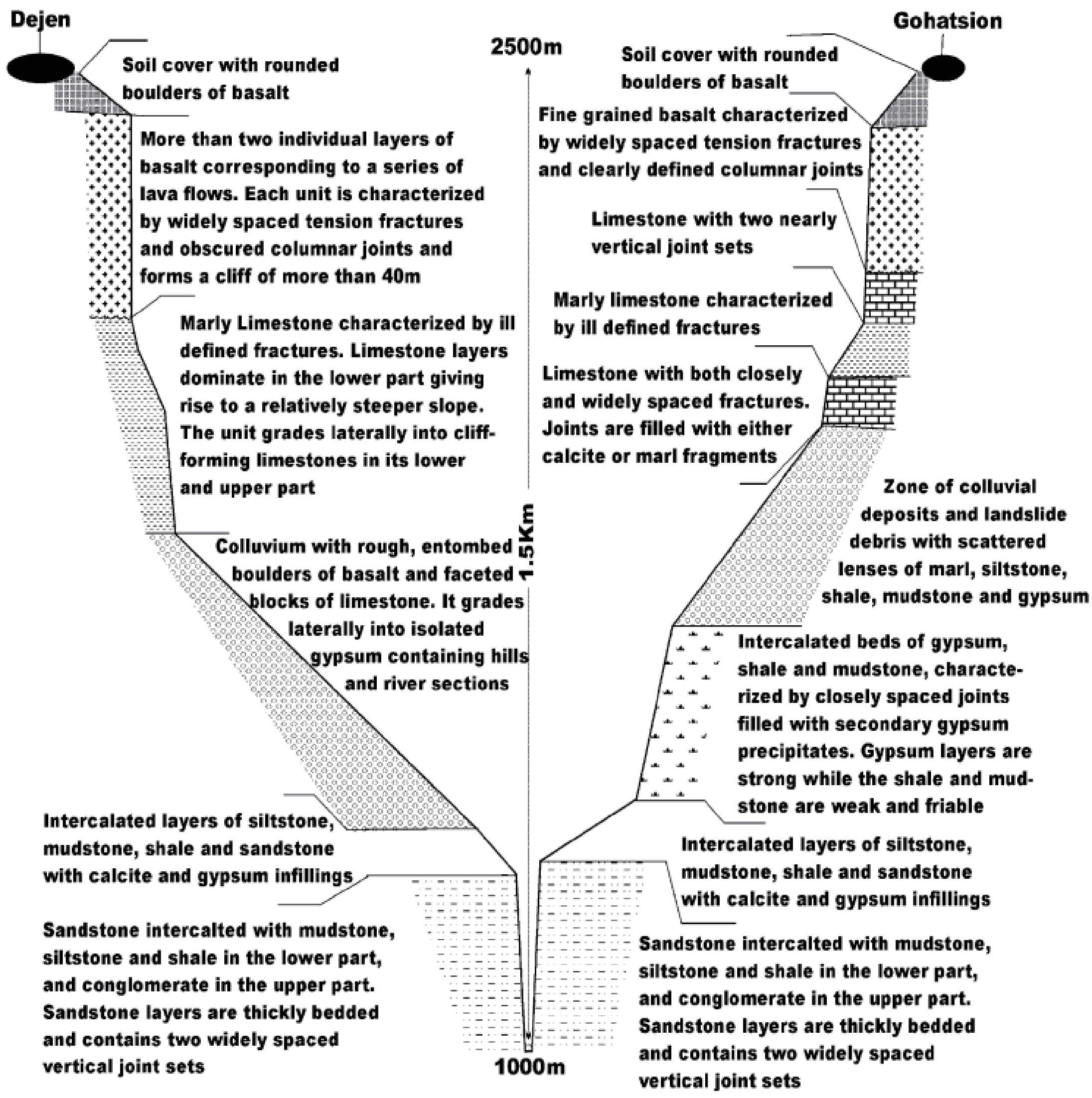

Figure 2.3.2 Schematic geological section in the Abay Gorge (Ayalew and Yamagishi, 2003)

Chapter 3

Landslide Survey

3 Landslide Survey

3.1 Hydrological Survey

3.1.1 Existing data interpretation

The five following meteorological observation stations are in the vicinity of the target area.

Table 3.1.1 Existing data List

Observation station name	Latitude (N)	Longitude (E)	Height (m)	Observation
Goha Tsiyon	10° 00.408'	38° 14.755'	2,500	rainfall, temperature
Filiklik	10° 03.200'	38° 14.886'	1,860	ditto
Dejen	10° 10.2638'	38° 09.0359'	2,420	ditto
Abay Sheleko	10° 06.7507'	38° 09.4057'	1,819	ditto
Yetnora	10° 14.696'	38° 14.696'	2,430	rainfall, temperature, radiation, sunshine, evaporation, humidity, wind direction/velocity

The above-mentioned observatories are under the jurisdiction of the Ethiopia National Meteorological Services Agency (NMSA), which receives observation data, recorded daily at 9 am, from each observatory on a monthly basis.

NMSA manages the collected observation records with a personal computer, and handles their sale. The data management, however, involves insufficient checks, with abnormal values apparent in the records that are possibly measurement mistakes.

Monthly rainfall data and return period in Goha Tsiyon station are shown in Figure 3.1.1.

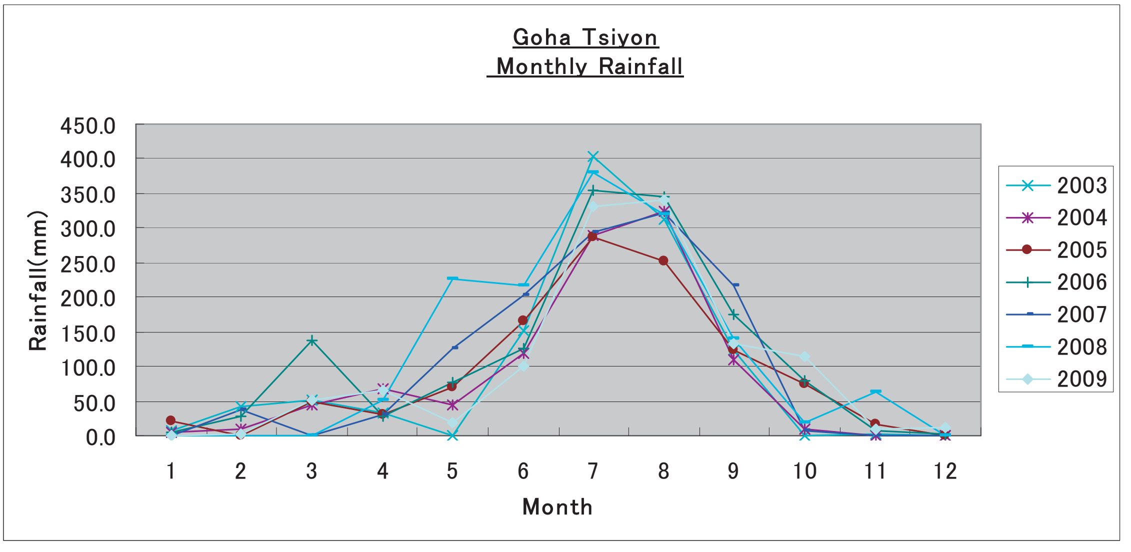

Figure 3.1.1 Monthly Rainfall (Goha Tsiyon)

3.1.2 Precipitation monitoring

The study team installed two rain gauges (tipping bucket type). The existing rain gauges are mostly installed near the main road. Locations were selected so as to be easy to make observations while being able to be protected against theft, and also being part way between the existing rain gauges. The locations of the newly installed rain gauges are as follows.

Table 3.1.2 Newly Installed Rain Gauges List

Observation station name	Latitude (N)	Longitude (E)	Elevation (m)
Abay Bridge	10°04.6498′	38°11.4483′	1,079
Gabrielle Church	10°06.4308′	38°09.5496′	1,739

The duration of the precipitation monitoring on the two sites is as follows.

Table 3.1.3 The duration of the precipitation monitoring

Station name	Starting day	Missing period	Remarks
Abay Bridge	29.Jun.2010	13.Aug.2010～3.Sep.2010 15 Feb. 2011～26 Mar. 2011 24 Ari. 2011～ 4 Jul. 2011 27 Jul. 2011～ 18 Aug. 2011	Data missing Cable disconnected
Gabrielle Church	2.Jul.2010	14.Jul.2010～23.Jul.2010 23.Aug.2010～18.Oct.2010 7 Dec.2010～1 Feb.2011 3 Aug.2011～19 Sep.2011	No battery Bad electrical contact Data logger trouble

3.2 Topographical Survey

3.2.1 Satellite Imaginary

New satellite imagery from the high resolution Geo-Eye1 (resolution 0.5 m) was taken for the topographic mapping (1/10,000 and 1/5,000).

Imagery was acquired, after waiting for a chance since April, on two days when there was almost no cloud cover, June 3 and 6, 2010. The imagery taken is shown in the figure below. Details of the data are as follows.

- 2 color stereo pairs (total: 4 sheets)
- Coordinate system: WGS84
- Projection method: UTM
- File type: GeoTiff
- Including RPC file

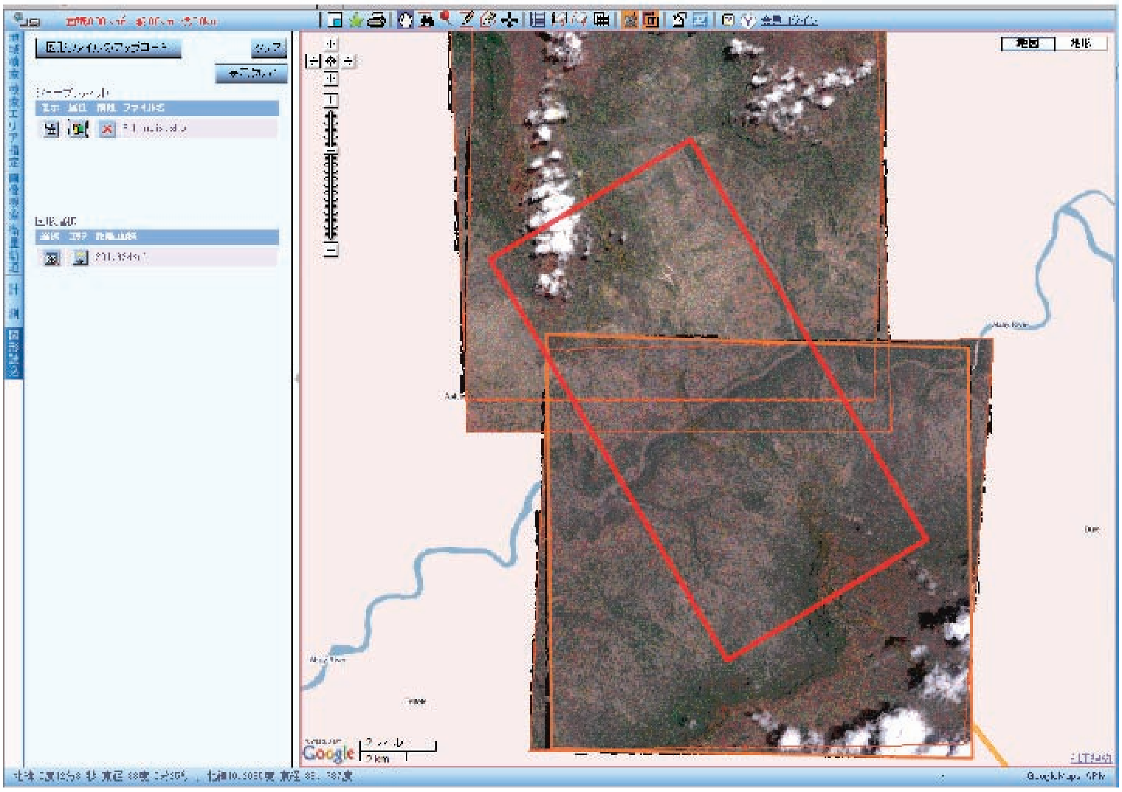

Figure 3.2.1 Acquired imaginary

3.2.2 Topographic mapping

a. Ground control point survey for topographic mapping

Ground control points, horizontal (ground control point survey) and height (ordinary leveling), necessary for aerotriangulation were established along 42 km of Route 3 between Goha Tsiyon and Dejen. The field work was undertaken over 51 days, from May 12 to July 1, 2010; and the number of points established is as follows:

i) Control point survey by GPS: 10 points
ii) Control traverse survey by total station: 60 points
iii) Ground control point survey: 20 points
iv) Ordinary leveling: 84 points

b. Digital topographic mapping

The digital topographic mapping implementation - generally using the stereo imagery data acquired in the abovementioned manner - involved various processes such as aerotriangulation, digital plotting and digital editing.

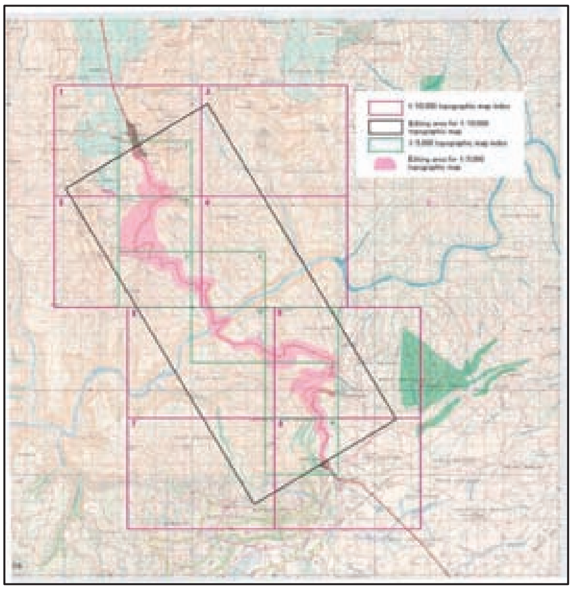

Figure 3.2.2 The area of the topographic mapping

c. Cross-section survey

The purpose of the cross-section survey was to obtain base data for planning the geophysical exploration and considering the landslide stability analysis. The basic specifications and work amount of the cross-section survey were as follows.

- Survey area: Monitoring sites presented after consideration by the Study Team
- Survey items (cross-section location specifications): A maximum area of 500 m from slip surface origin to toe was surveyed
- Outputs: Cross-sections (scale of 1/100 length; 1/200 width)

3.3 Preliminary Geomorphologic Survey

3.3.1 Vicinity of ST.0+000 to ST.1+200

A horse-shoe shaped depression surrounds the S-curve in the road near ST.0+000, which is the scarp of an old landslide (A). Within that, several smaller landslides, thought to have occurred more recently, can be identified. Within this large landslide there is a smaller landslide formation (B).

Landslide (C) is interpreted as moving in-line with or obliquely - west-southwest - to the road, judging from the mound near the foot of the moving mass. There is only one river system here (D), which flows from Goha Tsiyon Town.

Figure 3.3.1 Satellite image interpretation ST.0+000 to ST.1+200

3.3.2 Vicinity of ST.28+200 to ST.29+700

There are many landslides in this area. Amongst the larger landslides there are overlapping secondary-landslides, many of which continue to be active. There are also many new landslides with main scarps. There are large river systems (A) and (B) surrounding the landslides, while amongst them, there are only a few systems.

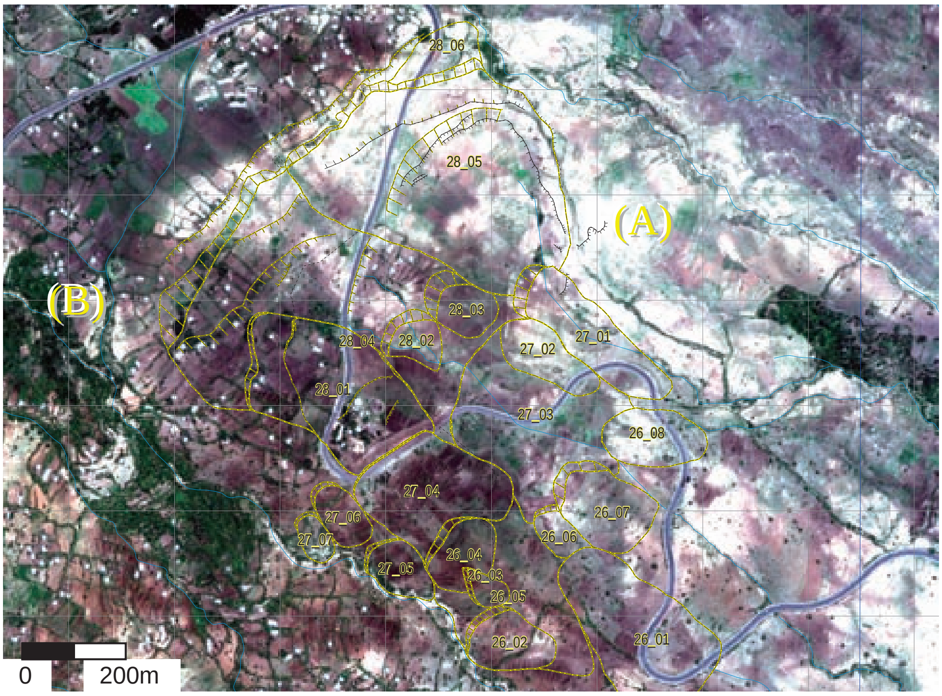

Figure 3.3.2 Satellite image interpretation ST.28+200 to ST.29+700