1 EXECUTIVE SUMMARY

The key features of the proposed Luegere hydroelectric scheme are summarized in Table 1 below.

Table 1. Key features of the proposed hydroelectric scheme

FEATURE	PARAMETER	VALUE	UNITS
Location	Region	Kigoma	-
	River	Luegere	-
Hydrology	Catchment area	1,317	km^2
	Median streamflow (Q50%)	4.56	m^3/s
	Firm streamflow (Q95%)	1.41	m^3/s
	Design flow	4.33	m^3/s
	Design flood (100 years)	220	m^3/s
Diverting structure	Structure type	Gravity weir (Overflowing section : Creager)	-
	Material used	Concrete	-
	Overflowing section crest length	50	m
	Total structure length	70	m
	Overflowing section height	4.50	m
	Non-overflowing section height	7.15	m
	Crest elevation	943.00	masl
	Slab elevation	938.50	masl
Gated flushing channel	Number of bays	2.00	pce
	Gate section	1.4 x 1.5	m x m
Intake	Number of bays	2	pce
	Invert elevation	941.00	masl
	Equipment	Trash rack (manual cleaning)	-
Desilting structure	Yes		
	Number of basins	2.00	pce
	Water level	943.00	masl
Waterway Canal	Headrace canal length	1 420	m
	Headrace canal section	2 x 2.3	m x m
	Average slope	0.001	m / m
Forebay	Yes	-	-
	Water level	941.58	masl
Penstock	Number of penstock(s)	1	pce
	Length	1 110	m
	Diameter	1.20	m
Powerhouse and electrical / electromechanical equipment	Floor elevation	786.00	masl
	Gross head	157.00	m
	Number of units	3	pce
	Turbine type	Pelton	-
	Operating discharge per unit	1.44	m^3/s
	Total installed capacity	5 340	kW
	Average annual energy generation	34.40	GWh/year
Access road	Length of road to build	9,000	m

	Length of road to rehabilitate	0	m
Transmission lines	Length	85	km
	Voltage	33	kV
Economic data	CAPEX - without access road and transmission lines	13.14	M$
	LCOE - without access road and transmission lines	0.05	$/kWh
	CAPEX - access road and transmission lines included	24.97	M$
	LCOE - access road and transmission lines included	0.10	$/kWh

2 INTRODUCTION

2.1 Overview of the ESMAP Program

ESMAP (Energy Sector Management Assistance Program) is a technical assistance program managed by the World Bank and supported by 11 bilateral donors. ESMAP launched in January 2013 an initiative to support the efforts of countries to improve the knowledge of renewable energy (RE) resources, establish appropriate institutional framework for the development of RE and provide "free access" to geospatial resources and data. This initiative will also support the IRENA-GlobalAtlas program by improving data availability and quality, consulted through an interactive atlas.

This "Renewable Energy Mapping: Small Hydro Tanzania" study, is part of a technical assistance project, ESMAP funded, being implemented by Africa Energy Practice 1 (AFTG1) of the World Bank in Tanzania (the 'Client') which aims at supporting resource mapping and geospatial planning for small hydro. It is being undertaken in close coordination with the Rural Energy Agency (REA) of Tanzania, the World Bank's primary Client country counterpart for this study.

The "Provision of Small Hydropower Resource Data and Mapping Services" IDA 8004801 Framework contract was signed on the 29th May 2013, while the specific contract " Renewable Energy Mapping: Small Hydro Tanzania", n. 7169139, is dated 4th of November 2013.

2.2 Objectives and Phasing of the Study

The objectives of the study are:

- To improve the quality and availability of information on Tanzania's small hydropower resources. The project will provide the GoT (Client) and commercial developers with ground-validated maps (at least 70+ sites up to 10 MW) that show the varying levels of hydro potential throughout the country, and highlight several sites most suited for small hydropower projects.
- To contribute to a detailed comprehensive assessment and to a geospatial planning framework of small-hydro resources in Tanzania; (ii) to verify the potential for the most promising sites and prioritized sites (~ 20 prioritized sites) to facilitate new small hydropower projects and ideally to guide private investments into the sector; and (iii) to increase the awareness and knowledge of the Client on RE potential.

The study is delivered in three phases:

PHASE 1: Preliminary resource mapping based on satellite and site visits.

PHASE 2: Ground-based data collection.

PHASE 3: Production of validated resource atlas that combines satellite and ground-based data.

2.3 Context and Scope of the Prefeasibility Study

This report is delivered in the context of PHASE 2 (Ground-based data collection). In accordance with our Terms of References (Revised Terms of References for the Phase 2 and 3 of the Project, 30 June 2016), the prefeasibility study covers the following aspects:

- Review of the existing data and GIS information ;
- Additional site visit to the sites and main load centers / national grid connection by relevant sector experts ;
- Additional topographic and geotechnical surveys, update of the hydrology, and assessments of environmental and social impact to reach study results at pre-feasibility level;
- Preparation of a conceptual design and drawings at pre-feasibility level; Schematic Layout of Hydro Powerhouse, weir or dam (when applicable), waterways and Transmission Lines to the main load centers / national grid connection;
- Preparation of a Budgetary Cost Estimate, including costs for environmental and social costs, and Electricity Generation Estimate for a range of installed capacities;
- Preliminary economic analysis.

3 CONTEXT OF THE LUEGUERE HYDROELECTRIC SCHEME

3.1 Project Area

The Luegere River originates in the Katavi region at elevations over 2,000 m. The Luegere River flows mainly from the Southeast to the Northwest and discharges into the Lake Tanganyika about 10 km downstream to the hydroelectric project. The geographical coordinates (WGS1984) of the proposed weir location are 30.028°East and 5.895°South.

At the proposed intake weir location, the watershed of the Luegere River drains an area of 1317 km². **Figure 1** presents the exact location of the proposed site in Tanzania. The administrative and location data are detailed in **Table 2** below.

Table 2. **Administrative data**

Item	Value
Atlas code	SF-022
Site name	Luegere
River	Luegere
Major river basin	Malagarasi and Lake Tanganyika
Region	Kigoma
District	Kigoma Rural
Division	Igalula
Village	Lokoma
Reference topographic map	Topographic map n° 132/3 (scale 1/50,000)

3.2 Site Access

The proposed site is located 130km South of Kigoma. Access to the site is possible by taking a good dirt road up to the village of Lokoma. Before reaching the village, a dirt road leads to the left bank of the Luegere River. From there, the proposed weir location is accessed with a 3km long track.

Figure 1. Study area

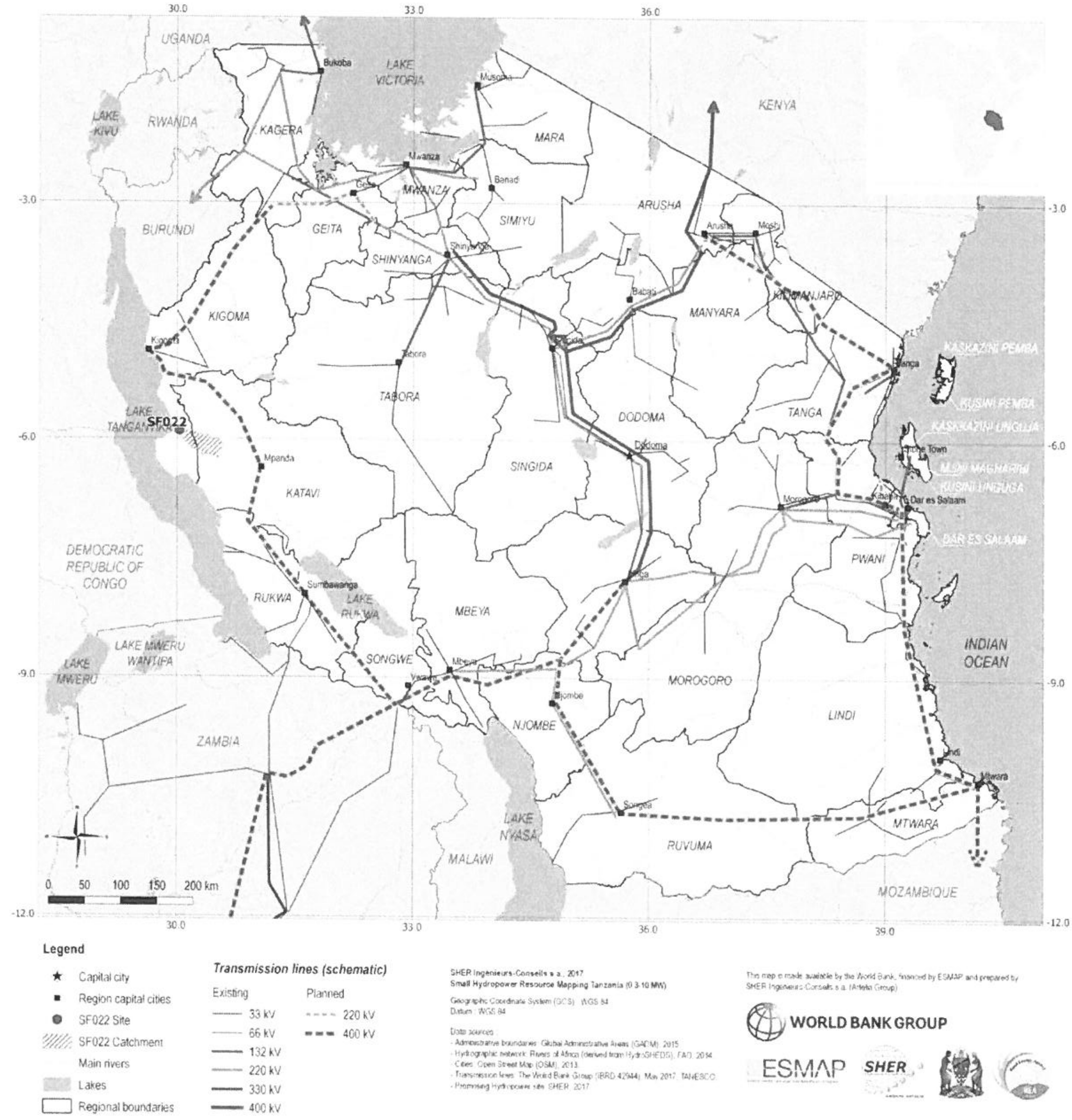


Figure 2. Site access overview

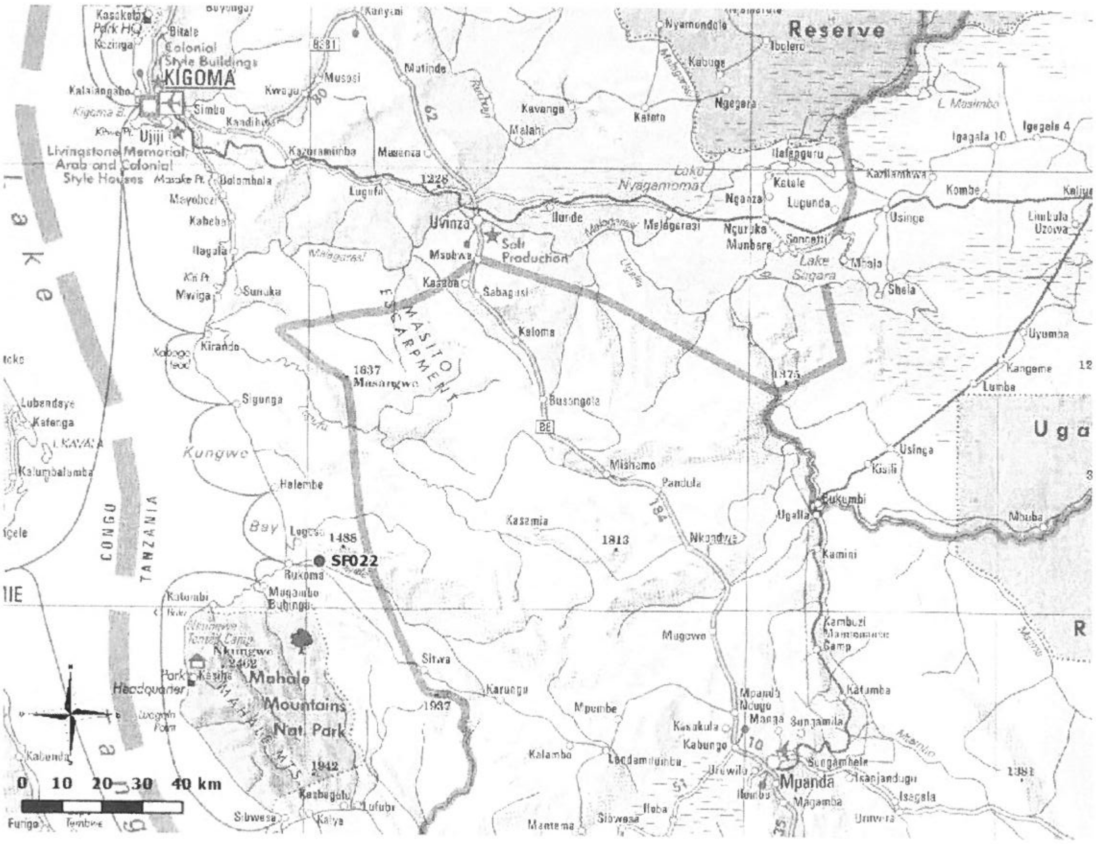
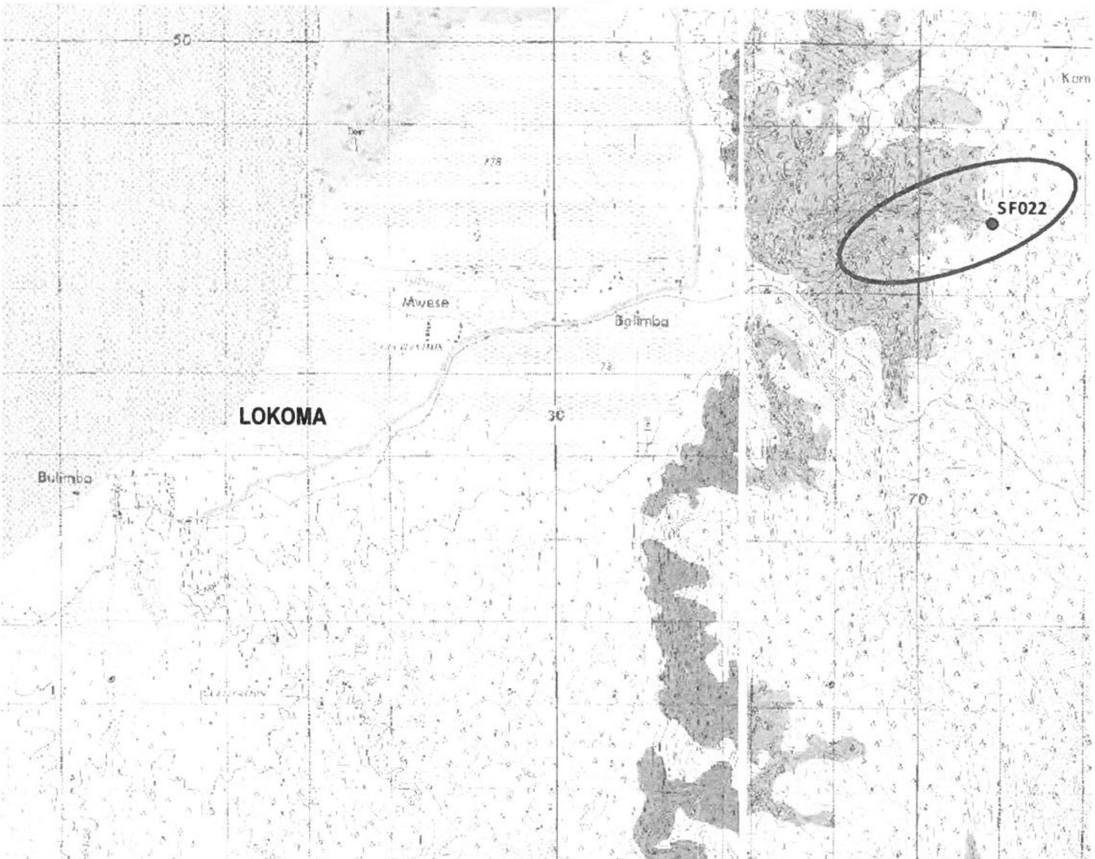


Figure 3. Access to the site (topographic map)



3.3 General Site Description

3.3.1 Site overview

The site is located East of Tanganyika Lake, in a large river (Luegere River) with a large waterfall (**Figure 5**). Slopes of the right and left valleys are steep. The project would supply the Kigoma mini-grid, towns along the Tanganyika Lake and Mahale National Park facilities.

Figure 4. Site overview (Google Earth)

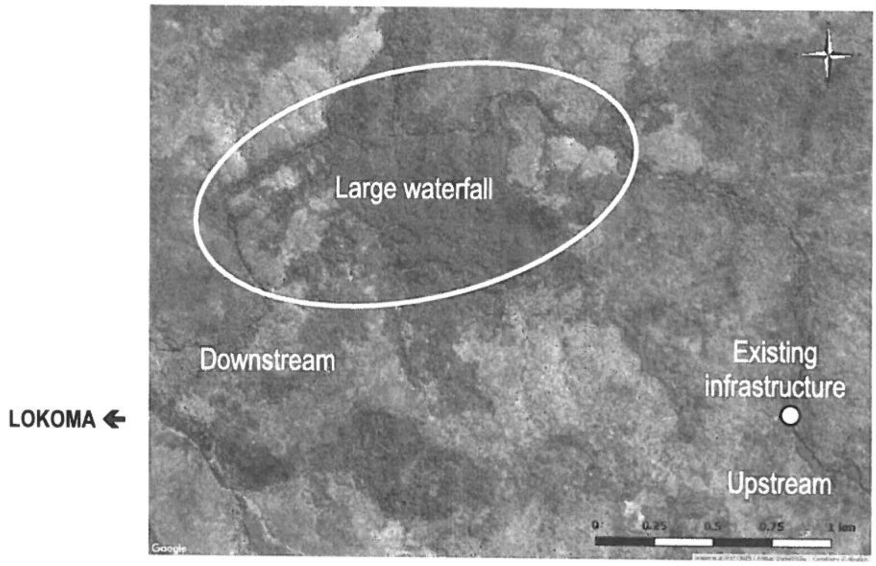
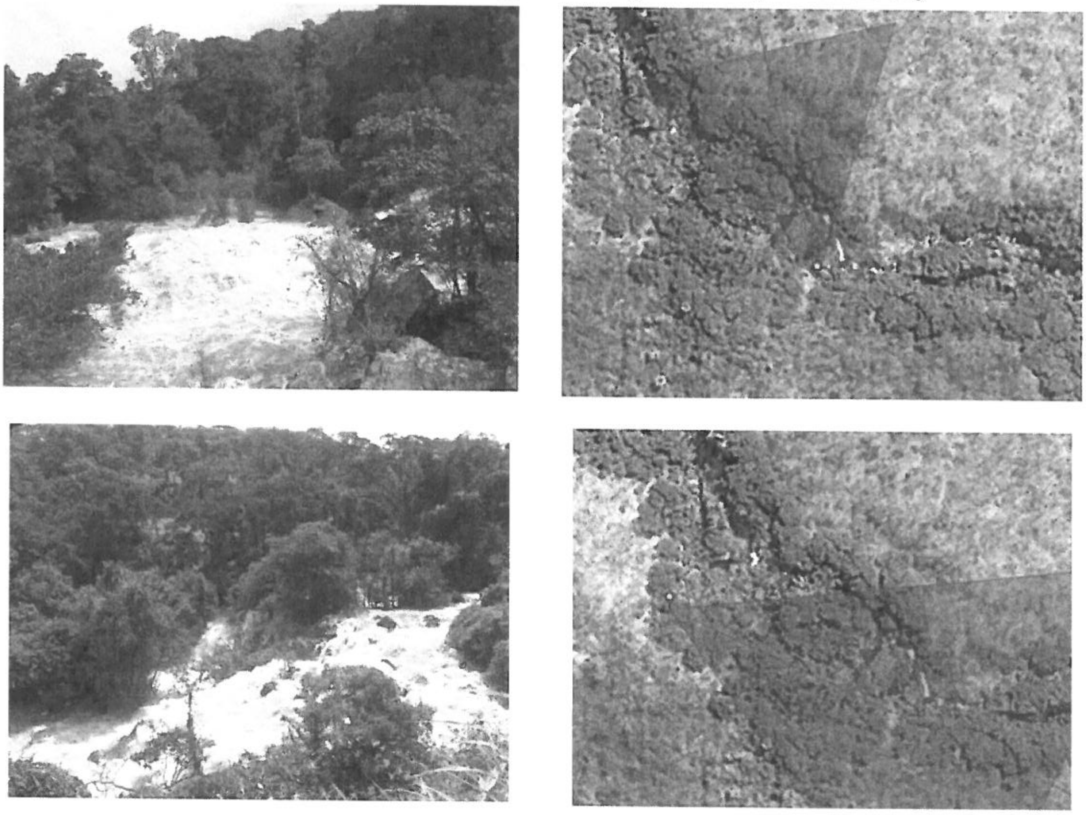


Figure 5. Views of the waterfall during the rainy season (March 2017)



3.3.2 Existing infrastructure

An existing intake structure is located 1.5km upstream the proposed weir location for water supply purposes (**Figure 6** and **Figure 7**)). The infrastructure is not in operation.

Figure 6. Existing infrastructure situated 1.5km upstream the proposed weir location. Water was overflowing both sides of the weir (March 2017)

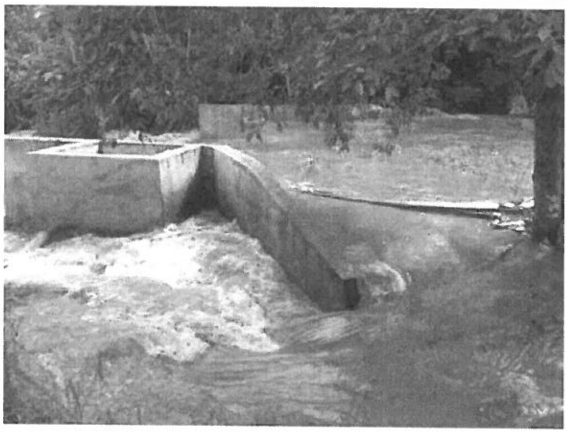
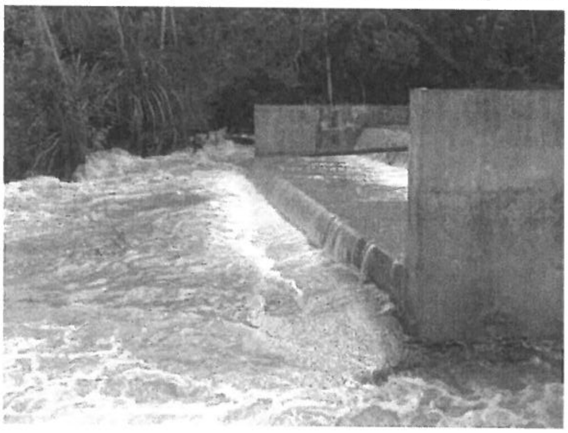
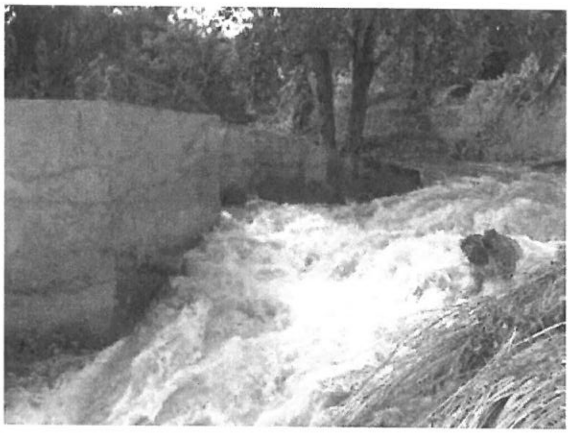


Figure 7. More details on the existing weir





3.4 PREVIOUS STUDIES

To the best of our knowledge, there are no previous studies of the proposed site.

4 TOPOGRAPHY AND MAPPING

4.1 EXISTING MAPPING

4.1.1 Topographic Mapping

The JPEG format (not georeferenced) 1:50,000 scale topographic maps have been acquired from the Survey and Mapping Department of the Ministry of Land in order to cover the entire study area. The JPEG format (not georeferenced) 1:100,000 scale topographic maps have been also obtained from the Ministry of Land. The 1:50,000 scale map of interest is the sheet 132/3. The contour lines interval is 20m. All the topographic maps have been georeferenced as described in section 4.2.

4.1.2 Thematic Mapping

Thematic maps and their key features, sources and format are presented in Table 3 below.

Table 3. Collected thematic maps

THEMATIC	FORMAT	KEY FEATURES	SOURCES
Administrative boundaries	Vector	Country / Regions / Districts / Divisions	FAO Global Country Boundaries, 2012 REA, 2014
Major cities	Vector	32 cities	Open Street Map, 2014
Topographical maps	Raster	1:250,000 (64 tiles) Full country coverage	Ministry of Land, Survey and Mapping Department
	Raster	1:50,000 (1,333 tiles) Full country coverage	Ministry of Land, Survey and Mapping Department
Digital Elevation Model	Raster	SRTM v4.1 Spatial resolution ~ 90m	NASA, 2014 http://www2.jpl.nasa.gov/srtm/
	Raster	ASTER GDEM v2 Spatial resolution ~ 30m (experimental)	http://www.jspacesystems.or.jp/en_/
Land cover	Vector		
Protected areas	Vector	Protected areas, National Parks and Game reserves	Tourist Board ; Tanzania Conservation Resource Centre ; Ministry of Land ; World Database on Protected Areas ; Protected Planet, 2014
Soil map	Raster	IPCC default soil classes derived from the Harmonized World Soil Data Base (v1.1)	ISRIC-WISE http://www.isric.org
Satellite image	Raster	Image Landsat 2013	Google Earth
Population	Shapefile	Census data at village and region levels	National Bureau of Statistics ; Ministry of Finance, REA
Lakes	Vector	Inland water bodies in Africa	FAO, 2000 http://www.fao.org/geonetwork
River network	Vector	River "flow accumulation" network from the HYDRO1k for Africa	FAO, 2006 http://www.fao.org/geonetwork
Rainfall	Raster	Monthly average rainfall grid Spatial resolution ~ 1km	WorldClim, v1.4 http://www.worldclim.org/
Road network	Vector	National, regional and other roads of Tanzania	World Bank AICD database
Rail network	Vector	Main rail network	World Bank AICD database
Ports	Vector	Major ports	World Bank AICD database
Airports	Vector	Major airports	World Bank AICD database
Power grid	Vector	Existing power grid	IED, 2013 ; REA ; TANESCO

4.1.3 Digital Surface Model

The digital surface model (DSM) used in the hydrological study is based on the "Shuttle Radar Topography Mission" (SRTM, version 1 arc-second). These data were acquired in February 2000 by the United States Space Agency (NASA) through radar measurements from space shuttle Endeavor. These data have a spatial resolution of 1 arc-second (about 30 m at the equator). The DSM of the study area is illustrated in Figure 11 of the chapter describing the Hydrological Study.

4.2 MAPPING CARRIED OUT AS PART OF THE STUDY

4.2.1 Digitization and geo-referencing

The 1:50,000 scale topographic maps were geo-referenced using the Quantum GIS software and the following projection parameters:

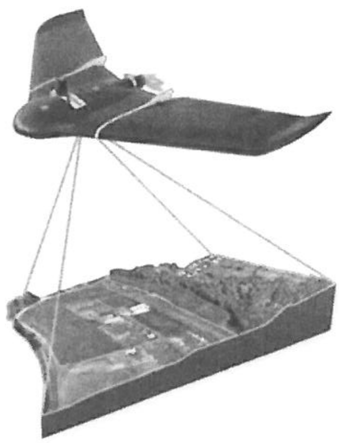
- Projection Transverse Mercator UTM zone 36S
- Latitude of origin = 0
- Central meridian = 33
- Scale factor = 0.9996
- False Easting = 500,000
- False Northing = 10,000,000
- Datum WGS 1984

4.2.2 Additional surveying

4.2.2.1 Digital surface model

The topographic survey was carried out by remote sensing. An eBee Plus drone equipped with a specific camera designed for photogrammetric mapping was used (**Figure 8**).

Figure 8. eBee Plus drone equipped with a camera for the topographical survey



Outputs from drone survey are (1) a high-resolution orthophotography (0.10m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetation cover, but it gives an excellent overview of the topographical features of the site of interest. Contour lines are calculated from the DSM. The ortho-photography as well as contour lines deduced from the digital surface model are presented at **Figure 10.**

Elevations resulting from this topographic survey are relative to each other and have not been linked to the national system. Consequently, the elevations of the works mentioned in this report are not the absolute altitudes of the Tanzanian national system.

4.2.2.2 Digital terrain model

The digital surface models was then post-processed to eliminate the effects of vegetation and hence represent the natural terrain elevation. This has been be achieved by identifying pixels at the natural terrain level (excluding vegetation and other anthropogenic elements) and performing a spatial interpolation of these points in order to obtain a digital terrain model (DTM). At this prefeasibility stage, only the weir/intake and tailwater areas were post-processed to obtain the DTM.

Figure 9. Digital Surface Model (DSM) and orthophotography from drone survey for SF022 site

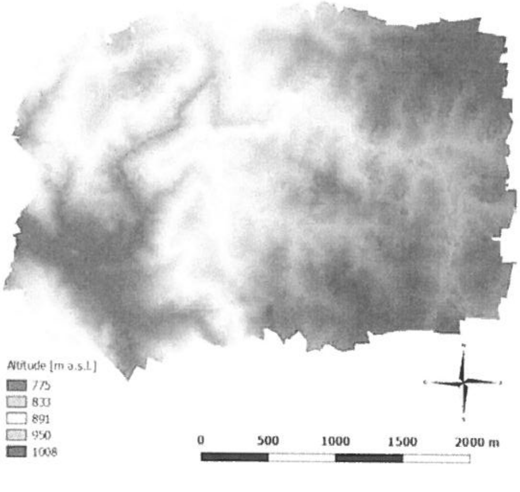
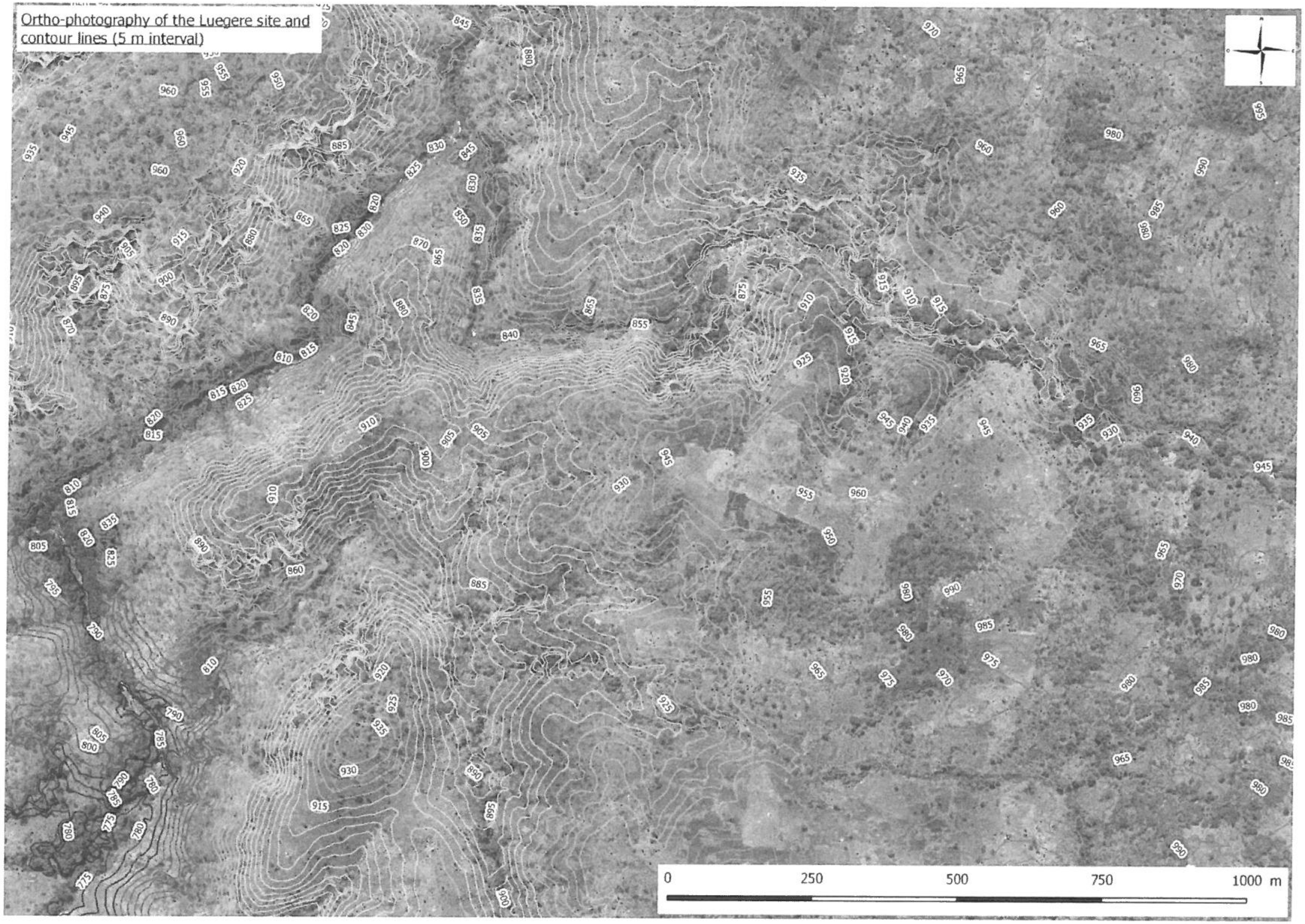


Figure 10. Ortho-photography of the Luegere site and contour lines (5 m interval)



5 HYDROLOGICAL STUDY

5.1 OBJECTIVES AND LIMITS

The objective of the hydrological study is to establish and quantify the climatological and hydrological characteristics of the study area in order to determine the hydrological parameters and time series required for the design of the Luegere hydroelectric project as well as for the economic analysis of the pre-feasibility study.

5.2 DESCRIPTION OF THE STUDY AREA

5.2.1 Physical Context

The Luegere River originates in the Katavi region at elevations over 2,000 m. The Luegere River flows mainly from the Southeast to the Northwest and discharges into the Lake Tanganyika about 10 km downstream to the hydroelectric project.

As shown in **Figure 11**, the Luegere catchment at the proposed hydroelectric project site features a marked relief with elevations between 2,036 m and 976 m (1,420 m on average). The drainage basin of the Luegere River at the proposed intake site is 1,317 km² (delimitation based on the SRTM DSM of spatial resolution 1 arc-second, i.e. approximately 30 m). The main physical and morphological features of the river catchment are presented in Table 4 below.

The hypsometric curve of the river catchment is shown in **Figure 12**. This curve shows the percentage of the catchment area above a given elevation. It shows that slopes are important in the upstream part of the catchment and that the rest of the catchment flows on a plateau characterized by a relatively steep slope. This is clearly observed in **Figure 12** and **Figure 11**.

Table 4. Physical and morphological characteristics of the catchment

PARAMETER	VALUE	UNIT
Area	1,317	km²
Average elevation	1,420	m a.s.l.
Maximum elevation	2,036	m a.s.l.
Maximum elevation (percentile 5%)	1,751	m a.s.l.
Minimum elevation	976	m a.s.l.
Minimum elevation (percentile 95%)	1,105	m a.s.l.
Slope index	8.6	m/km
Elevation range	646	m
Perimeter	271.8	km
Gravelius index	2.10	-

Figure 11. Luegere River catchment and Digital Surface Model

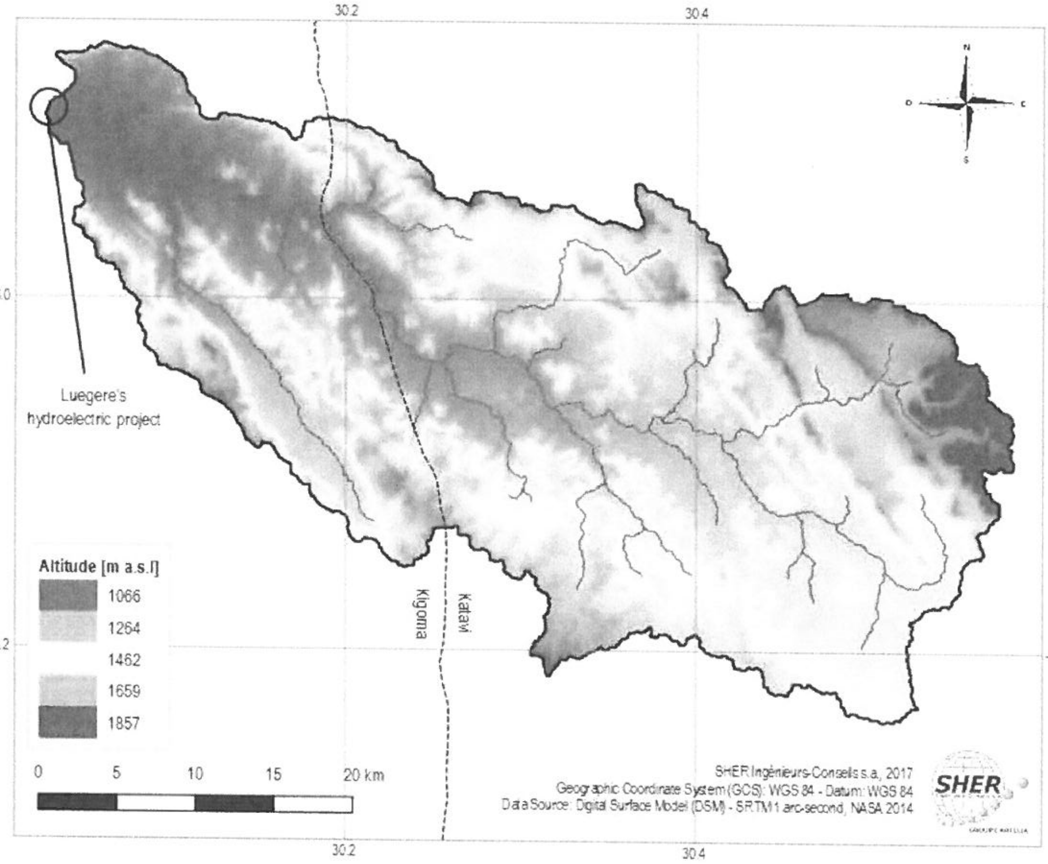
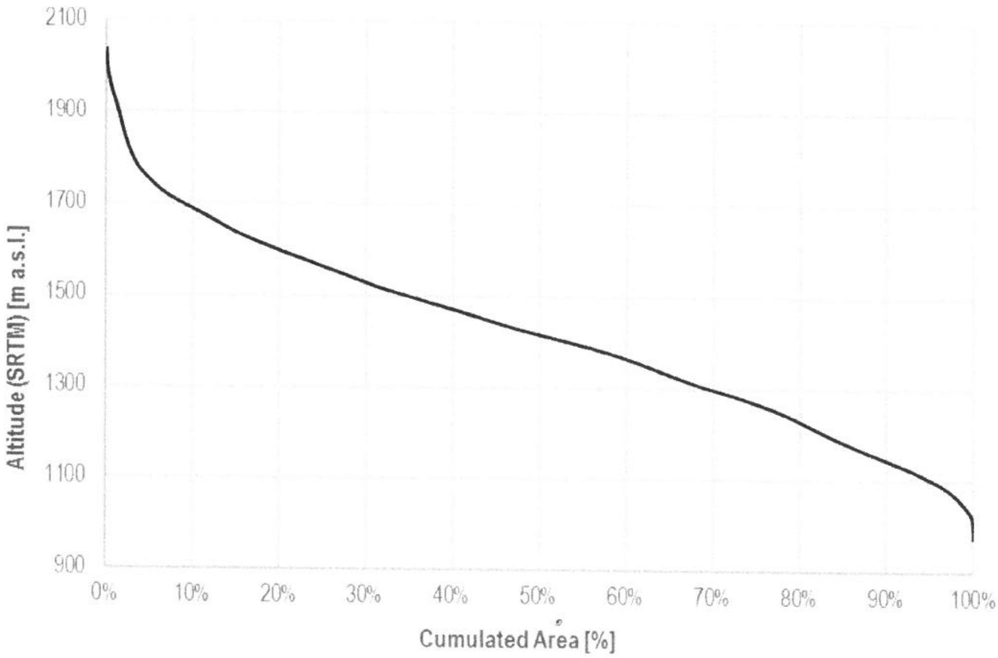


Figure 12. Hypsometric curve of the Luegere River catchment



5.2.2 Land cover and protected areas

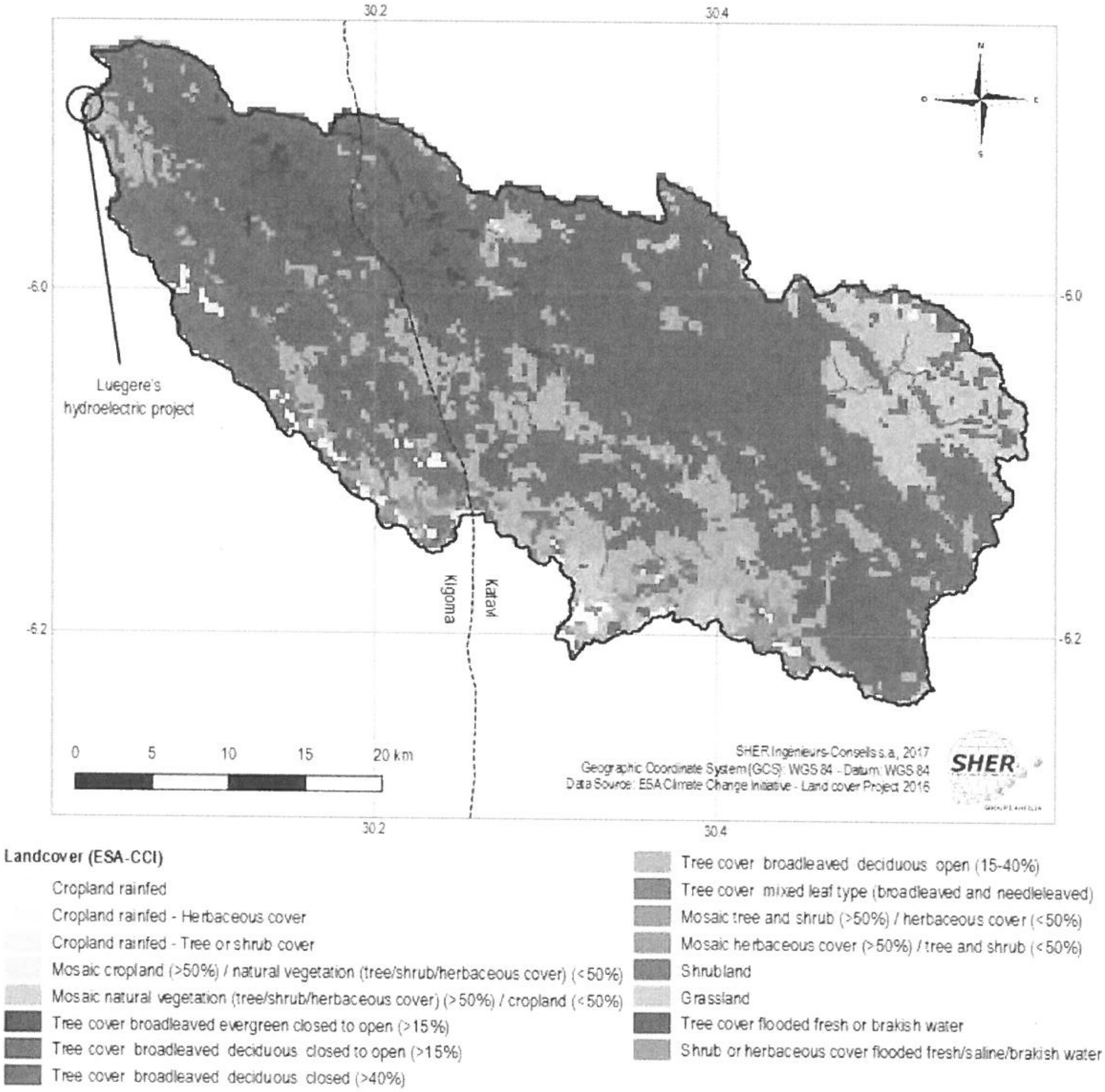
Data from the CCI Land Cover project (© ESA Climate Change Initiative - Land Cover project 2016) is a widely accepted source of information for land use around the world. These data are derived from satellite images acquired by the MERIS instrument of the European Space Agency. The land cover includes 5 years of satellite imagery acquisition between 2008 and 2012. The information is provided in raster format with a spatial resolution of 300m and allows defining the land use classes shown in **Figure 13**.

Figure 13 and **Table 5** show that the Luegere catchment is characterized by a very abundant vegetation cover composed mainly of a forest of deciduous (73.6% of the catchment area, i.e. 969 km²), shrubland (11.2%, i.e. 147 km²) and grassland (8.2%, i.e. 108 km²).

Table 5. Land cover in the Luegere River catchment

CODE	LEGEND	AREA	
		[%]	[KM²]
10	Cropland rainfed	0.3%	3.40
11	Cropland rainfed - Herbaceous cover	0.4%	5.10
12	Cropland rainfed - Tree or shrub cover	0.1%	0.66
30	Mosaic cropland (>50%) / natural vegetation (tree/shrub/herbaceous cover) (<50%)	0.5%	6.42
40	Mosaic natural vegetation (tree/shrub/herbaceous cover) (>50%) / cropland (<50%)	0.2%	3.12
50	Tree cover broadleaved evergreen closed to open (>15%)	1.0%	12.85
60	Tree cover broadleaved deciduous closed to open (>15%)	53.2%	700.30
61	Tree cover broadleaved deciduous closed (>40%)	2.8%	36.75
62	Tree cover broadleaved deciduous open (15-40%)	17.6%	231.50
90	Tree cover mixed leaf type (broadleaved and needleleaved)	0.1%	1.80
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	1.7%	22.67
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	0.0%	0.19
120	Shrubland	11.2%	146.90
130	Grassland	8.2%	107.90
160	Tree cover flooded fresh or brakish water	2.5%	33.07
180	Shrub or herbaceous cover flooded fresh/saline/brakish water	0.3%	4.06
	TOTAL	**100%**	**1317**

Figure 13. Land cover in the Luegere River catchment



5.2.3 Climate

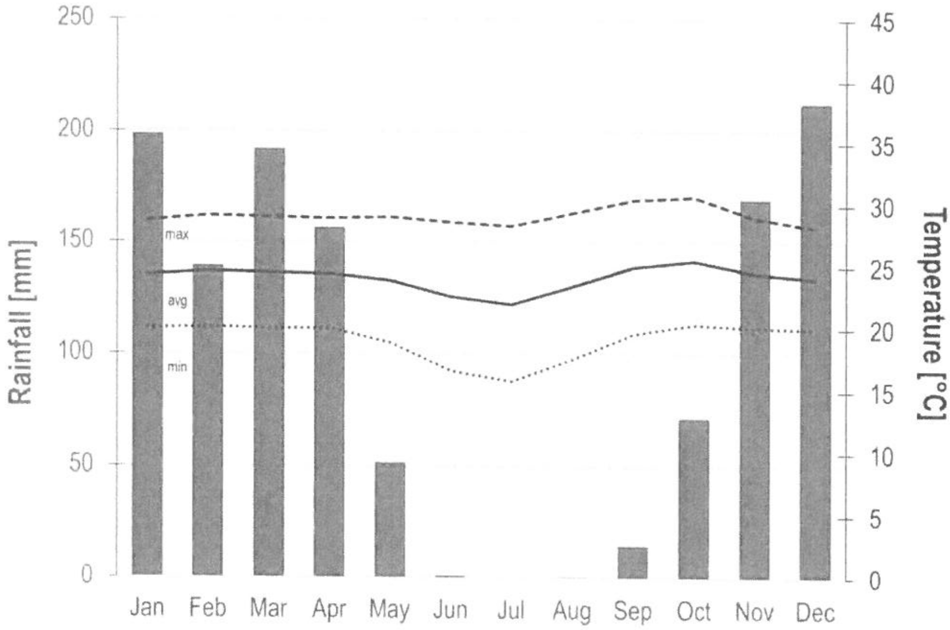
According to the Köppen classification based on rainfall and temperature, the study area (Luegere River catchment) is characterized by a tropical savanna climate with a pronounced dry season and constant high temperatures (*Aw* class). Köppen defines the temperate climate «*A*» by the following characteristics:

- Average temperature of each month of the year > 18 °C ;
- High annual precipitation (greater than annual evaporation) ;
- No winter season.

The rainfall regime « *w* » (dry season in winter) is defined by a savanna climate with a precipitation of the driest winter month < 60 mm and < [100 – (mean annual precipitation) / 25].

Figure 14 shows the climatic diagram as well as the temperature curve for the Luegere River watershed. Precipitations are very low during the dry season (June to September) but significant during the wet season. July is the driest month without precipitation (on average) whereas the wettest month is December with 213 mm on average. The average annual precipitation is 1,208 mm.

Figure 14. Climatic diagram of the Luegere River catchment



It is observed that the average annual temperature is 24.1°C. Temperature does not varies much throughout the year with an average amplitude of 3.5°C. The warmest month is October with 25.5°C and July is the coldest, with an average temperature of 22.0°C.

5.3 HYDRO-METEOROLOGICAL DATABASE

5.3.1 Rainfall and meteorological data

Rainfall data from two sources were used in this study: (i) the WorldClim climate database and (ii) the Climate Hazards Group InfradRed Precipitation database (CHIRPS).

WorldClim is a set of global data representative for the period ~1970-2000 available with a spatial resolution of about 1 km and at a monthly timestep. The spatial resolution is obtained by interpolation of ground-measured data.

Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 30+ year quasi-global rainfall dataset at a daily timestep. Starting in 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring. Values extracted from these satellite images are the means of the precipitation that falls each day on the entire catchment.

5.3.2 Hydrological data

An existing streamflow monitoring station (ref: Luegere River at Lubalisi, 4D1) is located 2 km downstream the hydroelectric project. Data have been collected in the Lake Tanganyika Water Basin Office. The completeness of the time-series (12% of daily data gap, 1975-1988) is not sufficient for a reliable statistical analysis.

To estimate the streamflows of the Luegere River at the hydroelectric project, a method based on the generation of synthetic streamflows on the basis of precipitation data through hydrological modelling was developed and is described in the next section.

5.3.3 Annual and monthly rainfall

5.3.3.1 Annual and monthly distribution

The analysis of the annual distribution of rainfall within the study area is based on the CHIRPS dataset, presented in section 5.3.1. The results are presented monthly in the section 5.2.3, **Figure 14**.

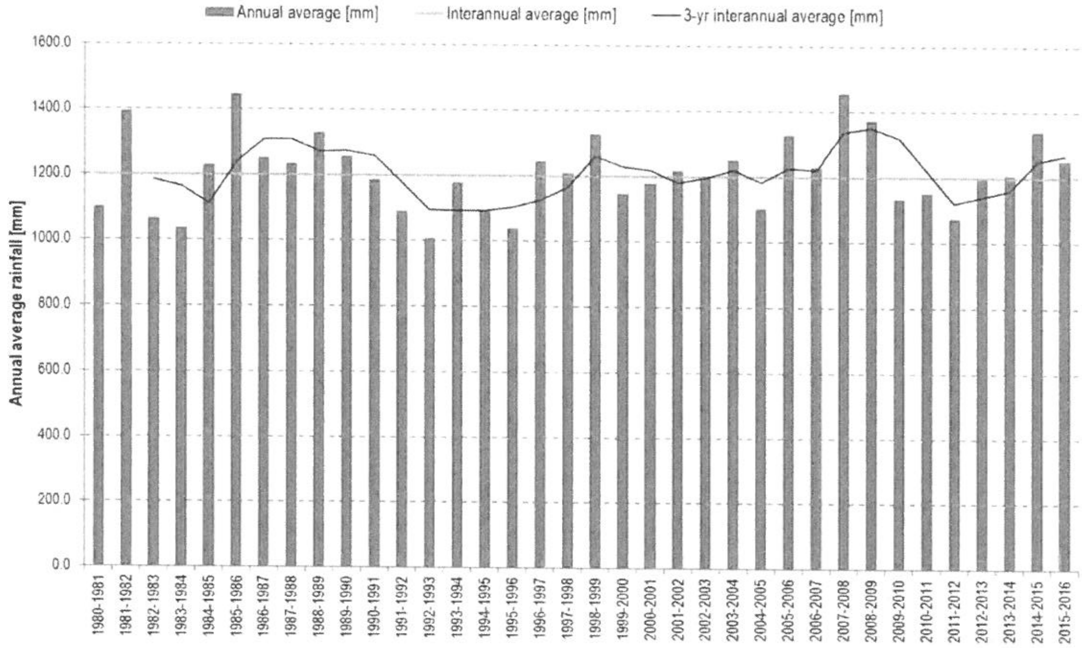
5.3.3.2 Spatial distribution

The analysis of the spatial variation of rainfall within the study area is based on the WorldClim dataset, presented in section 5.3.1. The spatial variation of average annual rainfall within the watershed is significant with a minimum of 1,056 mm in the northwestern part of the catchment and a maximum of 1,283 mm in its northern part. This is illustrated in **Figure 15**.

5.3.3.3 Temporal variation

The temporal variation in rainfall for the Luegere catchment has been studied from CHIRPS dataset (period 1981-2017) and the results are presented in the graph below. Annual average is fluctuating between 1,000 mm and 1,400 mm but it does not feature any clear trends in annual patterns.

Figure 15. Temporal variation in rainfall for the Luegere catchment



5.3.4 Inflow analysis

5.3.4.1 Methodology

Given the characteristics of the data available (daily datasets with gaps), the hydrological model selected was a daily lumped rainfall-runoff model called GR4J (in French, modèle du Génie Rural à 4 paramètres Journalier, https://webgr.irstea.fr/en/modeles/journalier-gr4j-2/).

First, the model needs three inputs:

- daily precipitation (obtained from CHIRPS satellite imagery)
- daily evapotranspiration (obtained from CLIMWAT agroclimatic stations)

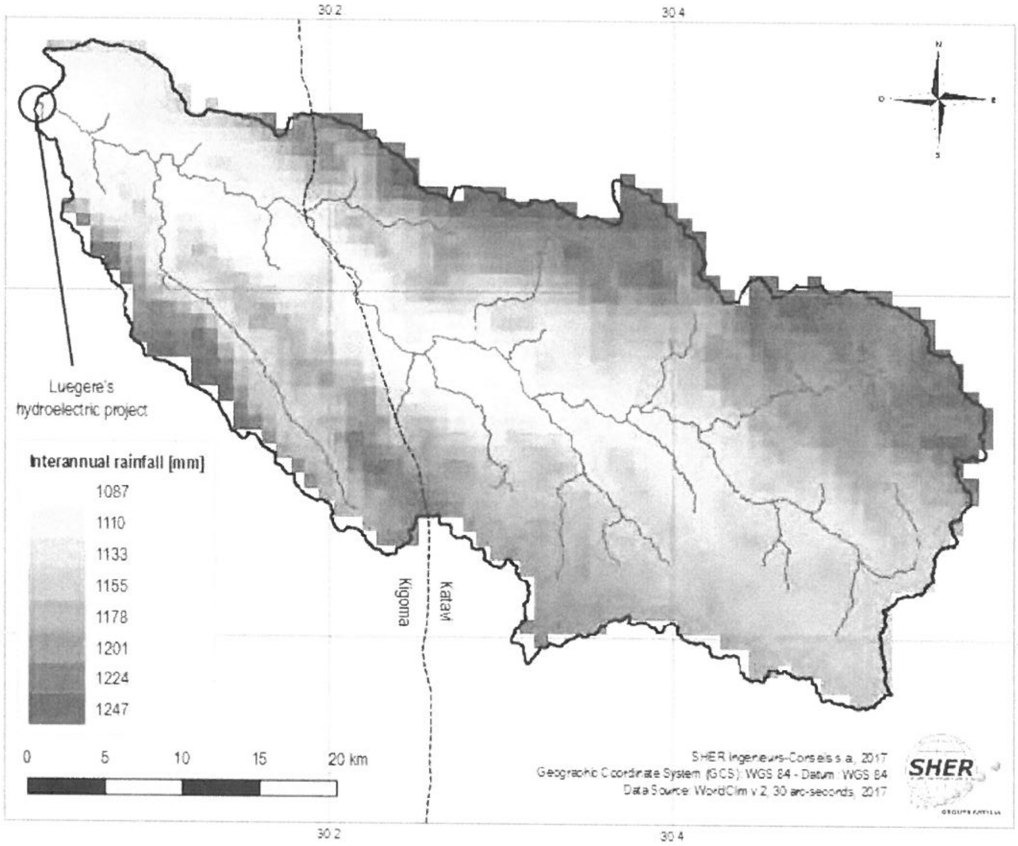
- daily observed streamflow (obtained from data collection in the Lake Tanganyika Water Basin Offices)

From these inputs, the rainfall-runoff relation is established by four parameters. The optimization of these parameters permits to reproduce as much as possible the observed hydrograph.

Once the model (or the rainfall-runoff relation) is optimized, the synthetic streamflows can be generated from the daily precipitation and evapotranspiration data. As these data are available for the period of 1981-2017, the synthetic streamflows can be simulated for the same period.

The hydrological modelling is only applicable if the time-series of observed streamflow period covers at least three consecutive high-quality hydrological years(1) after 1981 (first year of the CHIRPS data).

Figure 16. Spatial Variation of the annual rainfall on the Luegere catchment



5.3.4.2 Flow duration curve

Among the hydrological parameters, the determination of the flow duration curve is essential to know the availability of the flows in the river for the hydroelectric project. Indeed, this curve shows the percentage of time that the streamflow in a river is likely to equal or exceed some specified value of interest.

For the hydrological modelling method used in this study, the flow duration curve is made directly applying a probability function P(X>x) on the time-series of synthetic streamflow data. This function determines the probability of exceedance of each flow reaching the hydroelectric project.

[1] A hydrological year is defined as the 12-month period beginning after the dry season. In Tanzania, the hydrological year begins on November 1 and ends on October 31.