Eastern Nile Flood Risk Mitigation (EN-FRM) Project

Annex II- Data Status and Gap Analysis Report for the Eastern Nile Flood Risk Mitigation (EN-FRM) Project

ENTRO

4 April 2022

Eastern Nile Subsidiary Action Program

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1 Background

1.1 General

Flood and drought disasters are among the common issues that threaten livelihoods and economic growth across the Nile Basin. Climate shocks (mainly drought which covers large area) were among the leading causes of acute food crises and malnutrition in 2017, affecting 39 million people[1] in eight of the Nile countries.

Riverine flood forecasting system, producing forecasts (some hours to days lead time) of river flows and levels at critical points where flooding observed, provide a cost-effective solution to many flood risk management problems. Adequately constructed and calibrated riverine flood forecasting system is able to produce accurate, reliable and timely forecasts to make major decisions such as:

(a) evacuation of people based on warnings to local authorities and the affected population of the expected levels and extent of flood inundation.
(b) predictions of the inflow to reservoirs which enable reservoir operators to preserve dam safety, prevent or reduce flooding in the downstream reaches while avoiding panic flood releases.

Seasonal floods take place in almost all Nile countries every year. The rainy season of 2020 was an example of how serious the impacts can be—the water level of the Blue Nile in Khartoum hit the highest record in 100 years, and the flood waters are causing tremendous damage to Ethiopia, Sudan, and South Sudan, affecting over 1.5 million people, including more than 100 deaths. Disaster statistics in the region are under-reported, but the annual average economic losses in rural villages along the Blue Nile in Sudan alone, for example, is estimated to be US$25 million[2].

Three types of water-related disasters are of primary concern in the Nile Basin: riverine floods, flash floods, and drought. Their characteristics are summarized as follows:

- Riverine flooding is when streams and rivers exceed the capacity of their natural or constructed channels to accommodate water flow; and water overflows the banks, spilling out into adjacent low-lying, non-flooded land. It is characterized by excessive runoff from longer-lasting rainstorms over a larger catchment area (~> 100 km^2) that cause a relatively slower water-level rise (from few hours to days). Riverine floods are the most common and visible disasters in the region. A global database indicates all the Nile Basin countries suffered from at least 12 major flood events in the last four decades, with Kenya, Ethiopia, and Tanzania at the top, recording 56, 55, and 48 major flood events in the past 40 years, respectively. For example, the 2006 flood in Ethiopia resulted in the loss of 700 lives and the displacement of 242,000 people[3].

- Flash floods are characterized by excessive rainfall in a given often hilly catchments, and a rapid rise in the water level of a stream / creek or a normally dry channel. Flash floods are common even in areas with a dry climate and rocky terrain because lack of soil or vegetation allows torrential rains to flow overland rather than infiltrate into the ground. Though underreported due to their narrower spatial extent, flash floods are

[1] FAO (Food and Agriculture Organization), IFAD (International Fund for Agricultural Development, UNICEF (United Nations Children’s Fund), WFP (World Food Programme), and WHO (World Health Organization. 2018. The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition.

[2] World Bank. 2015. The Nile Story: 15 years of Nile Cooperation - Making an Impact. Entebbe: World Bank. https://openknowledge.worldbank.org/handle/10986/23579.

[3] Emergency Events Database (EM-DAT) https://www.emdat.be/.

rapid and destructive and cause significant damage in Nile Basin countries. In the rainy season of 2020 alone, flash floods and landslides triggered by these floods left more than 100 dead and displaced more than 100,000 people across the Basin.

- The Nile Basin is also prone to extreme and extended drought, which is characterized by abnormally low rainfall, delayed onset and cession of rainfall, and long period (> 12 days) of dry spell between storms leading to lower-than-normal water levels. recently experienced droughts that had devastating consequences for lives and livelihoods, causing crop failure and reduced water storage, which resulted in serious food security problems in the region. For example, in 2015, Ethiopia faced a devastating drought, during which around 10 million people were estimated to need US$1.4 billion in food aid, with 400,000 children severely malnourished[4].

1.2 Flood prone areas and early warning systems of Easter Nile sub-basins

1.2.1 Ethiopia

In the Eastern Nile part of Ethiopia, the flood prone areas are Fogera and Dembia plains contingent to Lake Tana, the Gambella plains, and the Humera area of the Tekeze basin (near Ethio-Sudan border), as well as flash floods at various locations.

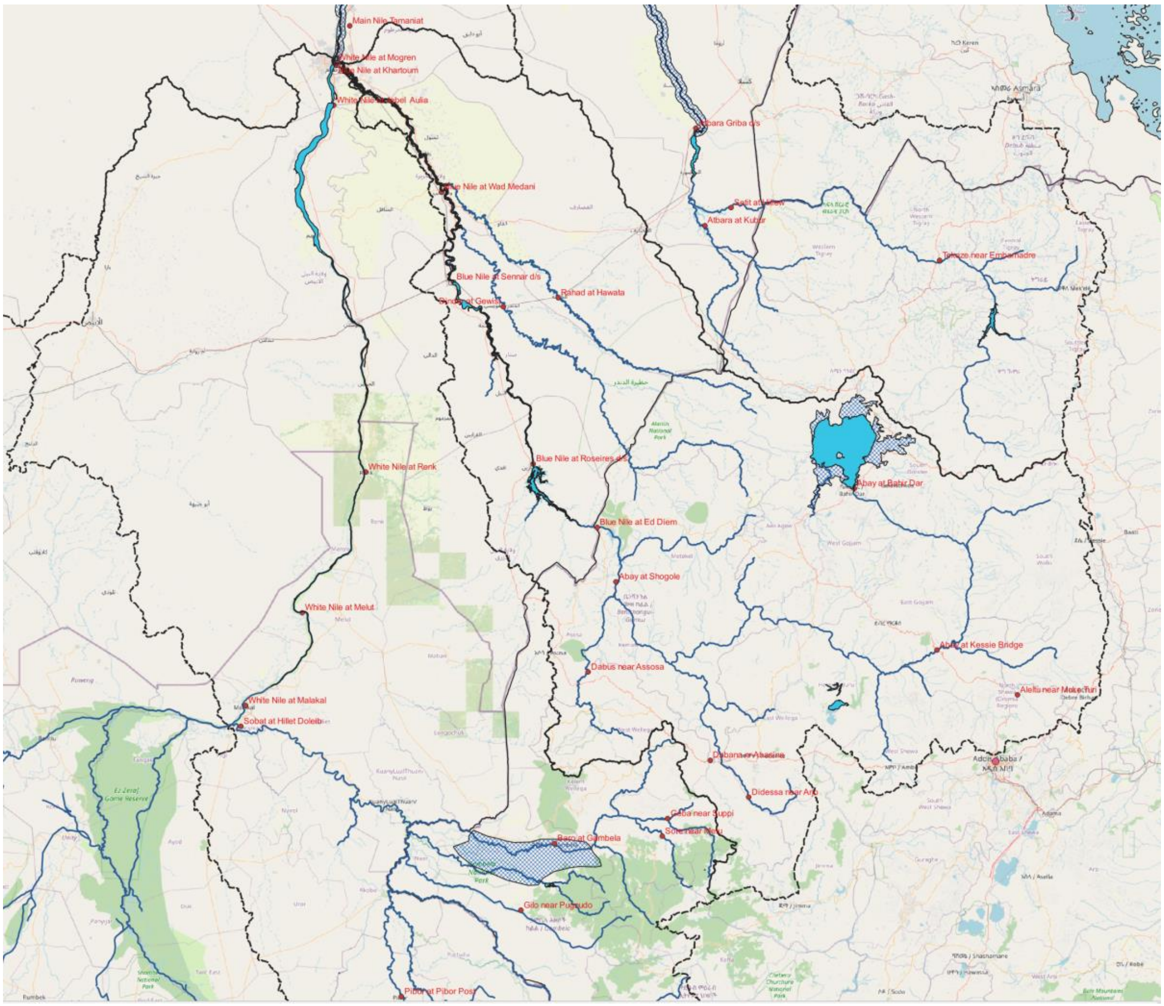


Figure 1: EN flood prone areas (hashed) key flow gauging stations (Red points)

[4] Maasho, A., and E. Blair. 2016. Drought Tests A Changed Ethiopia, Reuters. Retrieved from https://www.reuters.com/article/us-africa-drought-ethiopia-insight-idUSKCN0V908B.

Lake Tana: Flooding is a recurrent threat occurring almost every year in the Lake Tana area caused by the overflowing of the Dirma and Megech rivers which overflows into Dembia floodplain; whereas Gumera and Rib rivers overflows into Fogera floodplain. At the and of the rsiny season (September) often Lake Tana high water level (> 1787 masl) often causes backwater flow in these confluence rivers casing further flooding. Direct rainfall on the floodplains also contributes to inundations (Hydrological Study of Tana-Beles Sub-basins (SMEC, 2008) for the Ministry of Water and Energy of Ethiopia).

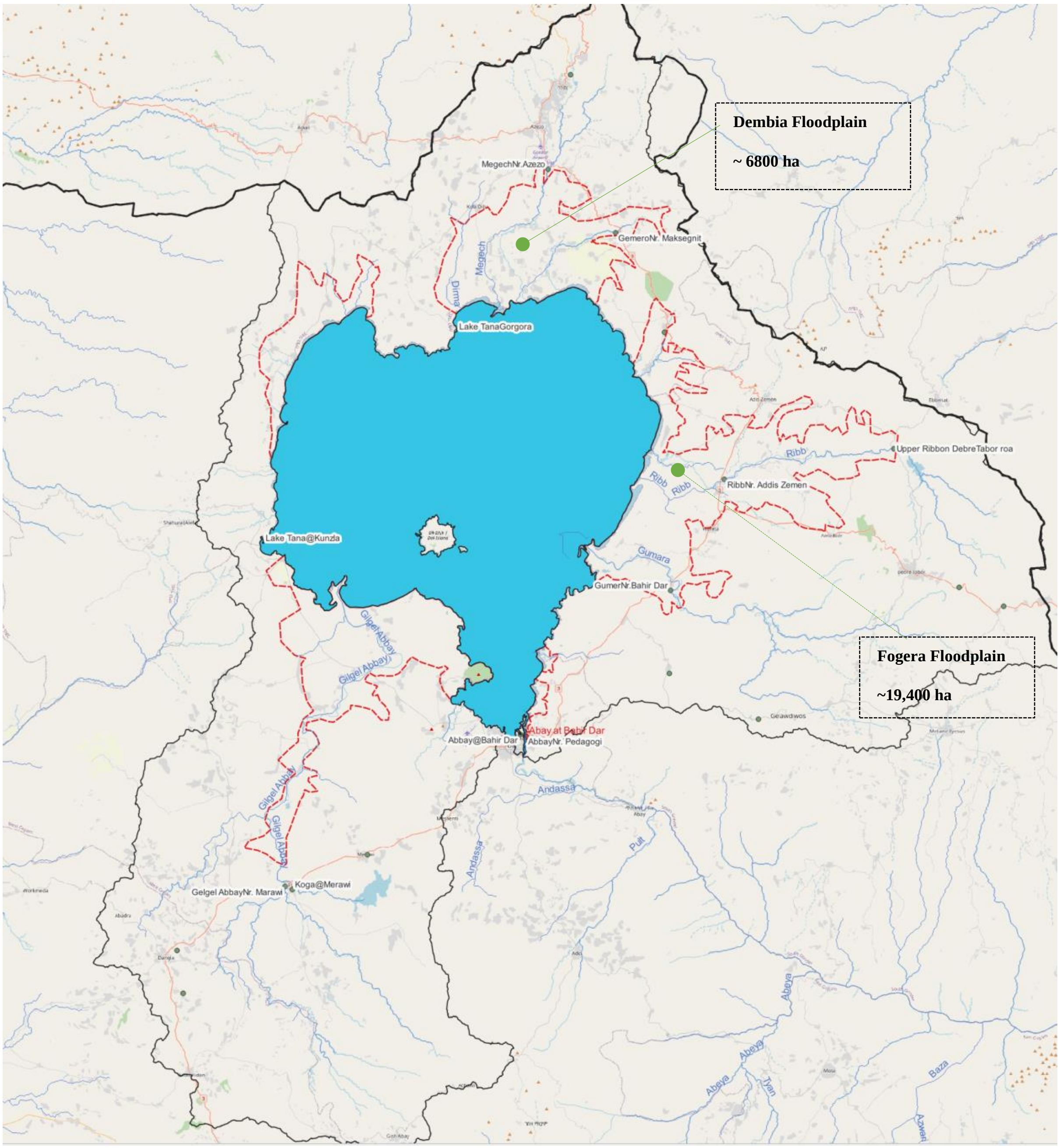


Figure 2: Lake tana flood prone areas (enclosed in dotted red lines) and key flow gauging stations (green points)

Gambella Plains: The flood plain area, belonging to the lowlands of Baro-Akobo Basin (below Gambela town), is partially inundated by floodwaters every year. Baro, Gilo, Alwero, Akobo, Pibor rivers are the main causes of flooding. While most of the agrarian land use has adapted to the seasonal flux of flood waters, there are rural areas and several settlements affected by larger floods including the city of Gambella.

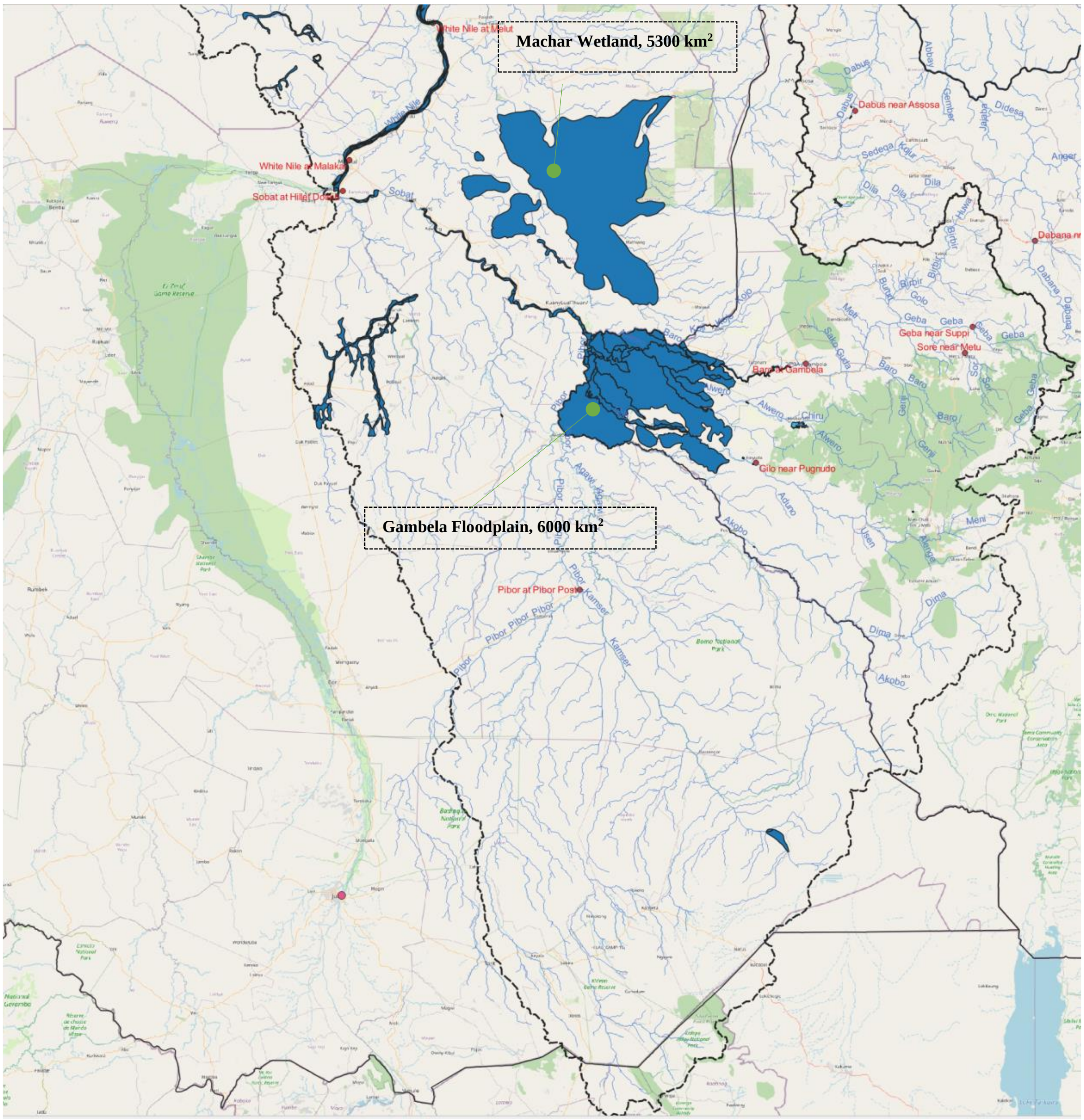


Figure 3: BAS flood prone areas (deep blue shaded) and key flow gauging stations (red points)

Tekeze near Humera: The flat area at Humera (near the Ethio-Sudan border) is occasionally flooded from overflow of the Tekeze river over its banks. This occurs during extreme rainfall conditions in the upper catchment of the Tekeze basin.

Figure 4: TSA flood prone areas (deep blue shaded) and key flow gauging stations (red points)

In many cases, issued flood early warning are not well implemented. For example, 16 rural Kebeles in Jore woreda in the Gambella region – do not have access to modern communication technology and local people may not have personal radios or sirens that are not functional; making disseminating alerts to the affected community is challenging. The situations in the different areas are aggravated by incidences where flooding at times take place without warnings being issued to the local people (e.g. Libo Kemkem in the Amhara region). ENTRO survey found that the is no evidence of monitoring mechanisms to check whether warning messages reach community members and/or are understood and interpreted correctly (EN-FFEW Enhancement Summary Report ENTRO, 2020).

Experiences in response activities to flood early warning at community level can be categorized as follows:

- Some respond positively to warnings by taking the necessary preparedness actions to save their lives and property (elderly and children will settle to high ground; grains and other properties placed at elevated platform; escape footpaths identified indicators maintained/ placed)
- Others are reluctant and do not respond to the flood warnings – e.g. Some in Fogera Woreda in Amhara region
- A third group of community members is without viable options to take the necessary preparedness action. For instance, the people living in the plains of Jore woreda in Gambela region cannot resettle in safer areas because the flat land is easily inundated.

1.2.2 South Sudan

In the Eastern Nile part of Republic of South Sudan, riverine floods as well as flash floods regularly affect settlements in the Akobo and Sobat river plains (Figure 3). Most people there live and work in settlements in flood prone areas because their livelihoods depend mainly on farming in floodplains, on fishing, and/or on livestock. The city of Malakal at the confluence of the Sobat and the White Nile is also affected. Most floods occur annually (May - October). There is no FEWS developed by ENTRO for these areas.

The main vulnerable settlement areas are the following:

> Akobo: The vulnerable settlements are in flood prone areas are Akobo town and Nadir town including surrounding small villages. These areas are affected by flash floods and riverine floods.
>
> Malakal: The vulnerable communities are the Shilluk, Dinka, Nuer and Burun, Koma and other small communities.

There are many local communities with strong social structures. The local communities have their traditional way of responding to the early warning. They are prepared to store their food in their houses to be used in case of flood incidents. They also dig drainage systems to drive away water that enters their houses when floods occur where topography allows.

1.2.3 Eastern Nile part of Sudan

Flood prone areas In the Eastern Nile part of Sudan are along the Blue Nile stretch from El Diem to Khartoum, the Gash river around Kassala City and around Nyala and El Fashir areas in the west of the country.

With respect to flood vulnerability and preparedness, the investigations in these communities reveal the following issues:

- Inadequate training initiatives to enhance local capacities to mitigate and cope with seasonal floods
- Not enough time given to community to evacuate if necessary
- No reliable forecasts or measurements - no fixed thresholds for warnings and alerts
- Sometimes alerts come from different channels, which may lead to confusion.

Community level surveys in Sudan have revealed that at least 7 days lead time is required to save livelihoods and assets from flood disasters. This needs to be weighed against the fact that longer lead times result in less reliable forecasts.

1.3 Previous activities of NBI - ENTRO.

Addressing hydrometeorological hazards, planning for flood mitigation has been one of the key service delivery areas of the NBI since its establishment in 1999. The Flood Preparedness and Early Warning System (FPEW) project focused on enhancing regional collaboration and national capacity in flood risk management, including flood mitigation, flood forecasting and early warning, as well as flood emergency preparedness and response. The project has been implemented in two phases FPEW I and FPEW II:

FPEW I focused on building the institutional capacity and developing critical baseline information to enhance the readiness of EN countries to implement subsequent FPEW phases. It delivered a platform for institutional settings and data/information collections/sharing at community and national levels, together with enhancing regional coordination and cooperation with the recommendation for subsequent phases. FPEW I was concluded in 2010.

ENTRO under the FPEW II phase created a regional Flood Forecast and Early Warning System (FFEWS) under the Eastern Nile Planning Model project (ENPM) and the FFEW activity continued under the Nile Cooperation for Result project (NCORE). the FFEW system has continuously been implemented since 2010 for every flood season (June–September). The FFEW system has helped the EN countries in reducing the loss of life and money by preparing flood forecast bulletins for *the three flood-prone areas* of (i) Lake Tana (Abbay/ Blue Nile-Ethiopia), (ii) Blue Nile - Main Nile (Sudan), and (iii) Baro-Akobo-Sobat (Ethiopia, South Sudan, and Sudan) sub-basins.

Over the last 10 years (2010-2020) of implementation, the FFEW system has been enhanced mainly in the following areas[5]:

(a) expansion of the coverage area of FFEW to part of South Sudan and Tekeze-Setite-Atbara (TSA) sub-basins;
(b) integration of flood models that depended on different tools for different sub-basins, into a uniform platform of MIKE suites; and
(c) update of stakeholder list of respective countries to reduce inefficient alert. During the 2020 flood, for example, the river flow forecast bulletin released through the FFEW system has been utilized by the Government of Sudan to issue evacuation advisory to people and livestock across the country.

The FFEW system has the potential to improve forecast accuracy by incorporating *ground observed data* collected through the NBI hydromet station network, operation rules of dams along the main channel and major tributaries, and river cross section and flood plain survey data to more accurately predict flood-inundated area.

Reliability of flood forecasts is dependent on robust and stable models (rainfall forecast, flood peak/volume forecast, inundation depth, extent and duration forecast, flood risk assessment) intrinsic capacity to represent reality and the input datasets to the models. that are used in the. It is found that, in the Easter Nile -Flood Forecasting and Early Warning (EN-FFEW) models, in general, the following datasets need to be improved:

- **Hydro-meteorological observations on the ground**: Historical and real-time timeseries of rainfall at spatially well distributed weather stations, river flows and reservoir water levels at key gauging stations need to be improved and made available.
- **Topographical data**: The river cross sections and floodplain topographic and asset survey data are limited, and the current hydrodynamic models are using data from DEMs. Moreover, information on vulnerable land use, and critical local flood protection infrastructure, such as levees and dikes (if they exist).
- Consistent **socio-economic** characteristics of flood prone communities
- Flood early warning **information dissemination** network (forward from forecaster and backward from community)

When new and improved datasets become available the hydrological, hydrodynamic, flood risk assessment models will be revised, calibrated, and validated further, to improve the quality of the FFEW products and services. This in turn is important to be useful for the flood affected community and ensure all stakeholder trust.

[5] EN-FFEW Enhancement Summary Report
http://ikp.nilebasin.org/sites/default/files/Flood_IKP_Reports/Reports/ENFFEW%20Enhancment%20Summary%20Report.pdf;
ENCORE 2020 EN FFEW Enhancement Report Annex -
http://ikp.nilebasin.org/sites/default/files/Flood_IKP_Reports/Reports/EN%20FFEW%20Enhancement%20Report%20Annex.pdf

2 Purpose of this report

The main purpose of this report is to assess data status and gap on: hydrometric, climatological, floodplain topographic and river cross-section, and socioeconomic characteristics of the communities in floodplains based on desktop study. This report is an input to the Work Package I (WP1) consultancy work.

Specifically, the main purposes of this *data status and gap analysis report* for the EN flood risk mitigation (EN-FRM) are:

- To identify flood prone area (additional ones in the BAS And TSA), extent and type of datasets (e.g. terrain data) need to be collected to be used for flood forecast, and flood risk mapping. The *flood-prone areas* are Lake Tana (Blue Nile-Ethiopia), Blue Nile - Main Nile (Sudan), and Baro-Akobo-Sobat (Ethiopia, South Sudan, and Sudan) sub-basins

- To identify flood prone communities and their characteristics including vulnerable land use, and critical local flood protection infrastructure, such as levees and dikes, community vulnerability and preparedness.

The WP1 consultant will use this report to further define survey areas during field work in the flood prone areas for the enhancement of the Eastern Nile Flood Risk Mitigation (EN-FRM) project conduct the necessary surveying, data compilation, collection as well as data quality control activities.

The next section present (a) the recent EN hydrology and hydraulic flood forecasting model network / structure employed in, (b) the hydrometeorological data status including rainfall forecast aspect, (c) terrain dataset in flood prone areas, (d) proposed topographic and asset survey flood prone sites (as part of gap assessment), (e) a guide to topographic and cross-section surveying specification, (f) a guide to identify and map vulnerable assets.

3 Recent hydrology and hydraulic flood and inundation forecasting models

3.1 Hydrologic and hydraulic models'

ENTRO (2020) flood forecasting and early warning system (FFEWS) enhancement project has started upgrading the existing FFEWS for the three Eastern Nile sub basins – Lake Tana, Blue Nile, Tekeze-Setit-Atbara (new), and Baro-Akobo-Sobat - using MIKE Operations platform, a software by DHI (Table 1). The NAM (hydrologic model) and Mike 11 (hydraulic model) were employed. These models will help to predict the flows and water level at the selected flood prone areas with a reasonable lead time of 3 days (72 hrs) based on 3-day lead time rainfall forecast generated from the Weather Research and Forecasting model (WRF) model with time step of 3 hr. Available observed flow and gauge levels were used for calibration and data assimilation.

Table 1: Characteristics of the hydrologic and hydraulic models of the EN basins as implemented in MIKE OPERATIONS (ENTRO 2020)

	Hydrologic models (NAM)			Hydraulic models (MIKE 11)			
Basin (Figure 1)	Modelled number of catchments	Catchment area range (km^2)	Number of flow forecast locations	Number of river reaches	Total length of river reaches (km)	Total number of cross-sections used in the model.	Downstream boundary condition
Lake Tana[6]	14	62-2,049	13	4	133	533[7]	Daily Lake Tana water level time series
Blue Nile[8]	28	890 – 32,167	7	2	2230	1072[9]	Q-H of the Blue Nile at Khartoum (observed rating curve)
Tekeze-Setit-Atbara[10]	13	3,847 – 33,599	5	2	947	489 (cross-section need major modification, direct from AIRBUS DEM)	Atbara complex dams and reservoirs are not included in the model
Baro-Akobo-Sobat[11]	10	9,235 – 112,727	10	3[12]	2038	240 (cross-section need major modification)	Calibration flow data are not provided in the MIKE 11 model

[6] Head waters of the catchments constituting four rivers flowing into Lake Tana namely Dirma, Gumera, Megech and Rib

[7] Lake Tana and Blue Nile modelled rivers cross-sections were imported from the HEC-RAS flood model having some measured cross-section; Rib reservoir is not included in the DHI model.

[8] Blue Nile river from Eldiem to Khartoum including the White Nile confluence (flood source area is Abay basin)

[9] Some of interpolated cross-sections and imported from HEC-RAS model are unrealistic.

[10] River reach from Tekeze river at Humera to Atbara river confluence with Nile river (Humera, Atbara cities are affected by flood)

[11] Extensive flooding on the lower reaches of Baro, Akob, Gilo, Alwero rivers are common. Strat of Sobat river (after Baro, Gilo, Akobo, Alwero joins) up to the confluence of White Nile at Malakal is prone to flooding.

[12] Baro, Pibor, Sobat and White Nile river are modelled; Gilo and Akobo rivers (which contributes much to flooding are not included in the modelling (see Figure 5).

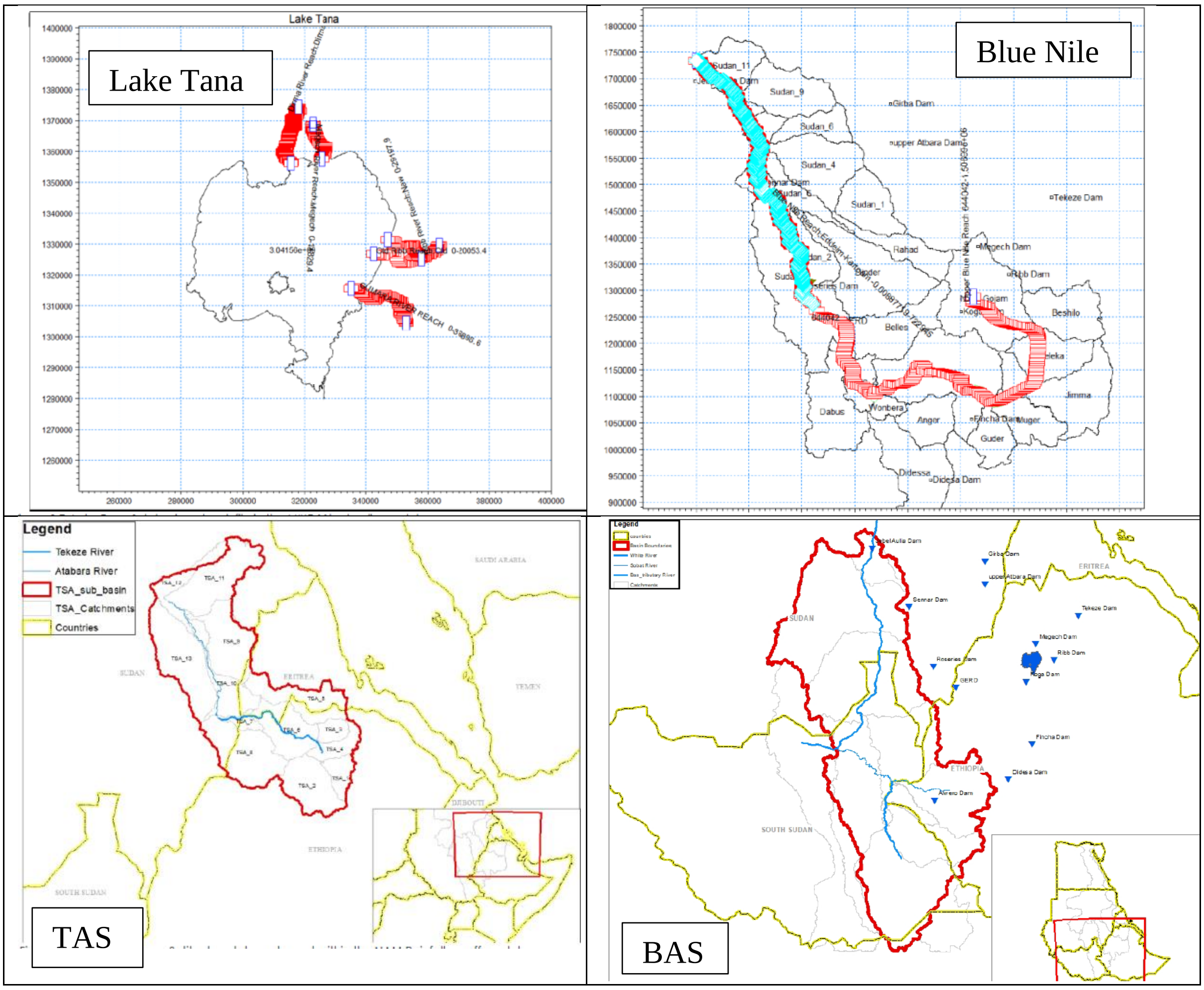


Figure 5: EN FFEWS modelling sub-basins (compiled from ENTRO 2020)

3.2 General NAM and Mike 11 model data need

The hydrologic model (NAM) and hydraulic model (MIKE 11) critical data needed for calibration:

Hydrological model input data:

- Catchment delineation area, river length, slope, land use land cover, soil type and hydraulic properties
- Meteorological data: rainfall (3-hr time step), temperature, potential evapotranspiration (monthly)
- Streamflow (3-hr time step, daily values may be used for large watersheds > 5000 km^2) data for calibration and verification purposes of the NMA and MIKE 11 models

River and floodplain topography

- Survey of river and floodplain cross-sections and structures
    - Where significant changes occur with respect to:
        - River sections shape
        - Bed level gradients

    - River width
    - Contractions or expansions
    - Recognized changes in flow dynamics from one section to another
- Topographic map including assets
- Channel and flood plain manning roughness
- Aerial/satellite/radar images of flood extents
- Hydraulic features of existing structures (culverts, bridges, diversion weirs, bottom outlet, etc) including flow-area of structure and inlet and outlet properties (elevation, slope, material, …)
- Reservoir data (control strategy, spillway etc.)
- Processed inundation depth, duration and volume (from satellite image) – high vertical resolution – 0.5 m

Hydrometric Data for Boundary Conditions

- Rainfall data (hourly to daily)[13]
- Stage & discharge hydrographs
- Rating Curves and velocity data
- Lake / reservoir water levels
- Drop / fall structure location (critical flow boundary condition)
- Peak water levels during significant events
- Local people recollections of flood behaviours (peak level, damage, extent, timing, location of breakouts)

Once we calibrate the models, then WRF 3-hr time step 3-day ahead forecast will be used to estimate flood peak magnitude, inundation extent, and the accompanying risk. MIKE II allows to use mixed time steps in modelling at the same time (for HD modelling we may use time step of few second and for the rainfall runoff modelling we may use 1-day time step). The daily flow, which is often available in the EN, can be used to calibrate NAM parameters for given watershed.

4 Hydrometeorological data

4.1 General

It is known that the accuracy of flood forecasts will depend on the accuracy of the boundary conditions (flow / stage) and rainfall forecasts, the model (structure and level effectiveness of calibration using observed discharge) and the efficiency of hydrologic and hydraulic models' parameters updating routine. Applying real-time updating (data assimilation) may provide accurate flood forecasting. It is expected that, the forecast models should be able to simulate the water flow and water level accurately up to the time of forecast (to do so dynamic calibration approach is required). In other words, updating consists of conditioning the model predictions to the observed data prior to the Time of Forecast.

[13] Rainfall data with any (variable) time increments can be specified in the rainfall input. The NAM model will then make the necessary interpolations according to the simulation time step. The rainfall data are treated as accumulated totals so the rainfall associated with any particular time is the rainfall volume since the last entered value. MIKE11 Reference Manual, Page 279.

4.2 Sources of data

Daily and sub-daily flow data are useful to calibrate flood forecasting hydrological models. Decadal and monthly flow data are also useful to assess inundation volume and extent. Only few stations with daily flow data are found at ENTRO database. There are about 20 and 3 streamflow stations in Ethiopia and Sudan respectively having daily streamflow data archived at the ENTRO. Several streamflow gauging stations are available with monthly flow data normally extracted from the countries master plan reports. There are about 9, 8 and 2 rainfall stations in Ethiopia, Sudan and South Sudan respectively which have daily rainfall data archived at the ENTRO.

Some reports for further assessing the availability streamflow, data compilation as well as data quality control, and climatic data at ENTRO system are indicated below:

- ENTRO (2020). Eastern Nile Flood Forecasting and Early Warning Enhancement (FFEW) project and Meta Database on Time Series.
- ENTRO (2017). Baro Akobo Sobat multipurpose water resources development study –Strategic Social and Environmental Assessment report, and other associated report the water balance study and modelling report.
- The Nile Basin Encyclopedia: Ten-daily observed flow data are available at various stations spread across the Nile Basin.
- Ethiopian Master Plan Reports: Monthly observed flow data at various stations across the Nile Basin.
- ENTRO BAS IMS: ENTRO maintains databases of monthly flow data at selected stations based on various sources.
- Deltares (2012). Development of the Eastern Nile Water Simulation Model. Monthly flows were generated at dam, diversions, and junction sites, imbedded in the Ribasim basin model developed for EN.
- Hassan A. (2012). Water balance model for the Eastern Nile Basin.
- NBI (2012). Data compilation and pilot application of the Nile Basin Decision Support System: Work Package 2: Stage 2: Integrated water resource development of the Baro-Akobo basin: Scenario Analysis report.
- Water Balance Consulting (2012). Eastern Nile River Ware Planning Model.
- Sutcliffe and Parks (1999). The Hydrology of the Nile.
- Selkhozpromexport (1990). Baro-Akobo basin master plan study of water and land resources of the Gambela Plain.
- And other reports, as well as those found in *http://ikp.nilebasin.org/en/knowledge-repository.*

4.3 Hydrometeorology data gap assessment

FFEW models calibration requires hourly to daily real-time rainfall and streamflow data. ENTRO recently developed (at initial stage) Rainfall runoff model based on NAM and Mike 11 hydraulic models running on Mike Operation operationally four flood prone sub-basins.

NAM / Mike 11 models "calibrated" under scarce data obtained (Table 2); and they need further development. The consultant thus specifies and identify further key rainfall and flow gauging stations that have reasonable long and reliable data to firmly calibrates these models.

Table 2: Hydrometeorological data required for hydrologic and hydraulic models calibration

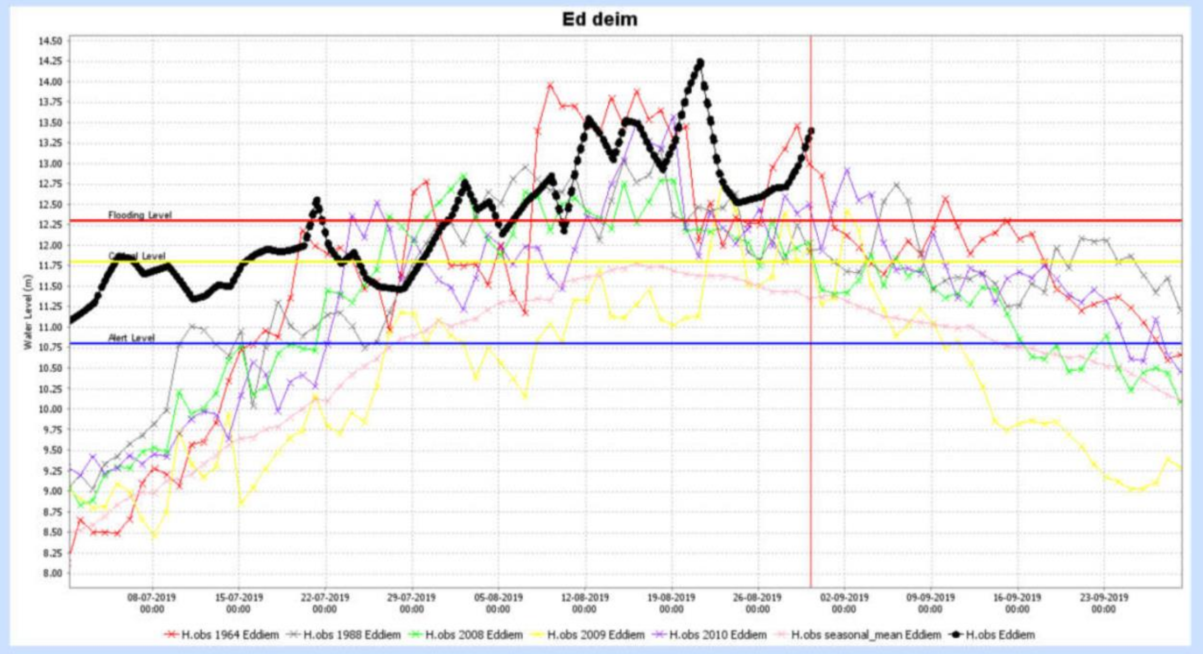
Sub-Basin	Hydrologic /hydraulic models (NAM / Mike 11) – Source: ENTRO (2020) Eastern Nile Flood Forecasting and Early Warning Enhancement Integrated Report.		
	Met stations used for modelling	River flow gauging station used for calibration	Remarks
Lake Tana	Rainfall for 2013, 2014 and 2018 was from satellite generated data (values) NOAA RFE[14] for all the sub catchments of the four basins of the Eastern Nile, and the calibration of the flows at gauges with available data was conducted.	Gumara near Bahrdar (1394 km^2), Ribb near Addis Zemen (1592 km^2)	Megetch near Azezo (462 km^2), Dirma near Kola Diba, Lake Tana water level data were not used
Blue Nile		Blue Nile at Eddiem,	Flow data were not provided. Blue Nile at Khartoum is not used for calibration.
Tekeze-Setit-Atbara		Upstream and Downstream Atbara, Girba dams, Tekeze at Humera,	Flow data were not provided, Atbara river (Atbara Kilo 3) and Nile at Atbara flows are also required for calibration
Baro-Akobo-Sobat		Baro at Gambela	Sobat at Hillet Doleib (near Malakla city) and White Nile at Malakal data were not used for calibration

5 ENTRO Flood alert levels

Flood alert levels used by ENTRO in Blue Nile and BAS are reproduced from "Flood Preparedness and Early Warning | Weekly Bulletin", Release No. 03 August 30, 2019. It is seen that if Blue Nile water level (local stage) at Eldeim is above 12.3 m then flooding downstream of Rosaries dam is expected (provided that dam is full). Further downstream, if Blue Nile water level (local stage) at Khartoum is above 16.5 m then flooding is expected in Khartoum along the Blue Nile river, where banks are low (Figure 6). The flood alert level for both Baro river at Gambela city and Itang town is 5.5 m (local stage).

Table 3 provides flood thresholds and alert designation (m^3/s) from ENTRO 2020 Flood Forecast and Early Warning Activity Report. It is good to check if this Q is corresponding with alert level discussed above.

[14] The NOAA RFE satellite-based rainfall estimate – 3hr interval - uses the WMO Global Telecommunication System (GTS) rainfall observation data taken from approximately 1000 stations which are assumed to be the true daily rainfall near each station for each day (https://link.springer.com/chapter/10.1007/978-3-540-75369-8_4).



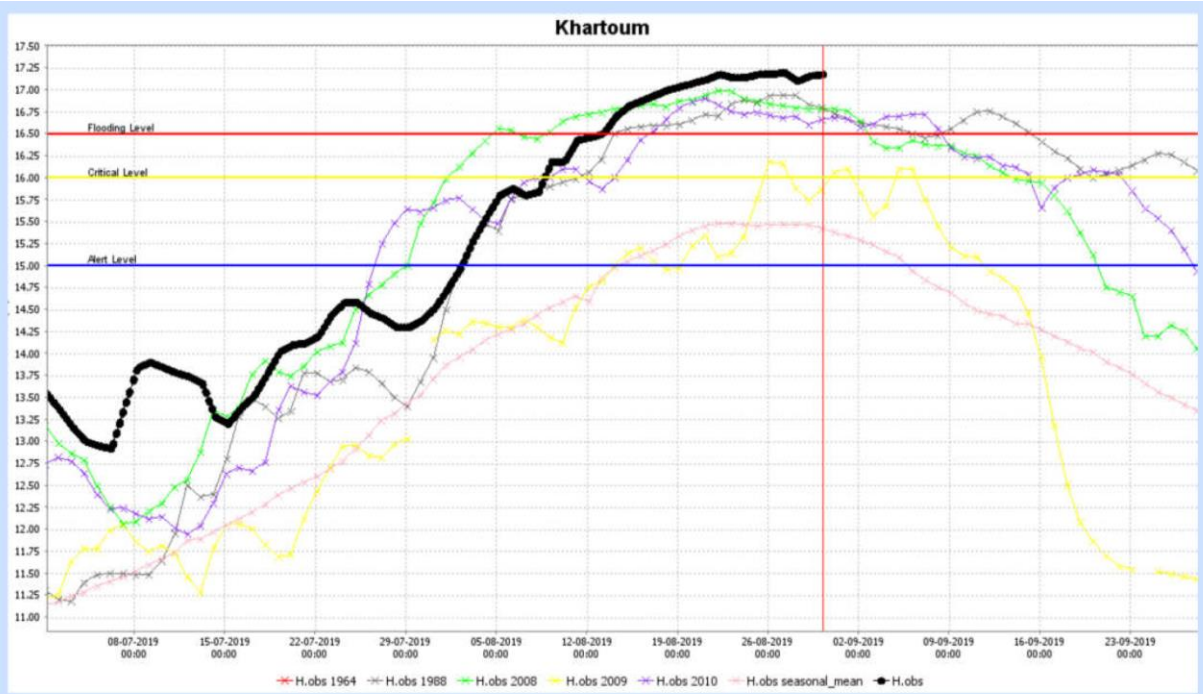


Figure 6: Blue Nile flood alert level at Eldiem and Khartoum gauging stations (15 m = 378 masl)

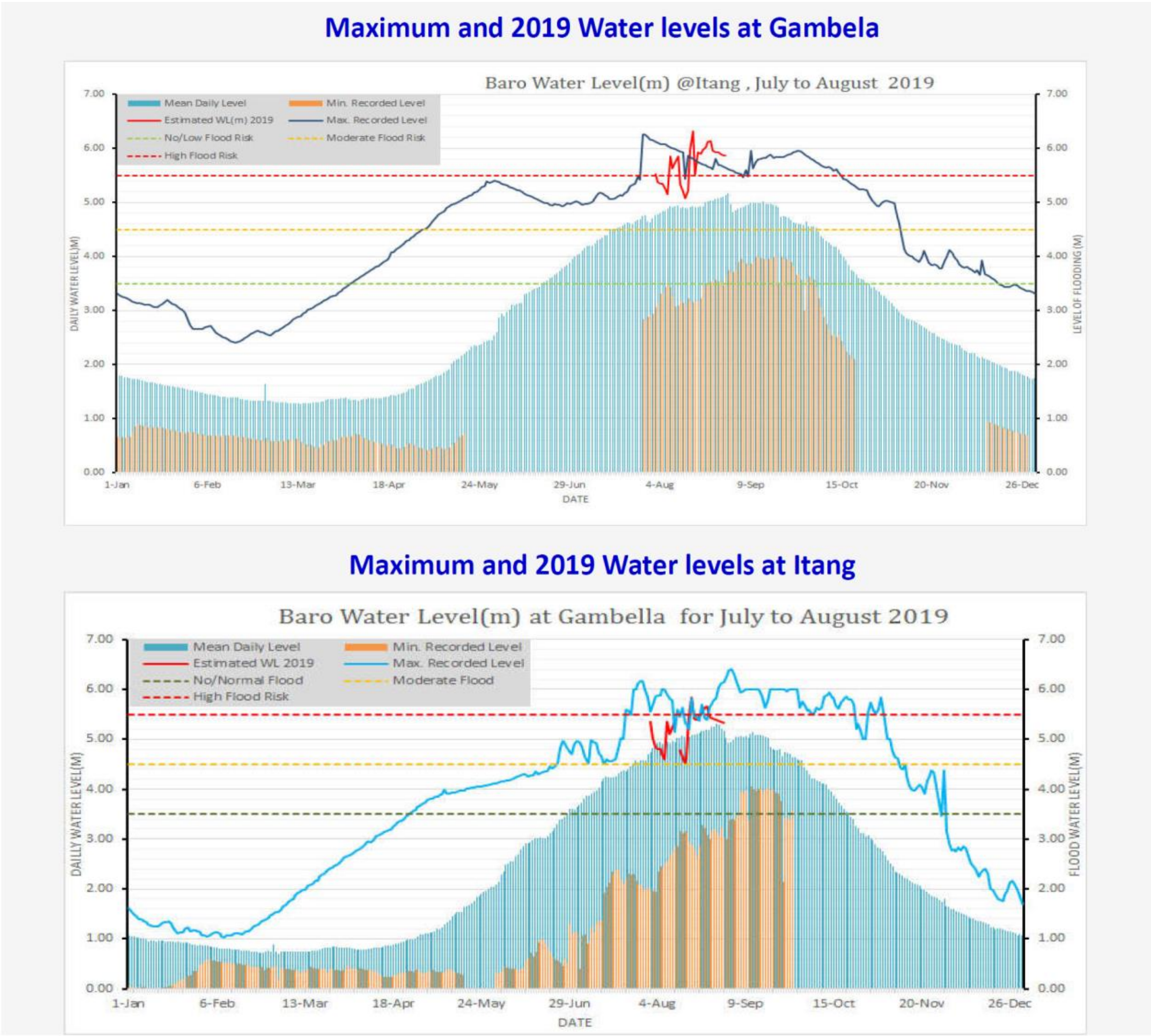


Figure 7: Baro river flood alert level at Gambela and Khartoum gauging stations

Table 3: Flood thresholds and alert designation (m^3/s)

	Tana				BN									MN	BAS			TSA				
	Dirma	Megech	Ribb	Gumara	Bahir Dar	Kesie	Border	Eldiem	DS-Roseries	Wad Elais	US-Sennar	Medani	Khartoum	Dongula	Gambela	Itang	Melakal	Embamadre	Humara	Kibur	Girba MC	Atbara
Extreme	126.0	355.3	218.7	307.9	697.0	5,897.0	12,684.4								1,702.1	1,338.1		3,390.1	2,184.6			
very High	94.5	266.5	164.0	231.0	522.8	4,422.8	9,513.3								1,276.6	1,003.6		2,542.6	1,638.4			
High	31.5	88.8	54.7	77.0	174.3	1,474.3	3,171.1								425.5	334.5		847.5	546.1			
above Normal	16.0	28.9	43.8	102.2	230.6	1,702.6	4,128.6								737.7	780.2		679.3	472.2			
Normal	3.7	9.1	15.2	39.1	135.5	715.1	1,987.4								365.2	407.6		322.7	172.7			
Low	2.8	6.9	11.4	29.3	101.6	536.3	1,490.6								273.9	305.7		242.0	129.5			
very Low	0.9	2.3	3.8	9.8	33.9	178.8	496.9								91.3	101.9		80.7	43.2			

6 Rainfall forecast generation

ENTRO currently uses the Weather Research and Forecasting (WRF) model, customized for the EN region, to produce a three-day lead rainfall forecast giving at 6km x 6km and 3 hr resolutions. In case the WRF forecast is not able to run, an alternative rainfall forecast data is sourced from NCEP (United States National Centre for Environmental Prediction) (Global Forecasting System (GFS) model (coarse resolution and low accuracy) with 25 km X 25 km resolution (NCEP-GFS0.25), afterwards re-gridded to 6 km x 6 km to provide alternative forecasts (3-day ahead forecast time steps at a 3-hourly interval). The 3-day ahead WRF rainfall forecast is updated daily. The 6-hourly 9-day ahead rainfall forecast made by NCEP-GFS0.25 may be used to forecast 9-day ahead rough forecast for large watersheds including Blue Nile at border; Tekeze at Humera, etc.

Forecasted rainfall is calibrated (retroactively) using CHIPRS derived rainfall (satellite-based observation with 5 km resolution but with data latency of 10 days), and alternatively Global Satellite Mapping of Precipitation (GSMaP) - with data latency of 4 hrs and spatial resolution of 12 km. Moreover, observed real-time rainfall data are also required to further calibrate the WRF forecast, and to model initialisation / update.

The consultant assesses the real-time rainfall gauging station that can be used for WRF forecast calibration. The consultant also investigates the NBI-Hydromet project utility in the forecast calibration[15].

7 Terrain dataset in the flood prone areas

In general, useful flood risk assessment requires accurate (< 1 m vertical resolution) terrain map of the floodplain including rivers longitudinal profile and its cross-sections as well as their geographic locations and hydraulic parameters including river banks, bed and floodplain roughness of river structures including dykes.

Floodplain maps consists of georeferenced base map imagery and the corresponding elevation data. Two-dimensional base map imagery available from digital “orthophotos,” aerial and satellite photographs like those viewed on Google Earth. Accurately displaying the flood elevation requires high-accuracy base elevation data. Satellite based topographic maps can also be produced with vertical elevation accuracy of ~ 1 m.

Light detection and ranging (LiDaR) technology is often used to collect high accuracy elevation data for extensive floodplain area in short period. Lidar can produce a bare-earth elevation model with 2-foot (0.67m) equivalent contour accuracy in most terrain and land cover types and a 1-foot (0.33 m) equivalent contour accuracy can be achieved in very flat coastal or inland floodplains (https://www.nap.edu/resource/11829/floodplain_mapping_final.pdf).

This chapter will assess the availability of the terrain data in Lake Tana, Blue Nile, BAS and TSA sub-basins flooding prone areas at ENTRO.

7.1 Lake Tana

The following section presents datasets (built in HEC-RAS) on river cross-section, floodplain survey data and assets/infrastructures in the Lake Tana sub-basin.

ENTRO in 2010 executed flood plain topographic survey in lake Tana sub-basin, and produced 591 river cross-sections data, and 54.2 ha floodplain survey near lake Tana (Table 3). The first ground control point was set up at Bahir Dar at the national reference point located 700 m to the right alongside the road from Bahir Dar to Adet.

[15] ENTRO - Nile Basin Regional Hydrological Monitoring Network Design, Final Design Report, 13 August, 2020

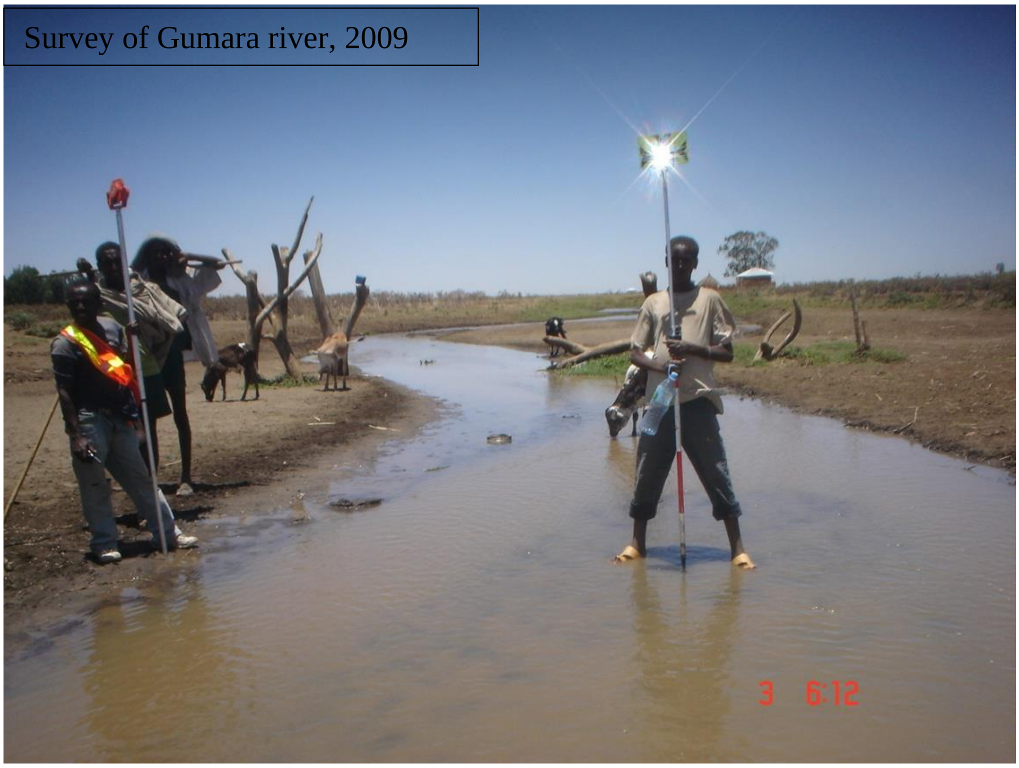


Table 4: ENTRO 2009 flood plain topographic survey in lake Tana sub-basin

Watershed for which river cross-section is surveyed	Ground control point	No of river cross-section surveyed	Structure/Infra structure Surveyed[16]	Flood plain area surveyed [17] adjacent to the lake (ha)
Megetch (15 km reach)	The ground Control Points (FR14 & FR15) for surveying the Megech River were established within the Zengi Robit School compound about 16 km south from Kola Diba town along the track through Guramba village.	90[18]	Dyke, footpaths, settlements, gaging stations, road,	48
Dirma (32 km reach)	Four ground control points established (FR12 & FR13, FR16, FR17)	183	Bridge, settlements	2

16 There are generally sparse settlements with mud houses coded as "CHK" and small huts (Gojo) coded as "TUKUL". Trees coded as "TREE".

17 Moreover, at the beginning, a conventional topographic survey was performed on about 2ha of land adjacent to Lake Tana where the Dirma River enters the lake. The Lake Tana water levels were recorded as part of this survey.

18 Each station of was designated by the 1st letter of the rivers name (M, D, G, R) followed by the distance in km from lake Tana (M0, M0.3, M0.7, M1, M1.3, …, M15). River cross at about 300-450m intervals upstream from Lake Tana. At each section/station, the left and right bank bottom levels, left and right bank top levels, side channels, river bed level and water level were surveyed. In addition, at about every km along the river, the cross-section survey was extended further out into the flood plain for about 1km to the left and right beyond the river channel. Moreover, at the beginning, a conventional topographic survey was performed on about 48ha of land adjacent to Lake Tana where the Megech River enters the lake. The Lake Tana water levels were recorded as part of this survey. A closer river cross-section picture with a reasonably higher pixel have also been take at the cross-section where ground survey have been conducted.

Watershed for which river cross-section is surveyed	Ground control point	No of river cross-section surveyed	Structure/Infra structure Surveyed[16]	Flood plain area surveyed [17] adjacent to the lake (ha)
Ribb (29 km reach)	Two Ground control points established (FRM8 & FRM9)	163	Dyke, Electric pole, Bridge, Settlements, Gauging stations	2
Gumara (37 km reach)	Six Ground control points established (FR2 at Gumera Bridge & FR3 at Gumara Gauging St, FRM3, FRM4, FRM5, FRM6, FRM7)	155	Dyke, Electric pole, Bridge, Settlements, Gauging stations, Culvert, Ditch	2.3
	Total	**591**		**54.2**

The Lake Tana water levels were recorded as part of this survey.

Table 5: ENTRO 2009 established 21 ground control points Lake Tana floodplains

Easting (m)[19]	Northing (m)	Ortho Height (m)	Site Description	ID
474317.099	998745.737	2452.967	Addis	ADIS
324150.129	1278375.026	1801.89	Bahir Dar Town	BDTW
334499.155	1379927.293	1940.015	Teda police station	FM12
350558.878	1355514.57	1933.72	Enfranz high school	FM10
342865.881	1369228.185	1926.92	Maksegit Total	FR11
318442.529	1374300.404	1843.335	Kola Diba TVTE school	FR12
318441.562	1374300.362	1843.362	Kola Diba TVTE school	FR13
324673.89	1362815.935	1792.242	Robit school	FR14
324723.461	1362861.702	1792.253	Robit school East	FR15
315346.155	1371488.305	1807.233	Gabikura south	FR16
315458.034	1371644.308	1808.25	Gabikura North	FR17
343129.959	1302833.284	1935.713	HAMUSIT	FRM1
351275.533	1309054.495	1795.298	GUMERA BRIDGE	FRM2
351531.47	1309050.308	1793.704	GOMARA GAUGING ST	FRM3
346497.167	1315417.278	1790.02	Hod Gebeya West	FRM4
346525.182	1315585.022	1789.8	HOD GEBYA East	FRM5
352857.548	1303414.023	1832.718	Yimer Meda junction	FRM6
352791.953	1304043.027	1813.005	Gedam Geregera Gumar	FRM7
359708.12	1326139.2	1794.556	Ribb river left GSTN	FRM8
359675.297	1326076.666	1794.316	Ribb River near road	FRM9
367334.606	1135987.49	2429.371	Debre Markos	TWQ3

Further note: in the ENTRO (2010) flood survey project the Riverside consultant obtained high resolution satellite imagery collected from the GeoEye-1 satellite to develop a more detailed mapping of the infrastructure in the Lake Tana region. Moreover, Riverside integrated the The

[19] UTM/WGS 84/UTM zone 37N

Riverside consultant used about 33,000 survey points (elevation and location with the datum of WGS_84) developed for the Fogera floodplain by the MoWE for the design of an irrigation infrastructure. The Ministry data were generated in 2006.

7.2 Sudan Blue Nile Survey and Hydrology Data

7.2.1.1 *Topographic and cross-section survey*

The main source of the flood survey data is the ENTRO (2010) Final Report, Flood Risk Mapping Consultancy for Pilot Areas in Ethiopia produced by Riverside & UNESCO CHAIR WR Sudan.

Riverside made an inventory of the existing available topographic data was performed to identify data gaps and the need for additional field surveys. They found about 337 cross-section data along Blue Nile:

- A total of 87 field-surveyed cross-sections for the Blue Nile from Roseires Reservoir to Khartoum were available from this system from 1992 Blue Nile survey.
- 2007 Bathymetric Survey for the 25 Km Blue Nile River Reach between Khartoum and Bagair at 100 m interval (250 cross-sections)
- 2007 Bathymetric Survey for Roseries Reservoir covered a reach of about 110 km upstream of Roseries Reservoir with geo-referenced data.

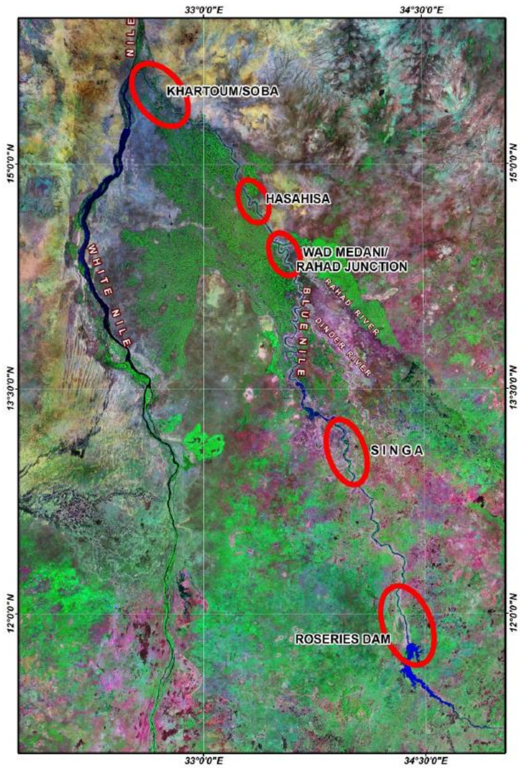


Figure 2-3: Pilot study areas in Sudan

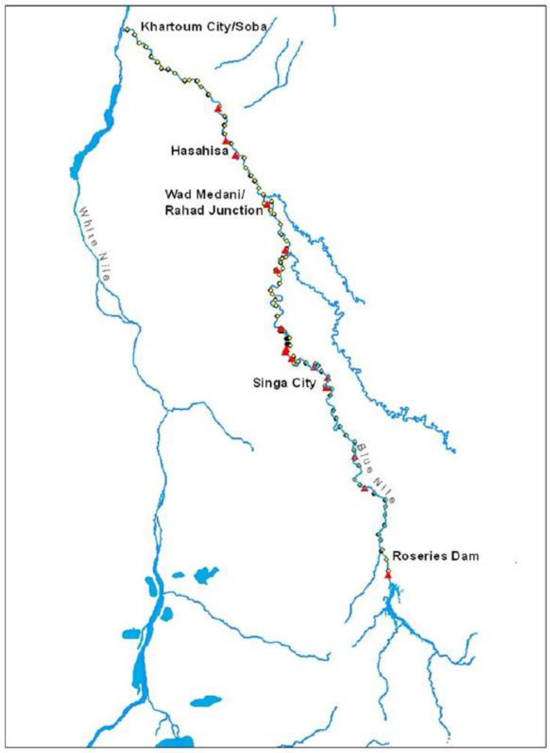


Figure 4-1: Layout of original cross-sections (yellow) and surveyed locations (red)

Figure 8: Flood prone areas in along the Blue Nile river and survey locations (ENTRO, 2010)

Using known control points such as flow gauging stations and hydraulic structures including pumping stations or irrigation features near the river a total of 42 additional river cross-sections along the Blue Nile River were surveyed. The additional cross sections made by ENTRO were at a closer spacing and extended further into the floodplain than previous surveys.

Figure 9: Blue Nile Roseires-Sennar reach (ENTRO, 2010)

7.2.2 Sudan - land use and infrastructure

As part of the 2009 field survey, land use and infrastructure data were collected. Detailed asset geo-databases along the Blue Nile in Sudan, including structures, infrastructure, and agriculture reported in "ENTRO (2010) Final Report, Flood Risk Mapping Consultancy for Pilot Areas in Ethiopia. Produced by Riverside & UNESCO CHAR WR Sudan". Can be found in the "Appendix B 2009 Field Survey.zip", which needs further revision after 10 years.

7.2.3 Hydrological data

Daily/10-day/monthly discharge measurements and timeseries data for the flowing stations along the Blue Nile and its tributaries ENTRO (2009) reported in Final Inception Report, Flood Risk Mapping for Pilot Areas in Sudan including.

- Blue Nile at Eldeim (Ethiopian-Sudanese boarder) for the period 1966-2007.
- Blue Nile at Roseries (U/S & D/S of Roseries Reservoir) for the period 1966-2007.
- Blue Nile at D/s Sennar Reservoir for the period 1966-2007.
- Blue Nile at Khartoum (Just u/s of the confluence) for the period 1966-2007.
- Dinder river at Gewisi for the period1966-2007.
- Rahad River at Hawata for the period 1966-2007.

7.3 Baro Akob-Sobat (BAS) – Survey data

7.3.1 Previous topography survey works

No floodplain and river cross-section survey work are found yet.

ENTRO - Francis Wajo Wani (2020) Final Report identified Akobo, Nasir and Malakal city among 6 flood prone sites properly falling in the BAS.

7.3.2 ENTRO (2020) EN FFEW Enhancement Integrated Report

The 1D MIKE 11 hydraulic model of the Baro-Akobo-Sobat sub-basin include three rivers namely Sobat river, White Nile river and a tributary to the Sobat river. The flow from Bahr el Ghazal is modelled as a boundary flow that is entering the White Nile river.

Cross sections of the White Nile river and Sobat river are generated from Airbus DEM[20] with a horizontal resolution of 25m provided by ENTRO.

- River bed resistance is derived from the land use of the river riparian and river bed
- Water level, flow data and Q-h relationship for gauges that were used in the data assimilation of the model.

7.3.3 ENTRO (2017) multipurpose water resources development on the Baro-Akobo-Sobat sub-basin

ENTRO commissioned a study on the hydrodynamic modelling of the river and floodplain and the water balance studies by BRLi and Aurecon (2016).

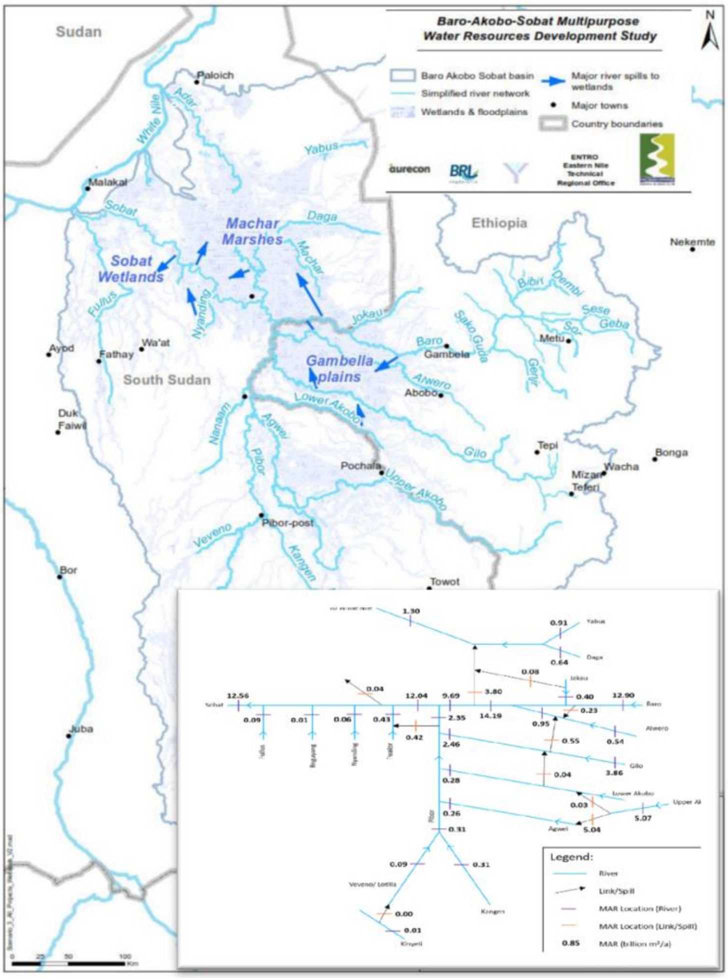
<u>Salient features of the study are:</u>

- The floodplain survey was obtained from a 30-m grid spacing SRTM data set of the study area. A grid of square cells 500 m in size was generated using the M21C grid generator.
- The DHI Mike21C curvilinear flow model for flood hydrodynamic modelling was used.
- Initial location of main rivers, spills and links and wetlands are provided (Figure 7)

Figure 10 shows the location and estimate of main rivers spills and links with major wetland. Estimated volume of flood spilled into the floodplains are also shown in the line diagram.

The study recommended that the model setup and calibration should be improved in future studies by accurate LiDAR and underwater surveys to generate a new model bathymetry, with field flow measurement by ADCP in several locations in the river system, during the low flow and flood seasons.

[20] AIRBUS DEM – in flat terrain – vertical accuracy is about 2.5 m absolute – so unless calibrated it will not accurately represent the floodplain extent, depth and velocity in hydraulic modelling.



The main river spill rules in BAS floodplain, which are based on the mean daily flows, are:

- Baro spill to Machar: the flow threshold assumed for the Lower Baro after which spill to Adura Junction occurs is 510 m^3/s; 78% of the flow above this threshold at the Adura Junction spills to Machar.
- Baro spill to Alwero: the Baro does not spill up to 940 m^3/s, after which it breaks its banks and spills up to a maximum 60 m^3/s to the Alwero river
- Gilo spill to Alwero: The Gilo River has a capacity of 250 m^3/s, after which it spills all surplus flow to the Alwero.
- Pibor spill to Twalor: The Lower Pibor has a capacity of 250 m^3/s, after which it spills all surplus flow to the Twalor.
- Upper Akobo to Agwei: The Upper Akobo spills a maximum of 200 m^3/s into the Lower Akobo, and the surplus spills into the Agwei.
- Akobo spill to Gilo: The Lower Akobo River has a capacity of 25 m^3/s, after which it spills all surplus flow to the Gilo.
- Sobat spill to Wal: The Sobat River has a capacity of 1 400 m^3/s, after which it spills all surplus flow to the Wal.

Figure 10: Location and estimate of main rivers spills and links and wetlands (ENTRO 2017)

7.4 Tekeze-Setit-Atbara (TSA)

7.4.1.1 *Previous survey works*

No previous floodplain topographic survey work found yet.

Cross sections of the Tekeze-Setit-Atbara river were generated from Airbus DEM with a horizontal resolution of 25m provided by ENTRO.

8 Proposed verification and topographic and infrastructure survey in flood-prone sites

8.1 General survey approach

This assessment found that Lake Tana and Blue Nile flood prone areas have relatively better topographic and asset survey datasets as compared to BAS and TAS flood prone areas. BAS and TSA flood prone areas have no detailed topographic and asset survey data on river cross-section and floodplains. It is proposed that WP1 survey (engineering and social) focuses on these two-flood prone sub-basins in particular on settlement areas and towns located adjacent to rivers and exposed to riverine flood. The following sections provide locations of proposed topographic and infrastructure survey flood-prone sites. Moreover, existing floodplain topographic and asset survey data in the Lake Tana and Blue Nile flood prone areas will be re-assessed and prominent changes regarding infrastructures will be incorporated. The cross-section survey is proposed to extend from left and right banks for [2 km] each in the flood plain for ground-based survey. Georeferenced asset survey, utilising remotely sensed data and other tools, may include agriculture (crops, fruit farms and vegetables), infrastructure (roads, power transmission lines, water supply lines), structures (residential development, government offices, and public service centres such as schools and health facilities) and community facilities (religious centres, markets, and recreational facilities).

8.1.1 Contingency plan

As contingency plan, in case the consultant is not able to conduct the field survey due to various reason beyond its control, the consultant provides alterative survey method (topographic and asset) mainly using high resolution satellite data (example Photosat[21] and other providers with < 1m vertical resolution) and integrate with the existing topographic survey data at ENTRO.

The proposed satellite based topographic mapping of 4250 km^2 with indicated areas:

Lake Tana
- Tana Lake – (Dembia plain – 500 km^2 + Fogera flood plain 500 km^2)

BAS
- Gambelia floodplain (Baro river from Gambela City to Itang) – 500 km^2 – 10 km band[22] on 50 km stretch
- Nasir City – 250 km^2 (10 km band on 25 km stretch)
- Malakal City - 500 km^2 (10 km band on 50 km stretch)

Blue Nile
- Blue Nile - 1500 km^2 (from Roseries to Khartoum on selected critical areas 10 km band on selected 150 km stretch)

TSA
- Atbara City – 500 km^2 (Nile Atbara Junction upstream and downstream) 10 km band on 50 km stretch

The WP1 consultant in the inception report will further refine and actualise these proposed topographic and infrastructure survey flood-prone sites and their method of detail survey for approval by ENTRO before commencing the actual field survey work.

8.2 BAS proposed topographic and asset survey flood prone sites

The BAS sub-basin has few river cross-section survey data, mostly at the flow gauging sites. Table 6 presents a summary of proposed reaches where river cross-section survey (bathymetric survey and flow velocity based on boat) to be conducted. In total 42 km reach, with 33 cross-sections, establishing 6 permanent control points, conducting 6 sediment and 6 discharge measurements.

[21] Rough cost of mapping is about 22,000 USD per 500 km^2 - https://www.photosat.ca/satellite-surveying-solutions/satellite-mapping/standard-mapping-packages/pricing/
[22] The band centerline is the river centerline.

Table 6: Proposed bathymetric / hydrographic survey sites in BAS

No	City/Town	Survey reach length (km)	No of cross-sections	Establish using GPS/GNSS a primary control point (permanent) if there is no existing	Discharge and sediment sample taken at gauging site	Remark: estimated population at town/city https://www.citypopulation.de/
1	Gambela	10	6 + gauging site	Yes	Yes	66,000 (in 2015 Est)
2	Itang	4	3 + gauging site	Yes	Yes	< 5000 (2020)*
3	Nasir	4	3 + gauging site	Yes	Yes	< 5000 (2020)
4	Akobo	4	3 + gauging site	Yes	Yes	< 5000 (2020)
5	Pibor	4	3 + gauging site	Yes	Yes	< 5000 (2020)
6	Malakal	16	9 + gauging site	Yes	Yes	118,331 (2008 Est.)
	Total	42	33	6	6	

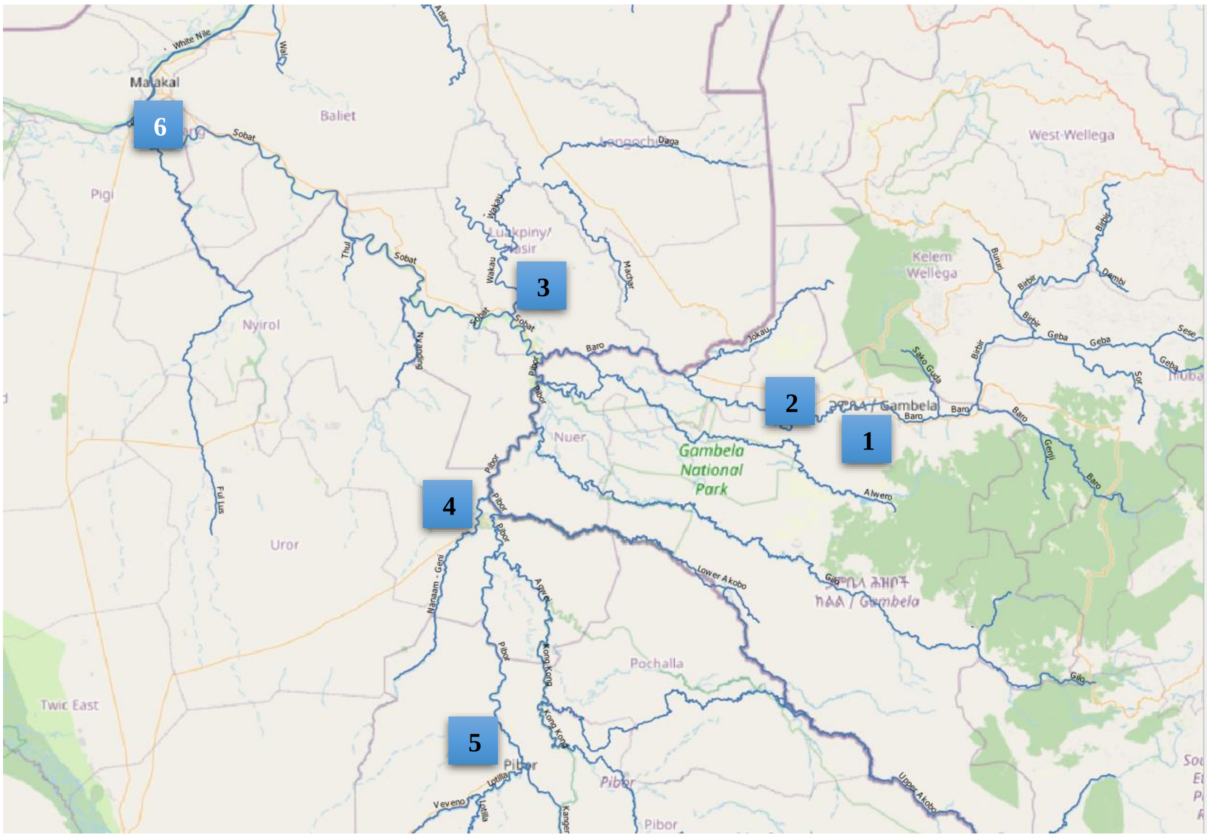


Figure 11: Proposed location of flood prone survey areas in BAS (number to be read with Table 5)

Some discussion is given below.

8.2.1 Gambela City (Ethiopia) – 10 km reach

During the 1988 flood, a significant portion of Gambella and almost the entire town of Itang were flooded. In Gambella city the flood caused severe socio-economic impacts due to administrative buildings, houses, hotels, the power station and roads (ENTRO BAS, 2017 study).

It is proposed to conduct river cross-section data at every 2 km (6 cross-sections).

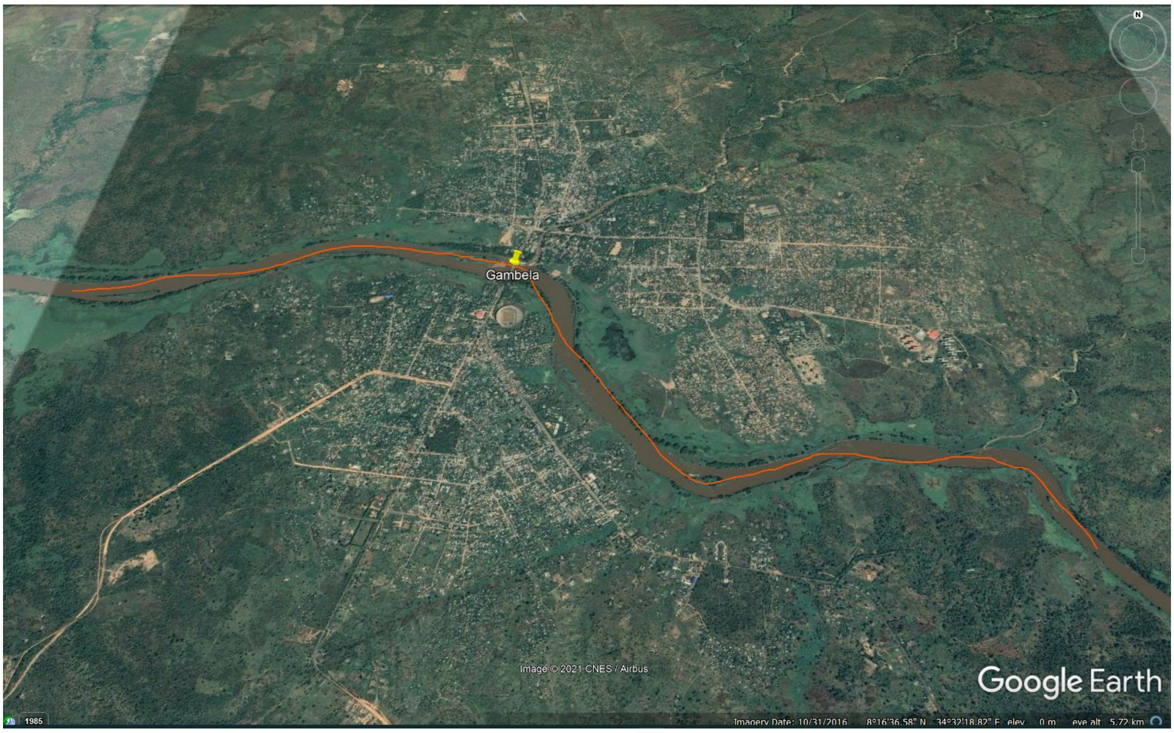


Figure 12: Gambela City - proposed location of flood prone survey areas

8.2.2 Itang town (Ethiopia) – 4 km reach

It is proposed to conduct 3 cross-sections at 2 km apart (both ends)

Figure 13: Itang -city - proposed location of flood prone survey areas

8.2.3 Nasir town (South Sudan) – 4 km reach

It is proposed to conduct 3 cross-sections at 2 km apart.

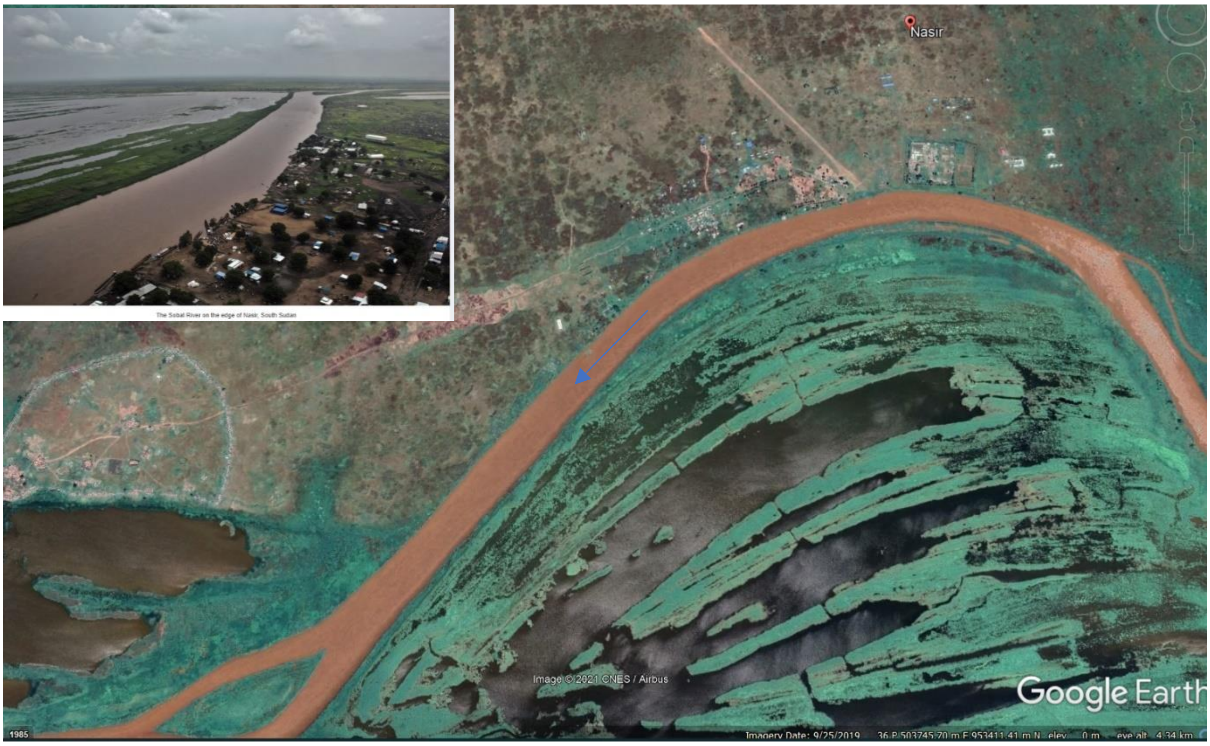


Figure 14: Nasir town - proposed location of flood prone survey areas

8.2.4 Akobo town (South Sudan)

Akobo town flooded in Oct 2019 as per the information: (https://reliefweb.int/sites/reliefweb.int/files/resources/REACH_SSD_FactMap_Flooding_October2019_final.pdf).

It is proposed to conduct river cross-section every 2 km spacing (two cross-sections).

Figure 15: Akobo town - proposed location of flood prone survey areas

8.2.5 Pibor town (South Sudan)

Pibor town was flooded in Oct 2019. (https://reliefweb.int/sites/reliefweb.int/files/resources/REACH_SSD_FactMap_Flooding_October2019_final.pdf).

It is proposed to conduct river cross-section every 2km spacing.

Figure 16: Pibor town - proposed location of flood prone survey areas

8.2.6 Sobat White Nile Junction and Malakal Town (South Sudan)

- It is proposed to conduct river cross-section on Sobat river at the existing gauging site at Hillet Doleib on Sobar river near Junction to White Nile

Figure 17: Sobat White Nile rivers junction - proposed location of flood prone survey areas

8.2.7 Malakal town (South Sudan) – 16 km reach

It is proposed to conduct river cross-section (9) on the White Nile river every 2 km in 16 km stretch.

Figure 18: Malakal City - proposed location of flood prone survey areas

8.3 TSA proposed topographic and asset survey flood prone sites

Tekeze Setit and Atbara (TSA) sub-basin has few river cross-section survey data, basically at the flow gauging sites. Table 7 presents a summary of proposed reaches where river cross-section survey (bathymetric survey and flow velocity based on boat) to be conducted. In total 16 km reach, with 14 cross-sections, establishing 3 permanent control points (if required), conducting 3 sediment and 3 discharge measurements. The cross-section survey is proposed to extend on both banks for 2 km.

Table 7: Proposed bathymetric / hydrographic survey sites in Tekeze-Setit and Atbara (TSA)

No	City/Town	Survey reach length (km)	No of cross-sections	Establish using GPS/GNSS a primary control point (permanent) if there is no existing	Discharge and sediment sample taken at gauging site	Remark: estimated population at town/city https://www.citypopulation.de/
1	Atbara (On Atbara river - Sudan)	4	3 + gauging site	Yes	Yes	132,000 (2020 Est.)
2	Atbara (On the Nile river - Sudan)	8	5 + gauging site	Yes	Yes	

3	Humera (Ethiopia)	4	3 + gauging site	Yes	Yes	32,600 (2008 Est.)
	Total	16	14	3	3	

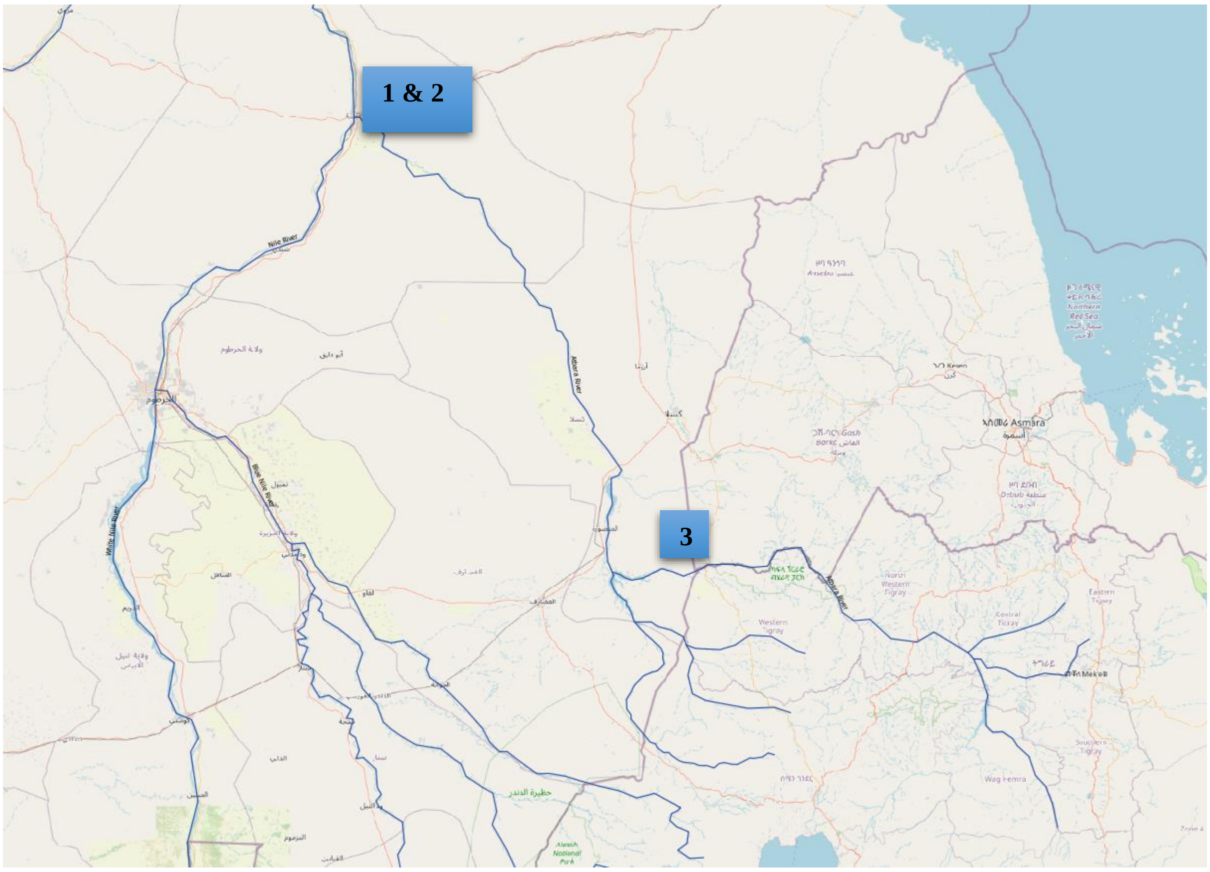


Figure 19: TSA- proposed location of flood prone survey areas (number to be read with Table 6)

8.3.1 Humera City (Ethiopia) – 4 km reach:

In 2006, two thousand people were displaced and around 2,000 ha farm land was also destroyed by overflow of Tekeze River at Humera.

(https://allafrica.com/stories/200608141182.html).

It is proposed to conduct river cross-section (3) on Tekeze river every 2 km in 4 km stretch.

Figure 20: Humera city - proposed location of flood prone survey areas

8.3.2 Atbara City (Sudan)

In 2021 in Atbara city a number of houses had "collapsed" due to the heavy rains.

It is proposed to conduct:

- Survey on Atbara river – 4 km reach at 2 km interval (3 cross-sections)
- Survey on Main Nile as indicated on the map - 8 km reach with 2 km interval (5 cross-sections)
- Survey flow gauging sites on Atbara river (Atbara Kilo 3) and Nile at Atbara. Measure also discharge and sediment.

Figure 21: Atbara junction with Main Nile rivers - proposed location of flood prone survey areas

8.4 Tana Lakes proposed verification of topographic and asset survey data in the flood prone sites

The existing river cross-section, floodplain topographic data and infrastructures and agriculture assets data of ENTRO will be quality checked. New infrastructures (such as Ribb dam, Sereba irrigations schemes and roads, and settlements) be assessed from recent Google Earth image and be integrated into the assets map.

Consultation with Ministry of Water, Water Bourses and Regional Disaster Risk Management offices provides additional information regarding the above data.

8.5 Blue Nile proposed verification of topographic and asset survey data in the flood prone sites

The existing river cross-section, floodplain topographic data and infrastructures and agriculture assets data of Blue Nile flood prone areas residing at ENTRO will be quality checked. New infrastructures (such GERD, irrigations schemes; roads, and settlements) be assessed from recent Google Earth image and be integrated into the assets map.

Consultation with Ministry of Water, Water Bourses and Regional Disaster Risk Management offices provides additional information regarding the above data.

9 Social indicators of the flood prone communities

9.1 Scope of the socio-economic survey

The scope of the socio-economic survey will focus on the linkages between hydrological characteristics in the flood prone areas and socio-economic indicators of the flood prone communities in the nine selected flood prone areas in Ethiopia, South Sudan and Sudan (Section 8.1 and 8.2).

9.2 Approach

The Consultant will adopt a range of consultation techniques in the nine flood-affected communities in BAS and TSA. These will include focus group discussions, formal meetings with community leaders or village elders, and interview with individuals from different identifiable groups (e.g., women, youth, ethnic groups, heads of households). Individual interviews can be more in-depth than focus group discussions and can be used to highlight specific results obtained from more general analysis.

9.3 Method

The method is to conduct a questionnaire survey, a door to door survey, with flood victims in nine flood prone localities (20-30 people in each of the nine flood prone areas, gender, community leaders, and others accounted) to map the community awareness/knowledge, preparedness and response to the flood risk. The questionnaires should be developed using the guide provided herein (minimum requirement) which addresses the flood preparedness, flood damage and post-flood recovery features.

Adopting the ENTRO (2009) identified several factors in the areas of flood preparedness, flood damage and post-flood recovery that influenced the ability of individuals and a community to respond to floods in Ethiopia (Lake Tana flood prone areas) and in Sudan (Blue Nile river flood prone areas):

- Flood preparedness
  - local knowledge on the history of flooding;
  - community organisation;
  - household preparation (for example, high beds, food silos);
  - early warning systems based on local knowledge;
  - communications infrastructure; and
  - structural preparedness, such as terraces, drains and levees.
- During flood damage
  - loss of lives, properties and businesses;
  - damage to property, food stocks and businesses
  - physical isolation and displacement
  - damage to public infrastructure, such as roads and telecommunications;
  - loss of economic productivity;
  - human and animal diseases; and
  - environmental damage.
- Post-flood recovery
  - access to public relief and rehabilitation assistance;

- rehabilitation of residential buildings;
- rehabilitation of public facilities and services;
- rehabilitation of crops and lands;
- recovery of local businesses;
- management of water-borne diseases and other disease vectors; and
- Issues of voluntary resettlement way from flood prone areas

The social survey will utilise the nine flood prone communities topographic survey data prepared by this consultant team including:

- Survey of detailed asset (georeferenced) including structures (houses), infrastructure (road, dyke, etc), and agriculture (crops, seasonal / permanent)
- Economic value to land use types and develop depth-damage relationships (Chapter 9)

The consultant also integrates the following key features in the questionnaire survey:

- The economy bases of the community (gender, education, pastoral, crop, fishery, etc)
- Local flood risk knowledge (the impact and experience of the past flood events)
- Indigenous flood monitoring and forecasting capability
- Communities interest to get flood alert
- Capacity to receive flood warning communication
- Evidence of warning messages reach, understood and interpreted into action by the community (in case there is practice)
- Location-specific flood indicators (land marks, trees, rock outcrop, etc) Community / people tendency to take fast action (if there is preparedness) after they received the flood early warnings (responsibilities in flood risk management).
- Community capacity to respond to flood damage (indigenous and newly introduced if any)

A detailed questionnaires guide is given in Attachment II (ENTRO (2006) project preparation, Eastern Nile flood preparedness & early warning, prepared by SMEC).[23]

10 Attachment I – A guide to river and flood plain cross-section surveying

The availability of suitable topographical data to accurately represent the river channel and surrounding terrain is one of the main impediments for flood modelling in many places.

Hydraulic modelling requires an accurate representation of the stream channel and surrounding area. Low resolution (>10 m) DEMs are insufficient for hydraulic modelling of river channels as it cannot represent sharp changes in the topography of the terrain.

The flood extent image should preferably be captured within 8 to 24 hours after the flood event has occurred. The selection of imagery for the verification and calibration of the flood model depends on the selected study area and the availability of imagery for the period during which the historical flood events occurred.

In addition to topographic and bathymetric information, hydraulic models require the specification of the hydraulic roughness, or resistance to flow, of the river channel and the floodplain. The roughness is low in bedrock river channels that are free of vegetation or debris

23 http://ikp.nilebasin.org/en/browses?field_date_of_issue_value%5Bvalue%5D%5Bmonth%5D=&field_date_of_issue_value%5Bvalue%5D%5Byear%5D=&title=early%20warning%20project%20implementation%20plan&sort_by=field_date_of_issue_value&sort_order=ASC&items_per_page=20&page=1

and high in a debris-filled river channel or a floodplain that has thick vegetation or buildings. Estimates of hydraulic roughness are usually based on expert judgment using visual surveys or aerial photography.

Field survey works is vital activity to validate and supplement the river cross-section data obtained from DEM. Minimum guideline for such survey is given below.

10.1 Topographic survey methodology

This methodology of topographic survey is adopted from ENTRO (2009) document prepared by Riverside Technology in collaboration with Tropics, Shebelle and Civil Engineering Department of Addis Ababa University. Flood Risk Mapping Consultancy for Pilot Areas in Ethiopia, the topographic data, particularly cross section data of the main rivers in the pilot study area were developed. This methodology provides minimum basic specifications that will be understood and followed by the parties involved. Also, the methodology provides instructions and guidelines for the survey team.

10.2 Objectives

The location of the survey points will be roughly indicated on the map that will be provided to the survey team. The floodplain and river cross-sections that are generated from this survey project are critical components of the hydrodynamic modelling as well as flood inundation mapping of the study area. In order to accomplish this objective, the following guideline is provided.

10.3 Field Work

10.3.1 Survey Instruments

Prior to starting work, the team members shall be given on-site instruction on instrument work and good surveying practice by the Engineers. The team is expected to be equipped with the following:

- GPS/GNSS to establish a primary control point (Horizontal and Vertical Datum (bench mark))
- Electronic total station or similar, Ancillary equipment comprising tripods, retro-prisms, detail poles, levelling change plates.
- Acoustic Doppler Current Profiler (ADCP) and flow trackers could be deployed for measuring flow velocity and taking additional bathymetry as a cross-check.
- Motor boat with safety features

10.3.2 Survey Methods

Controls, Vertical and Horizontal References

Control surveys shall be carried out as required at the sites by closed loop theodolite traversing. Semi-permanent stations shall be established at key locations around the sites (towns identified). These stations shall comprise <u>a mark painted on rock or a steel reinforcing bar driven into the ground</u> and then surrounded with concrete.

Horizontal and vertical control will be established to a local grid system by incorporating the stations in a closed 3D traverse. The horizontal angle, vertical angle and slope distance between adjacent stations will be measured by the electronic total station. To ensure accuracy, each angle will be measured twice on each theodolite face and the mean result used in calculation. Slope distances will be measured both ways. Any angular closing errors will be distributed equally among the measured angles prior to calculation of co-ordinates.

Small level misclosures shall be distributed between survey stations in proportion to the lengths of the measured distances. In no case shall the angular misclosure be greater than 20" or the vertical misclosure greater than 50 mm.

From each of the traverse stations, local topographical features will be surveyed by bearing and distance to provide x, y, z co-ordinates for each point surveyed.

10.4 What to Survey and to Document

In addition to compliance to the control standards described above, the survey project shall gather, and document data as specified in the flowing 12 points.

i. River cross-section survey shall be carried out as indicated above 2 km interval. The Universal Transverse Mercator (UTM) coordinates for the intersection between the cross-section's lines and the river centre line shall be prepared by measuring from the maps, this will be useful to locate the axis vector on the ground to conduct the surveying. The sections shall be taken perpendicular to the flow direction.

ii. The 2 km spacing is quite sufficient, however take additional surveys at a. hydraulic structure (for example, bridges, dikes)

iii. Sites that are easily accessible such as pedestrian road crossing the river. This helps to identify future addition of observation sites.

iv. At current river stage observation sites (gauging sites).

v. The cross-section survey shall be taken in <u>1m(banks) -5m (river bed) horizontal interval</u> across the main channel and 5-50 m horizontal interval (depending on variation in elevation and also limited to accessibility) outside the riverbanks depending on the slope of the area. The survey <u>shall extend to about 2 km to the flood plain</u> from both left and right river banks. Unique topographic features such as abrupt change of elevation shall be recorded regardless of the distances set in between two consecutives target points.

vi. Digital photos of the cross-sections shall be taken using a high-resolution camera for the purpose of judging the roughness coefficient for the both the main channel and the flood plain. USGS Water Supply Paper 1849 shall be used as a plausible reference for estimating the roughness coefficients. Each photo shall be related to the site by having consecutive pictures of cross-section as survey proceeds from downstream to upstream. Setting up the time correctly and noting the date and time on survey recorded can help to relate cross-section pictures to surveyed data.

vii. Naming of cross-sections (River Stations). River stations shall be named with using the first letter of the name of the Town and river and the river distance from the most downstream point. For example, for Gambela_Baro River GB0, GB1, …etc for 0km, 1km, …distance downstream from the start.

viii. For each cross-section, survey and record coordinates shall be made from left bank to right bank. Left and Right bank are designated by looking towards flow direction (downstream).

ix. In each cross-section, the left and right river bank limits shall be indicated as LB and RB, respectively. These are the approximate limits of the bank-full flow.

x. The water surface elevation during the survey period shall be recorded.

xi. For each cross-section, high water marks related to historical floods could be noted, if there is any information available from any marks on structures or from locals.

xii. If cross-section location much with gauging site conduct flow and sediment measurements.

10.5 Expected Results

Upon completion of the day's work, data shall be downloaded to laptop computers. Raw data shall be filed in a separate folder. The raw survey data shall be plotted using mapping software to produce contour maps. Cross sections at the surveyed sections will be generated, checked and if need be shall be checked or resurveyed the next morning.

11 Attachment II- A guide to identify and map vulnerable assets

11.1 Identifying

Vulnerability to flooding at a point or for a specific structure or asset can be represented by a depth vs. damage curve for that structure or asset. The vulnerability of agricultural land (which may vary seasonally) can be described by a curve of depth vs. damage per unit area. The spatial representation of vulnerability to a given flood level, however, depends not on a single depth at a point but on the interaction of the varying depths across a floodplain with the specific assets that are impacted. It requires spatial identification and classification of vulnerable assets, development of depth-damage functions for each type of asset, and intersection of the hazard (the depth grid) with the location of vulnerable assets and their associated damage functions to identify the spatial distribution of damages. The following sections describe the identification and classification of vulnerable assets, including infrastructure (roads), agriculture, and structures (ENTRO 2010).

Delineation of the different structures, infrastructures, and agriculture was based on visual interpretation of remotely sensed data, available topographic maps, field checks, and consulting local references. The Satellite data that may be used are mosaics of Landsat7 ETM+ images and Google Earth geo-referenced images. Digital and scanned geo-referenced Survey topographic maps, if available, can be used to identify different localities, towns, and villages and major infrastructures.

11.2 Mapping

All vector layers will be digitized and coded under a GIS framework. The final GIS products will be transformed to a Universal Transverse Mercator “UTM” projection, WGS84 Spheroid. The main layers to be created include agriculture, infrastructure, and structure. The extent of the mapped area covers about 2Km off the Baro, Pibor, Akobo, Sobat and white Nile rivers banks on both sides where they cross towns / cities (Gambela, |Itang, Nasir, Akobo, Pibor). The total length of the reach mapped is about 68 Km.

11.3 Depth-damage relationships and risk assessment

11.3.1 Depth-damage relationships

The following general procedure will be used to develop the depth-damage relations. They are defined in a slightly different manner for transportation infrastructure, structures, and agricultural areas. In all cases the relationship will be divided into assignment of value to assets and definition of the depth-damage relationship in terms of the percent of value lost due to flooding of a given depth. The guide is that:

a) Estimate values of structure classes, crops, and transportation infrastructure using local knowledge, survey estimates and expert judgment;
b) For structures, estimate value of structure contents for each structure class. This can be a value for each structure or a value per unit area for a neighbourhood of structures of the same class;
c) For transportation infrastructure, estimate replacement value. This is specified as a value per unit length;
d) For agriculture, estimate value of lost production as a value per unit area for each agricultural class
e) Estimate damage to structures, transportation infrastructure, and crops due to flooding to various water depths at the site, using a depth versus percent damage function for the various classes in each asset type.

Asset values and damage curves will be developed for each type of asset in the geographic database. Figure 22 shows examples of damage functions for the three different asset types: structures, infrastructure, and agriculture.

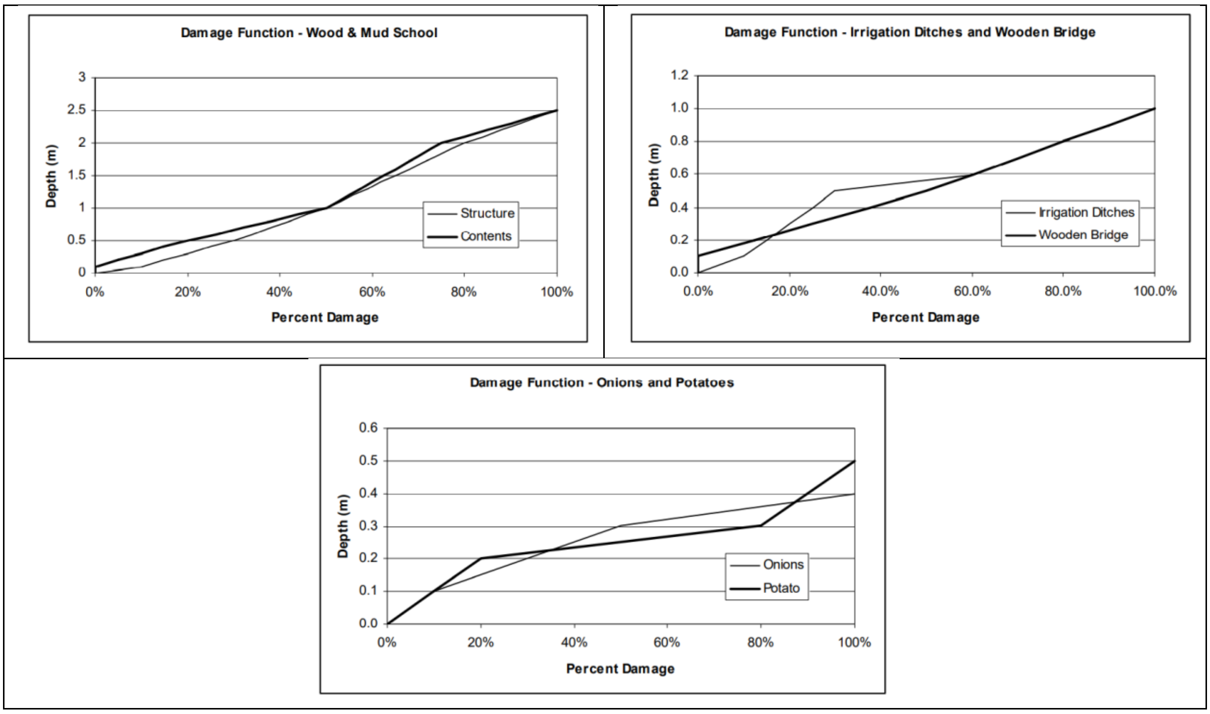
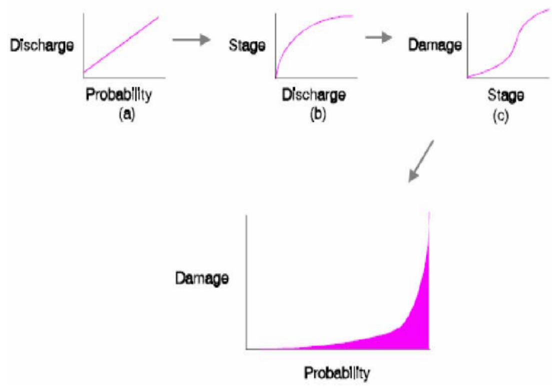


Figure 22: Damage curve types for (a) structure asset (top left), (b) infrastructure asset and (c) agricultural asset (bottom)

For example, a risk assessment of residential properties would require exposure on information on the locations of the properties, the type, the number of floors, the floor area, etc.

In the case of flood mitigation works such as levees, the resistance and effectiveness of infrastructure can be represented by fragility curves (also referred to as fragility functions for a flood control levee, in which the probability of failure ranges from 0.0 at zero water depth to 1.0 at the maximum height of the levee (at which point the levee fails due to overtopping).

Risk incorporates the concepts of hazard and vulnerability. In quantitative terms, annualized risk can be estimated as the product of probability of occurrence of the flood and the actual consequence, combined over all scenarios. Given a flood frequency curve, a rating curve, and a depth-damage curve, it is possible to compute a damage-probability curve. The damage probability curve can then be numerically integrated to estimate the expected annual damages, thus quantifying risk (see the Box below).



ENTRO, 2010 discussed that given a flood frequency curve developed based on observed data / rainfall-runoff model results (a), a rating curve of the river at control points – where flood forecasting is made (b), and a depth/stage-damage curve (c), it is possible to compute a damage-probability curve. The process of flood risk mapping can be used both as a tool in evaluating risk and as an alternate means of developing a damage probability curve for determining average annual damage. The central elements of the process are:

- Flood hazard mapping based on hydraulic model output, in which not only the extent of inundation but also the depth of inundation for a flood of a given probability is estimated in a spatially distributed manner across the flood prone area.
- Identification of vulnerable assets subject to damage from the effects of flooding, including buildings, transportation and other infrastructure, and active agricultural production, including its location;
- Development of local depth (stage) - damage functions for the identified assets falling in the flood prone areas, which spatially (and temporality for crops) vary; and
- Vulnerability mapping, or the spatial computation of expected damage for each flood event by computing damage for discreet assets based on flood depth and the appropriate depth-damage curve.
- The economic risk mapping, or the spatial integration of expected monetary damage for each event with event probabilities to yield a grid of expected annual damages. probability curve can then be numerically integrated to estimate the expected annual damages, thus quantifying risk.

11.4 Social and economic data from flood prone community

11.4.1 Agricultural damage function

There are two approaches to the agricultural damage function; the first calculates crop damage based on the percentage of crop area, and elevation is not considered. The second designates an elevation-area function for each crop type. Both methods account for timing and duration of flooding and require the data inputs namely:

- Elevation-Area function for a type of crop
- Percent of impact area covered by that type of crop
- Yield per ha
- Unit and unit price value
- Harvest cost per ha
- Additional losses associated with flooding
- First and last planting date
- Full yield date
- End of harvest date
- Dry-out period
- Initial and last plan loss function
- Inundation duration loss function

Note that the vulnerability of agricultural land can vary seasonally, with highest vulnerability at the point just prior to harvest.

11.4.2 Survey Infrastructure and vulnerable Structures

The consultant will also survey vulnerable infrastructure (building type, construction type, contents) and assets (e.g. crops). Vulnerable infrastructure will be surveyed to facilitate (i) development of damage functions, and (ii) extrapolation of vulnerable infrastructure to the new survey area.

Urban Elevation-Damage Function may include

- Flood Elevation-Population Impacted function – Accurate (0.5 m vertical accuracy) topographic survey is required
- Flood Elevation-Number of Structures affected function
- Elevation-Area function (flooded crop area)

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