EASTERN NILE FLOOD FORECASTING AND EARLY WARNING INTEGRATED REPORT

FLOOD FORECASTING AND EARLY WARNING ENHANCEMENT PROJECT

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ENTRO
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ENTRO is an organ established to implement the Eastern Nile Subsidiary Action Program within the framework of Nile Basin Initiative

Egypt, Ethiopia, South Sudan, Sudan

Acronyms

BAS	Baro-Akobo-Sobat sub basin
CMORPH	CPC MORPHing Rainfall product
DA	Data Assimilation
DHI	Danish Hydraulic Institute
EN	Eastern Nile
ENB	Eastern Nile Basin
ENFFEW	Eastern Nile Flood Forecasting and Early Warning
ENMA	Ethiopian National Meteorological Authority
ENPM	Eastern Nile Planning Model
ENSAP	Eastern Nile Subsidiary Action Program
ENTRO	Eastern Nile Technical Regional Office
FAO	Food and Agriculture Organisation of the UN
FEWS	Flood Early Warning System
FFEW	Flood Forecasting and Early Warning
FPEW	Flood Protection and Early Warning
GFS	Global Forecasting System
GIS	Geographical Information System
GsMAP	Global Satellite Mapping of Precipitation
HEC-HMS	Hydrologic Engineering Center -Hydrological Modelling System
HEC-RAS	Hydrologic Engineering Center- River Analysis System
HEC-RTS	Hydrologic Engineering Center– Real Time System
IDEN	Integrated Development of the Eastern Nile
JAXA	Japan Aerospace Exploration Agency
MoU	Memorandum of Understanding
NAM	Nedbør-Afstrømnings-Model Rainfall Runoff model
NBI	Nile Basin Initiative
NBI	Nile Basin Initiative
NCORE	Nile Cooperation for Result
NELSAP	Eastern Nile and the Nile Equatorial Lakes Subsidiary Action Program
NGO	None Governmental Organization
NGO	Non-Governmental Organisation
NOAA	Japan Aerospace Exploration Agency
RFE	Rainfall Estimates
TOR	Terms of Reference
TSA	Tekeze-Setit-Atbara sub basin
UN	United Nations
UNICEF	United Nation Children’s Fund
UNOCHA	United Nation Office for Coordination of Humanitarian Assistance
USGS	United States Geological Survey
WFP	World Food Programme
WRF	Weather Research and Forecasting Model

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EXECUTIVE SUMMARY

The Nile Basin Initiative (NBI)is guided by a Shared Vision which envisages achieving *"sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile Basin water resources".".* NBI member countries launched a Strategic Action Program with two sub-programs: the basin-wide Shared Vision Program (SVP) that aimed at building confidence, capacity and knowledge base (now phased out), and two Subsidiary Action Programs (the Eastern Nile and the Nile Equatorial Lakes Subsidiary Action Program – ENSAP and NELSAP) that initiate concrete joint investments and action on the ground at sub-basin levels. The EN Flood Protection and Early Warning Project (FPEW) has been one of the earliest successful IDEN Projects. The Project aims to reduce human suffering caused by frequent flooding, while preserving the environmental benefits of floods.The current FFEWS has gaps on the inadequacies of existing flood monitoring systems, limited data exchange and technical cooperation; uncoordinated and incomplete flood forecasting and warning systems and limited institutional and capacity development. The existing system use different models and way of dissemination for the different flood prone area in the basin. There is a need to have a single unified flood forecasting and early warning system for the entire EN basin.

The objectives of this project are; to expand, enhance and develop a unified flood forecast system for EN basinservices to new, so far unsupported flood prone communities and areas, particularly South Sudan and TSA sub-basin, to ensure a robust issuing and warning system that effectively minimize loss of life and damage, to support other studies under FFEW that contributes in addressing flash flood, Stakeholder analysis and flood related DSS development.After analysing the available flood forecasting models and systems, it was recommended to set up the system under Mike Operations.The MIKE Operations platform allows an integration of data management, modelling or scenario manager and reporting on operational or real-time basis, which makes it a suitable platform to a flood forecasting system.The work for enhancing the ENFFEW system also included development of WRF model to be installed and customized for the ENTRO region.The approach undertaken in this project to enhance the flood forecasting and early warning system in the EN was three pronged;carry out an assessment in each of the three EN countries to understand current actors, existing FEW system, communication means and needs; development of WRF system for the Eastern Nile to provide a 6km 3hrs resolution precipitation forecasts and set up, calibrate and validate hydrological and hydraulic models and an FFEW system that will integrate the meteorological outputs and models as well as communication system.

The results of the EN country assessment indicated that are many key actors in the disaster early warning, mitigation, evacuations, relief and building resilience at regional,national and local level. At regional level the main actors are the ENTRO and ICPAC while at national level the main actors areNational Ministries of Water and related affairs, National Meteorological Agencies, National Disaster Risk Management Agencies and Other Non-Governmental UN agencies such as UNICEF, WFP, FAO and UNOCHA.A three day rainfall forecast generation process was implemented at ENTRO at 6km and 3hr spatial and temporal resolution. This process relies on the WRF model, a dynamical model that has been customized for the EN region. As an alternative to the WRF rainfall forecasts, tools to acquire and process the GFS 25km rainfall forecast data were developed. The data is downloaded in its native format, grib2, then processed for the Eastern Nile region at hourly intervals.Tools for acquisition and analysis of TAMSAT, CHIPRS, CMORPH, ARC2, RFE2

and GsMAP rainfall estimates were developed for the EN to provide near real time QPEs. Of importance, the GsMAP accessed through the JAXA web portal is at 10km resolution and provides data with 4hour latency, and thus provides a practical source of ENTRO's QPE**.** The verification results of the WRF indicates a general bias of upto 10mm in a day, for both 2013 and 2014 test years. Furtheranalysis of the real time forecasts indicatesa maximum bias by day two of the forecast.

NAM models were set up for the Tana, Blue Nile, Tekeze-Atbara-Setit and Baro-Akobo-Sobat sub catchments of the EN.The delineation of the basin was guided by the need to break to catchment into smaller sub-catchment to identify the flood that occur downstream as earliest as possible. As well, the delineation was also guided by available infrastructures within the catchment/basin to isolate the inflow to the infrastructures.Discharge data was available for the Tana and BAS sub basins, therefore calibration was done for these two sub basins using the Ribb ,Gumera and Gambella stations. The NOAA RFE rainfall data and USGS Global PET was used as input data. The results show coefficient of determination (R^2) of between 0.5 and 0.68. A 1D MIKE 11 hydraulic model was set up for the four major rivers in the EN sub basin.The Early Warning Flood Forecasting System (EWFFS) of the five sub basins of the Eastern Nile was setup using MIKE Operations. The hydrologic, hydraulic models were registered in the Mike Operation and data acquisition and model simulation implemented operationally.

As a conclusion, the country social assessment was completed. An operational WRF and Mike Operation system for the for the basins of EN namely, Lake Tana, Blue Nile, Tekeze-Atbara-Setit and the Baro-Akobo-Sobat sub catchments was set up. This system can give rainfall, river discharge and water level forecast for upto 72hrs. It is recommended that ENTRO continues to improve system performance by re calibrating the models as more observed data is availed by the member states. This will be strengthened by having an MOU with data providers such as the national meteorological and hydrological institutions. It is also recommended to improve the infrastructure particularly internet speed and have a power backup. Finally ENTRO is encouraged to implement the recommendations from the flash flood assessment report.

1. INTRODUCTION

1.1Background

The Nile Basin Initiative (NBI)is an intergovernmental partnership of ten Nile Basin states (Burundi, D.R. Congo, Egypt, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania and Uganda) established to develop the river cooperatively; reduce poverty and environmental degradation; share substantial socio-economic benefits, and promote regional peace and security. The NBI is guided by a Shared Vision which envisages achieving *"sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile Basin water resources"*. NBI member countries launched a Strategic Action Program with two sub-programs: the basin-wide Shared Vision Program (SVP) that aimed at building confidence, capacity and knowledge base (now phased out), and two Subsidiary Action Programs (the Eastern Nile and the Nile Equatorial Lakes Subsidiary Action Program – ENSAP and NELSAP) that initiate concrete joint investments and action on the ground at sub-basin levels.

The NBI constitutes the 'development track' in Nile Basin cooperation. The countries have also launched a 'political-legal track' aiming at an inclusive Cooperative Framework Agreement (CFA).

The Eastern Nile Subsidiary Action Program (ENSAP)was launched by Egypt, Ethiopia and the Sudan (South Sudan joined in 2012 following its independence) to initiate concrete joint investments in the Eastern Nile (EN) sub-basin. ENSAP is governed by the Eastern Nile Council of Ministers (ENCOM) and implemented by the Eastern Nile Technical Regional Office (ENTRO) headquartered in Addis Ababa, Ethiopia. ENSAP is funded by the four member countries and bilateral and multilateral Development Partners.

The Integrated Development of the Eastern Nile (IDEN) was the first ENSAP project agreed by the member countries in 2002. IDEN consisted of a first set of seven subprojects aiming at tangible win-win gains in watershed management; flood preparedness and early warning; irrigation and drainage; power supply interconnection and regional power trade; planning model along with the Joint Multi-Purpose development Project (JMP) of the Eastern Nile and Baro-Akobo-Sobat Multipurpose Water Resources Development Study Projects.

Currently, ENTRO is implementing its 2nd, 2014-2019, Strategic Plan. The Strategic Plan which is oriented in four strategic directions (i.e. Facilitating Cooperation, Promoting Water Resources Management and Planning, promoting Water Resources Development and Power Trade, and Institution Building) strives to position ENTRO for effective pursuance of its focus on Investment.

The EN Flood Protection and Early Warning Project (FPEW) has been one of the earliest successful IDEN Projects. The Project aims to reduce human suffering caused by frequent flooding, while preserving the environmental benefits of floods. The project emphasis on enhancing regional collaboration and national capacity in flood risk management, including flood mitigation, forecasting, early warning systems, emergency preparedness, and response. The FPEW project that ran until 2010 operated in Egypt, Ethiopia, and Sudan. It created a regional Flood Forecast and Early Warning System (FFEWS), strengthened national offices both in terms of capacity and equipment and overall reduced the risk of flood devastation for 2.2 million people in the region. FFEWS has also been an important partner in the EN

Internship Program, engaging and benefiting from the young professionals in preparing flood forecast bulletins for the Lake Tana region (Ethiopia), the Blue Nile-Main Nile (Sudan) and BAS flood prone areas. This flood forecasting and early warning activity have continued under NCORE produced daily and weekly flood forecast for the last five flood seasons. These forecasts and flood bulletins have been made available on ENTRO web portal, disseminated to ministries, flood prone area communities till thee kebele level.

1.2 RATIONALE

The current FFEWS has gaps on the inadequacies of existing flood monitoring systems, limited data exchange and technical cooperation; uncoordinated and incomplete flood forecasting and warning systems and limited institutional and capacity development. The existing system use different models and way of dissemination for the different flood prone area in the basin. There is a need to have a single unified flood forecasting and early warning system for the entire EN basin. This will allow to consider other flood prone areas in the Tekeze-Setit- Atbara (TSA) where no prior work is done.

Moreover the system is limited in considering flood forecasting during flood season where the river flow forecast and seasonal forecast are not considered. But the seasonal forecast is as much important since it have significant effect with frequent drought and crop failures in the EN basin and with climate change it will only get worse.

The other challenge is to ensure continued relevance of this vital program, forecast communication and dissemination need to be more easily accessible to rural communities and other important stakeholders. There is the need for further in-depth understanding of most vulnerable communities, their socio-economic characteristics in order to design fit-for-purpose response and preparedness mechanisms.

1.3 Objective

The objective of this project is;

- To expand, enhance and develop a unified flood forecast system for EN basinservices to new, so far unsupported flood prone communities and areas, particularly South Sudan and TSA sub-basin
- To ensure a robust issuing and warning system that effectively minimize loss of life and damage
- To support other studies under FFEW that contributes in addressing flash flood, Stakeholder analysis and flood related DSS development.

1.4 The Study Sub-basins

The Eastern Nile is composed of three sub basins namely Tekeze-Setit-Atbara (TSA), BaroAkobo-Sobat (BAS), Abbay/ Blue Nile (ABN). For the purpose of upstream localised flood modelling the Lake Tana which is part of the Blue Nile is also mentioned.

Lake Tana Basin– Lake Tana basin is located on upstream area of Blue Nile River. Head waters of these sub basins are steep hills with good forest cover. Flow coming up from surrounding hills converge in to low land area and eventually enters to Lake

Tana. Four small rivers identified as important water ways to the lake, namely Dirma River, Megech River, Ribb River, and Gumara River. There are dams proposed across those rivers and they are at different stage of development and operation (Figure 1).

Baro Akobo Sobit Basin– BAS sub watershed encompasses Sobatriver from South Sudan to White Nile confluence. The river segment from Sobat/White confluence to Khartoum is part of this watershed in the new model. Almost 80% of the sub watershed area is relatively low elevation and remaining area towards to the east of the sub basin is high elevation mountain range.

Blue Nile Basin– Blue Nile sub watershed encompasses Blue Nile River from Lake Tana to Eldiem station at Ethiopia / Sudan border. Upper watershed is mountainous and with forest over, and lower part of the basin is from Eldiem to Khartoum is generally of low slope.

Tekeze-Setit-Atabara (TSA) Basin– TSA basin head water starts from Mekele, Ethiopia and discharged in to Main Nile near Atbara. The upper watershed is hilly terrain with good forest cover and lower are is low grade land with little vegetation.

Main Nile– The Main Nile sub watershed encompasses land mass between Blue Nile/White Nile confluence to City of Dongola. The area is mostly flat and arid environment with little rainfall.

1.5 An Overview of Current Eastern Nile (EN) Flood Forecast and Early Warning

Two recent (2012) projects supported by ENTRO have developed a hydrologic model (using HEC-HMS) for the entire Blue Nile basin, including the portions of the basin in Ethiopia, and a hydraulic model (using HEC-RAS) for the Blue Nile from El Diem to Khartoum. The existing flood forecasting models and systems are;

Lake Tana - Lake Tana area consist of four major flooding streams that originate from high mountain range to Lake Tana at the exit. These models were developed using HEC HMS, HEC RAS and WRF rainfall data. Combination of these tools produce flood forecast with 3 days lead time.

Upper Blue Nile Segment – The forecasting model from Upstream of El-deim gage was based on HEC HMS and HEC RAS models.

Sudan FEWS – This section of Nile River from Elddeim to Ethiopia Sudan boarder model was prepared using WRF rainfall data, HMS and RAS models. This model was further updated from earlier Sudan FEWS with Delft University Delteras. The rest on Main Nile River is based flood prediction was based on Linear Correlation method.

Baro Akobo Sobat - The hydrology of the BAS model was based on HMS software and hydraulic was based USGS GIS flood Tool. The water elevation from the model is transpose to digital elevation model to find inundations extent for this basin area

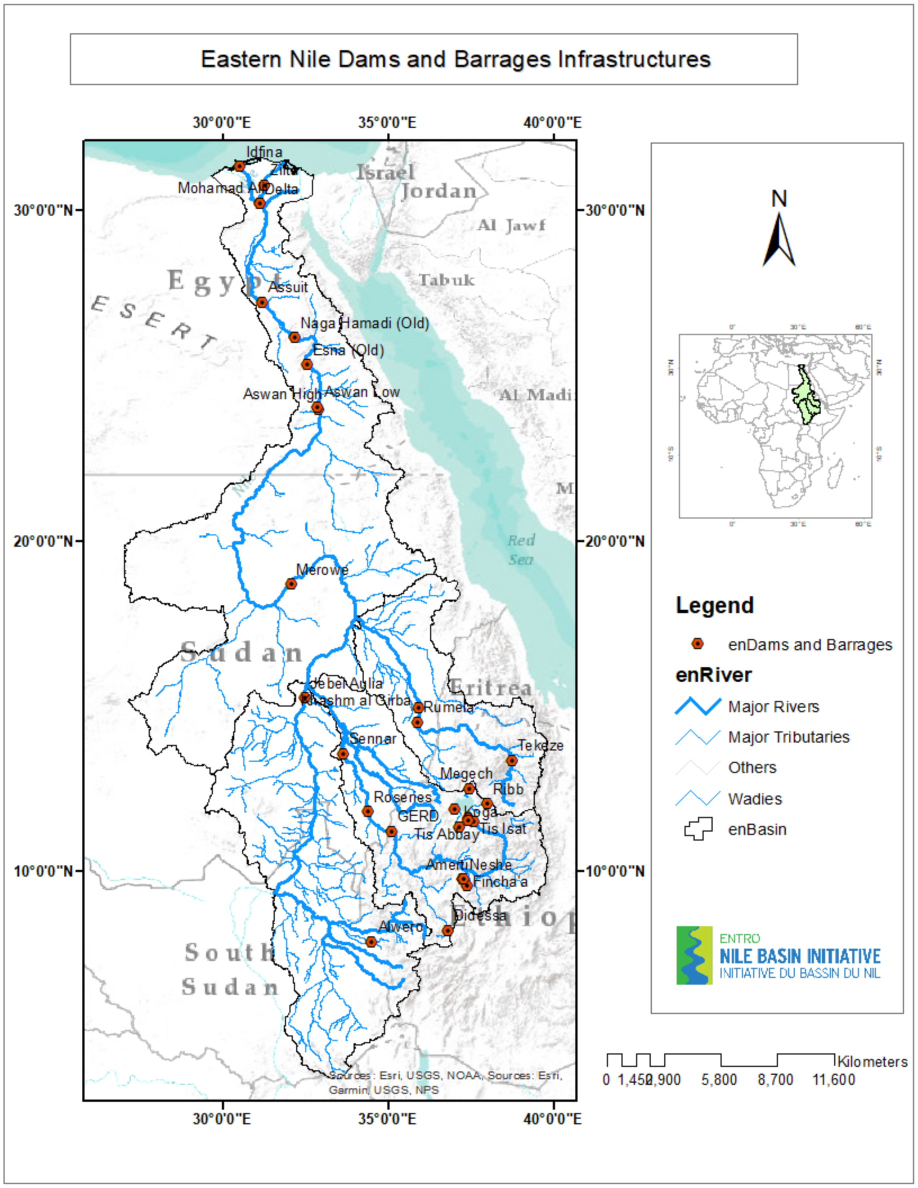

Figure 1 Dams in the Eastern Nile

1.6 Identified Flood Prone areas in the EN

Ethiopia

In Eastern Nile Part of Ethiopia the well-known flood prone areas are the flood plains abutting Lake Tana, Gambella plain, and Humera area (near Ethio-Sudan Boarder) of Tekeze basin and flash floods in different locations.

- **Lake Tana**: Flooding is a recurrent threat occurring almost every year in Lake Tana area caused by the overflowing of the Rib, Megech, Gumaro and Gumara rivers and the spillover of Lake Tana (Woldeab, 2006).

- **Gambella Plains:** The plain area, belonging to the lowlands of Baro-Akobo Basin, is partially inundated by floodwaters every year. While most of the agrarian land use has adapted to the seasonal flux of flood waters, there are several towns affected by larger floods including the city of Gambella, and larger floods also cause hardship in rural areas.

- **Tekeze near Humera (Ethio-Sudan Boarder):** The flat area at Humera (near Ethio-Sudan boarder) is flooded from overflow of Tekeze River over its banks. This will occur during extreme rainfall conditions in the upper catchment of Tekeze basin as in the case of August 2006.

South Sudan

The specific places that are regularly affected with floods are the Jonglei, Lakes, Eastern Equatoria, Western Equatoria, and Aweil. Unity, Western Bahr el Ghazal and Malakal. These are some of the heavily flood affected or flood prone areas in the Republic of South Sudan.

It is also worth mentioning that most types of floods that are very common in the Republic of South Sudan are the flash floods which happen in most parts of South Sudan but is more frequent in places such as Kapoeta in the former Eastern Equatorial States. Riverine floods also occurs in South Sudan, this type of floods mostly happens around Bor and Malakal.

Sudan

The prone areas in 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. Blue Nile catchment include river Dinder and Rahad in Sudan. River Gash catchment up to Kassala town. Small streams catchment around El Fashir City. Small streams catchment around Nyala city.

1.7 Gaps and effected enhancementsin the existing EN Flood Forecasting System

The Existing models were subjected to an evaluation against the critical areas that are important for FEW such as Coverage, type of hazard forecasted, modelling system, Flood forecasted and Dissemination system. The enhancements which were also discussed and recommended by the Flood Forum (Annex) are as follows:

The Identified Gaps and Proposed Enhancement to the existing EN Flood Forecasting and Early Warning System

Coverage: Current FFEW activities does not cover the entire Eastern Nile. Models have been developed for upstream of Lake Tana basin, Upper Blue Nile (u/s El diem) and Baro Akobo Sobat (BAS)

Enhancements: Develop the Flood forecasting system for Tekeze-Setit-Atbara (TSA) sub basin

Type of forecast (hazard forecasted): The EN FFEW addresses riverine floods in the stated sub basins but does not address flash floods

Enhancements: It is necessary to start work on flash flood early warning for catchments which are prone. Rank Catchment on impact of flash flood and existing hydromet network.

Flood Forecasting System

- There is no unified operational flood forecasting system for the Eastern Nile Flood Forecast system. Only the Upper Blue Nile (u/s of El diem) has the Deft FEWs as the FFS. The other two sub basins (upstream of Lake Tana and BAS) do not have an FFS. The flood forecasting is usually carried out during the rainy season.

- The FFEW system need to be tightly coupled and or automated (from data transmission/collection to output/dissemination) of results/warnings

Enhancements: It is necessary to have an operational common flood forecasting system for all the models

(Options: DelftFews or Mike Operation HEC)

Table 1 Evaluation of Different Flood Forecasting Systems

FFS	**HEC-HMS model compatibility**	**HEC-RAS model compatibility**	**Web compatibility**	**Free for operational use?**	**Technical Support Available**
Delft FEWS	Yes	Yes	No	No	Yes (at a cost)
Mike Operation	No	Yes	Yes	No	Yes (at a cost)
HEC-RTS	Yes	Yes	No	Yes	No

Considering the above option it was recommended to set up the system under Mike Operations. The reason being that on top of the above advantages, the Mike suite of models will be used for the upcoming river flow forecasting models and the integration will be ensured. Moreover DHI and NBI have an agreement for free software upgrade until the year 2022.

Rainfall forecasting:

Between the years 2010-2015, ENTRO utilized ETA numerical weather forecasting model. Since there are many limitations in the management and running weather forecasts using ETA model ENTRO shifted to use WRF model in 2016 and was customized for use with the Lake Tana basin Model. Currently a WRF model is run for Tana basin of the Eastern Nile with 3 days forecasts. Depending on one forecast system alone without an economical back up or fall back system can mean no forecast is issued on such occasions.

Enhancements

- Set up a WRF v4.0, a 2018 release, is installed and customized for the ENTRO region

- It is important to take advantage of global forecast data that is freely available and continuously improved. This can also be used to validate the locally produced WRF outputs
- Options to supplement and validate the existing in house WRF Model
    - Global Forecasting System (GFS) by NOAA, free download from the internet (upto 7 days forecast, daily, 0.25deg spatial resolution

Flash Flood forecasting:

While evidence shows significant portion of the Eastern Nile basin is frequently affected by flash floods. As urbanization grows many more areas in the basin are expected to be affected more frequently by flash floods. Thus ENTRO has contracted an individual consultant to conduct an assessment study on flash flooding and to development of the conceptual design of flash forecast system.

The objective of this assessment is to identify the extent and types of flash flood in the Eastern Nile basin and develop a design specification of flash flood forecast system. This will contribute to the objective of this project which is to ensure a robust forecasting, issuing and warning system that effectively minimize loss of life and damage.

2. METHODOLOGY

2.1 Conceptual Framework of Enhanced EN Flood Forecasting System

The approach undertaken in this project to enhance the flood forecasting and early warning system in the EN is three pronged;

- Carry out an assessment in each of the three EN countries to understand current actors, existing FEW system, communication means and needs
- Develop and WRF system for the Eastern Nile to provide a 6km 3hrs resolution precipitation forecasts
- Set up, calibrate and validate hydrological and hydraulic models and an FFEW system that will integrate the meteorological outputs and models as well as communication system

2.2 Social Survey

There are many key actors in the disaster early warning, mitigation, evacuations, relief and building resilience including national and local disaster management agencies; national meteorological and hydrological services; military and civil authorities; media organizations; businesses in vulnerable sectors; community based and grassroots organizations; international and UN agencies. Thus the social survey was carried out map out the key actors were surveyed by the country based experts. In this regard, the following level of actors and detailswere surveyed.

a) **Country level actors:**

- Agencies provide, receive and relay flood early warning and what is their specific mandate on flood early warning.
- Perform of their function; how many warnings have they issued or transmitted in the recent past.
- The content of their warning
- How the received information acted upon by the affected community.

b) **Early Warning issuing institutions**

- Do they issue either riverine, flash flood early warning or both?
- Does the warning issued cover the whole country or only certain area?
- Which actionable information do this institutions like to get from ENTRO to support the issuing of the (flood) early warning?
- Identify what support these institutions are comfortable giving ENTRO to support the regional early warning

c) **Flood affected communities**

- Location of stakeholders/households affected by flood
- Assessment of the approximate population affected by flood
- Assessment of the frequency and level of impact
- Communication means mostly used in times of disaster

2.3 Meteorological Modelling

The customization of the meteorological (WRF) model involved running experiments to evaluate the model skill based on different model set-up, and gauged against the time taken to complete the process for 3 days lead time forecast. Given that majority of rainfall events in the tropics originate from convective systems, one major task in the customization process was evaluating the rainfall biases that result due to use of several convection types available in WRF.

The model was initialized using GFS 0.5 deg (approximately 54km) initial and boundary conditions of the 00 UTC cycle, with the parent domain at 18 km and the nested domains for the three catchments (L. Tana, Blue & Main Nile and BAS) at 6km so that the forecast is ready by 07 UTC. In addition, rainfall maps are produced on daily timescales. Theprecipitations outputs from the WRFare compared with the satellite estimates and the model biases was established and the necessary correction factors will be applied. The flow of the work is summarized in the chart in Figure 2.

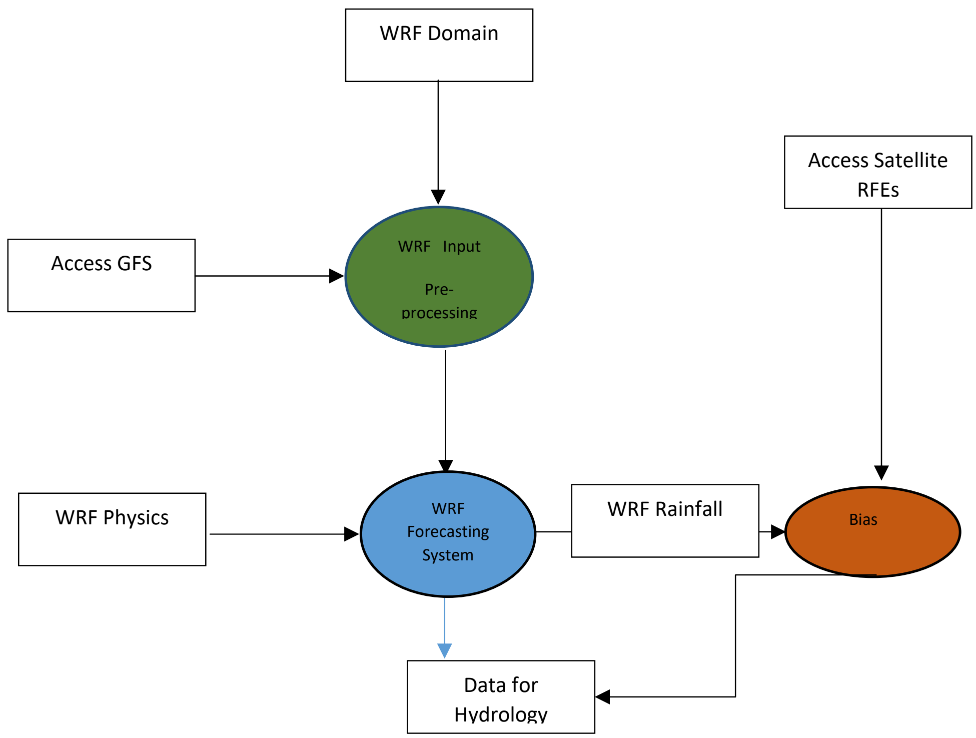

Figure 2 Workflow of the proposed implementation of WRF rainfall forecasting at ENTRO

2.4 Hydrological-Hydraulic and Flood Forecasting Modelling

The Early Warning Flood Forecasting System (EWFFS) of the five sub basins of the Eastern Nile was setup using MIKE Operations. The MIKE Operations platform allows an integration of data management, modelling or scenario manager and reporting on operational or real-time basis, which makes it a suitable platform to a flood forecasting system. The hydrologic, hydraulic models were registered in the Mike Operation and data acquisition and model simulation implemented operationally. The NAM and Mike 11 hydrologic and hydraulic models which are compatible with the Mike Operation were set up, this model when run operationally will help to predict the flows and water level at the selected flood prone areas with a reasonable lead time normally 72 hrs.The methodology for setting up the hydrologic and hydraulic models is discussed next.

Data acquisition

Data will be sourced from different source providers and will be stored in one central database. The types of data required to implement the EWFFS are as follows:

- DEM: The sub-catchment that are used in the NAM Rainfall-runoff model were delineated using the Airbus DEM with ahorizontal resolution of 25m provided by ENTRO.
- In Operational mode the NOAA RFErainfall and global PET was used for model initialization while the forecast rainfall was Weather Research and Forecasting model (WRF) previously discussed.
- Available observed flow and gauge levels, where there is an observed flow or gauge levels the information will used for calibration and data assimilation

NAM Hydrology Model

The hydrological modelling system used by MIKE 11 is the NAM model. Therefore, this is the tool which will be used to simulate runoff for the four sub-basins of the Eastern Nile River. NAM is the Danish abbreviation of "Nedbør-Afstrømnings-Model" which translates into English as "Rainfall-Runoff Model". NAM simulates the terrestrial phase of the hydrological cycle. It is a deterministic and lumped model; therefore, it is a catchment-based modelling system. More detailed description of the model is given in the hydrological report.

Hydraulic Model

A MIKE 11 1-dimensional hydraulic models was set up for the four sub-basins of the Easter Nile River. The design of the final MIKE 11 setup was developed jointly with the NAM rainfall-runoff model to enable integration between the models. The MIKE 11 Data Assimilation module (MIKE 11 DA), extensively used in flood forecasting modelling applications, was also be setup to be used in future when real time data is available.

2.4 Flood Forecast System

Once the prediction models have been set up and calibrated, they are imported and integrated with the near real time and forecasted data. The Mike Operation has been selected to be used as the EN Flood Forecast system and it is compatible with the Mike Models. Then the components that are to complete the setup of the Eastern Nile EWFFS to be configured are:

- Thresholds
- Forecast Dissemination
- Desktop User interface
- Web Portal
- SMS and Emails

3. MAPPED STAKEHOLDERS FOR FLOOD EARLY WARNING SYSTEM FOR THE EN

3.1 Data and Forecast providers

Eastern Nile Technical Regional Office (ENTRO)

ENTRO in addition to issuing weekly, monthly and seasonal reports also produces daily reports with three-day lead-times for forecasts of rainfall and hydrological modelling for flood prediction. The information generated sent to ministries of water resources and universities collaborating with ENTRO in Ethiopia, South Sudan and Sudan.

National Ministries of Water and related affairs

The Ministries of Water, Irrigation and Energy (Ethiopia), Water Resources and Energy (South Sudan) and Water, Irrigation and Electricity (Sudan) undertake the management of water resources, water supply and sanitation, large and medium scale irrigation and electricity. In addition to receiving forecast data from ENTRO they also collect hydromet data which they process and issue forecasts to other stakeholders primarily in the disaster risk agencies and other stakeholders.

National Meteorological Agencies

The National Meteorological Agency (Ethiopia), South Sudan Meteorological Authority and the Sudan Meteorological Authority are the primary meteorological data and forecast providers to their respective countries. Ethiopia and Sudan undertake short range (up to 7days) meteorological forecasts, exchange meteorological data as per international agreements and give warnings on adverse weather conditions.

IGAD Climate Prediction and Application Center (ICPAC)

ICPAC is a specialized Institution of IGAD with the strategic objective for medium to long range (seasonal) forecast for the Greater Horn of Africa region to mitigate climate-related risks and disasters. They organise three forums in a year to bring together meteorologists and climate sensitive sectors (such as water and agriculture) from the IGAD member states to discuss the forecasts and come to consensus. Though season forecasts are not as accurate as short term forecasts, if ICPAC seasonal forecast can be available to ENTRO seasonal (up to 3 months) flood forecasts can be undertaken for flood preparedness.

3.2 Forecast and Early Warning Users

National Disaster Risk Management Agencies

The National Disaster Risk Management Commission (Ethiopia), the Ministry of Humanitarian and Disaster Management (South Sudan), Humanitarian Aid Commission and National Council for Civil Defense (Sudan) are the national disaster risk management institutions that use forecast and early warning information. The information provided by ENTRO and other national and regional institutions is used to support actions on disaster mitigation. At times questions have been raised on the accuracy and specificity of the forecasts and this has seen some institutions reluctant to directly convey/use this forecasts.

Other Governmental agencies

The Ministries of Water, Irrigation and Energy (Ethiopia), Water Resources and Energy (South Sudan) and Water, Irrigation and Electricity (Sudan) other than being forecast and data providers are recipients of ENTRO forecast information which they pass to relevant departments and agencies under it. Other ministries that do benefit from forecasts are those with mandates on Agriculture & livestock, transport, information, energy and health.

Non-Governmental Organizations

Key UN agencies that are involved in disaster mitigation, relief and rehabilitation that use forecast information are UNICEF, WFP, FAO and UNOCHA. These agencies are regular members of Government disaster risk management committees and do (re)process the forecast they receive to meet their requirements.

Other non-governmental organizations that receive and use forecasts are local NGOs and CBOs which receive forecasts and early warning information in a form they can understand from the Disaster risk management agencies and media. They inturn reach the communities with this information.

4 METEOROLOGICAL WRF MODEL SETUP AND VERIFICATION

4.1 WRF model set up

A three day rainfall forecast generation process that has been implemented at ENTRO at 6km and 3hr spatial and temporal resolution. This process relies on the WRF model, a dynamical model that has been customized for the EN region. Since this a regional model, global input from NCEP's GFS are utilized to provide the initial and boundary conditions. Figure 3 presents an overview of the forecast generation process. The operational WRF forecast process which is automatically launched by the system using crontab job scheduler. This has improved efficiency has the forecasts are readily available as long as the server is on

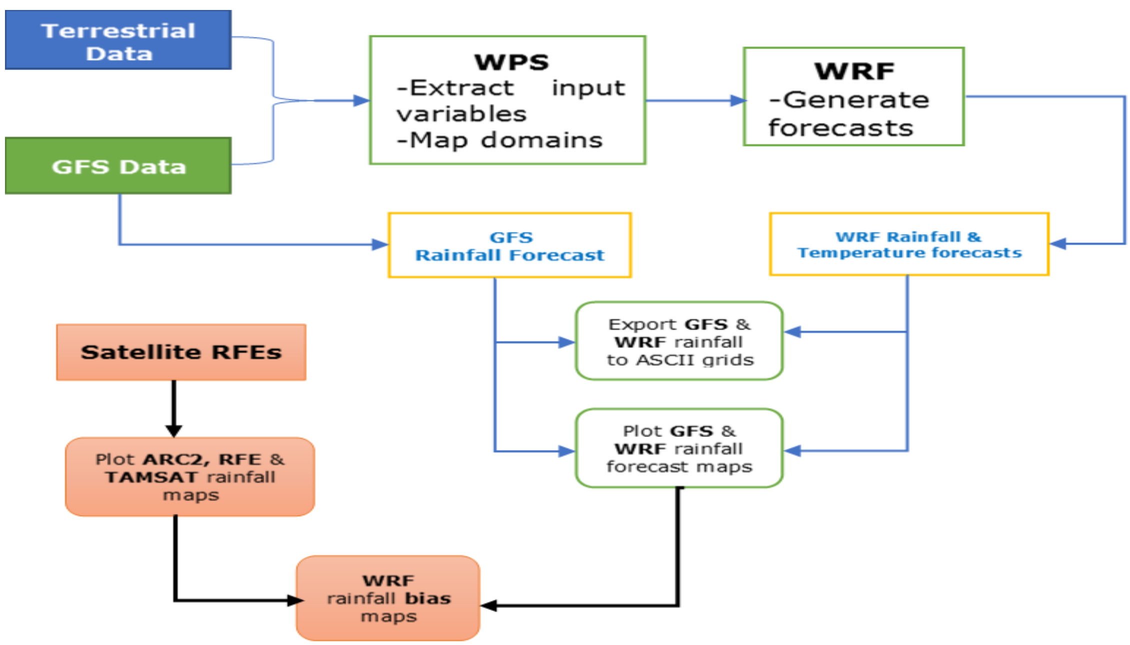

Figure 3 Operational rainfall forecast process implemented at ENTRO (NB: Black arrows indicate tasks that are accomplished at 3-5 days lag)

As an alternative to the WRF rainfall forecasts, tools to acquire and process the GFS 25km rainfall forecast data were developed. The data is downloaded in its native format, grib2, then processed for the Eastern Nile region at hourly intervals. The final format is saved as raster, ESRI ASCII grid format (.asc), which is the required format for input to hydrology models (MIKE 11-NAM).

The bias analysis was done for 2013, 2014 and 2018 hindcast simulations in order to understand the large-scale rainfall biases within the June, July and August (JJA) rainy season.

The WRF run usually takes three hours to provide the EN rainfall forecast in netcdf format, which is compatible with the hydrology model. In case WRF is not able to run for some reason, an alternative rainfall forecast data is sourced from NCEP GFS model. The 25km GFS three day forecast is downloaded and re-grided to 6km to provide alternative forecasts when need arises.

4.2 Results Verification

The results in Figure 4 below shows the results for 2013 and 2014, with CHIPRS used as the reference data. The results indicates a general over-estimation of rainfall in central Ethiopia upto 10mm in a day, for both 2013 and 2014. These biases are less pronounced in South Sudan for both simulations. Considering the areas of interest, over BAS, there is considerable under-estimation of about 1-4mm in a day. However, over the Tana, the wet biases are above 5mm in a day. In the Sudan region, a general dry bias is observed ranging from 1-3mm, though with pockets of wet biases upto 10mm in the western regions outside the catchment. The analysis clearly points out that in the regions marked with heterogeneous topography, especially in Ethiopia, wet biases are more pronounced. The biases are however minimal in the BAS region. Although the biases cannot be completely eliminated, the analysis indicates minimal biases in the flood prone areas and this indicates that WRF is a useful tool to provide to support rainfall forecasting for flood early warning in the EN region.

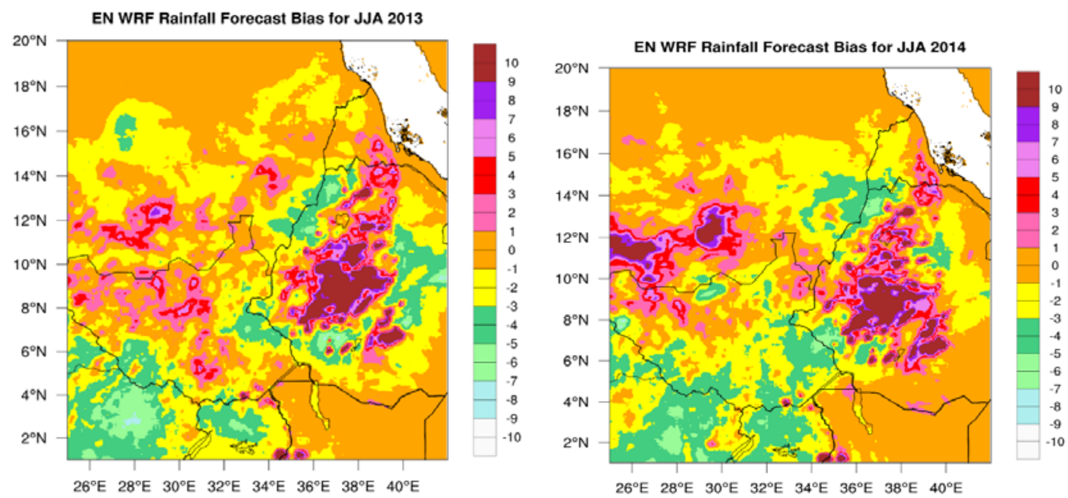

Figure 4 Rainfall biases (mm/day) for the June-August season for years 2013 and 2014

Further, analysis of the real time forecasts was also done to identify the optimum model configuration. For instance, Figure 5 indicates that Old KainFritcsh and Multi-scale KainFritcsh scheme, KFO and MK respectively closely matched observations for the three days forecast. Both the Tiedtke (TDK) and Kain–Fritsch Cumulus Potential(KFP) schemes indicated a grow in maximum bias by day two of the forecast, with TDK being worse.

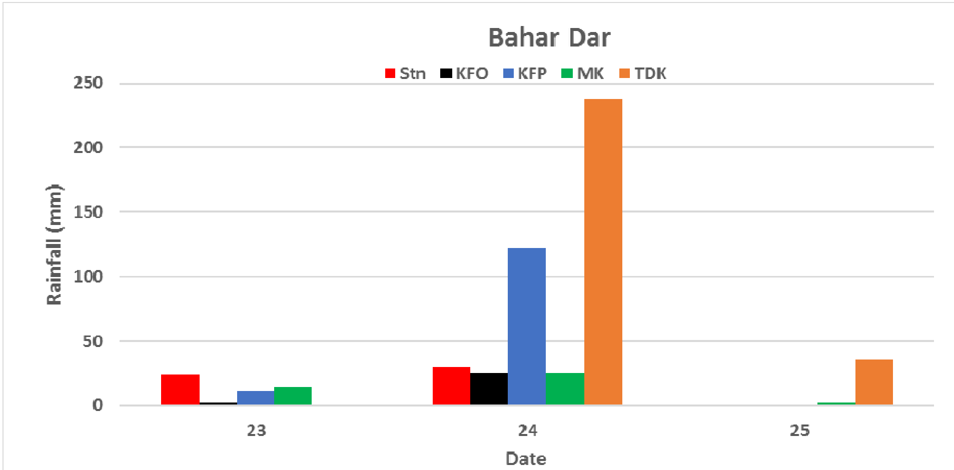

Figure 5 Comparison of station records at Bahar Dar with different WRF configurations

4.3 Alternative Precipitation Estimate and Forecast Data

Satellite Precipitation Estimate Data

Near-real time rainfall data, QPE, is a crucial input for operational flood forecasting model initialization and there exists several near-real time satellite-based rainfall datasets (Table 2). It is therefore important to quantify the temporal (intensity & amount) and spatial distribution of the rainfall biases in these datasets.Based on this, tools for acquisition and analysis of TAMSAT, CHIPRS, CMORPH, ARC2, RFE2 and GsMAP rainfall estimates were developed for the EN to provide near real time QPEs. Of importance, the GsMAP accessed through the JAXA web portal is at 10km resolution and provides data with 4hour latency, and thus provides a practical source of ENTRO's QPE.

Table 2 Various near-real time rainfall datasets that can be used as QPE for hydrology

Dataset	Centre/Source	Spatial Resolution	Temporal Resolution	Data Availability	Latency	Format	Regional Coverage
TAMSAT	University of Reading, UK	0.04 degrees	Daily	1983 - present	1 day	NETCDF	Africa
CMORPH	CPC - NCEP	0.25 degrees	Daily, 3-hourly	2012 – present	1 day	NETCDF	Global
ARC2	CPC - NCEP	0.1 degrees	Daily	1983 - present	1 day	NETCDF	Africa
RFE2	CPC - NCEP	0.1 degrees	Daily	2000 - present	1 day	NETCDF	Africa
GsMAP	JAXA	0.1 degrees	1 hour / 30min	2001 - present	4hours	Text	Global
CHIRPS	USCB	0.05 degrees	Daily	1981 – present	10 days	NETCDF	Global
PERSIANN	University of California	0.25 degrees	Daily and 6, 3, 1hours	1983 - present	2 days	NETCDF/GeoTIFF	60^{o}S-60^{o}N 180^{o}W-180^{o}E
IMERG	NASA	0.1 degrees	30min, 1 hour & 3 hours	2000m-present	6 hours	NETCDF/ASCII/geoTIFF	Global

Quantitative Precipitation Forecast Data

Quantitative Precipitation Forecasts (QPFs)are useful in facilitating hydrological forecasts with a good lead time. For this task, QPFs available from global models were surveyed and relevant candidates introduced into ENTRO's flood early warning system. In this regard, QPFs are stand-alone forecasts that can drive hydrological models as an alternative input to ENTRO WRF forecasts.

In this regard, forecast data availability is a key consideration in identifying a potential source of QPF to support flood early warning over the EN. Based on this criterion. Table 3, a summary is provided of the aforementioned model, bringing into consideration the spatial resolution as well.

Table 3Global models selected as potential sources of QPF for the EN

Model	Spatial Resolution	Temporal Resolution	Forecast Length
NCEP -GFS0.5	50km	Six - hourly	10 days
NCEP -GFS0.25	25km	Six - hourly	10 days
NCEF -CFS	50km	Six - hourly	9 months
UKMO	60km	Daily	2 months
KMA	60km	Daily	6 months

Both UKMO and KMA forecast data is at 60km, which is too coarse for use in flood forecasting over the EN catchments. On the other hand, NCEP provides high resolution GFS0.25 as well as coarse resolution forecasts, GFS0.5 and CFS. Given the need for high resolution information, GFS 25km forecasts were adopted to provide QPFs for the EN flood forecasting models

5. HYDROLOGICAL-HYDRAULIC MODEL SET UP, CALIBRATION AND VALIDATION

5.1 Model Set Up and Input data

Lake Tana Basin

Hydrologic Model– Lake Tana basin is located on upstream area of Blue Nile River. Head waters of these sub basins are steep hills with good forest cover. Flow coming up from surrounding hills converge in to low land area and eventually enters to Lake Tana. Four small rivers identified as important water ways to the lake, namely Dirma River, Megech River, Ribb River, and Gumara River. The delineated rivers and sub-catchment that are implemented in the Rainfall-runoff and the hydraulic model is shown in the Figure 6. The delineation of the basin was guided by the need to break to catchment into smaller sub-catchment to identify the flood that occur downstream as earliest as possible. As well, the delineation was also guided by available infrastructures within the catchment/basin to isolate the inflow to the infrastructures.

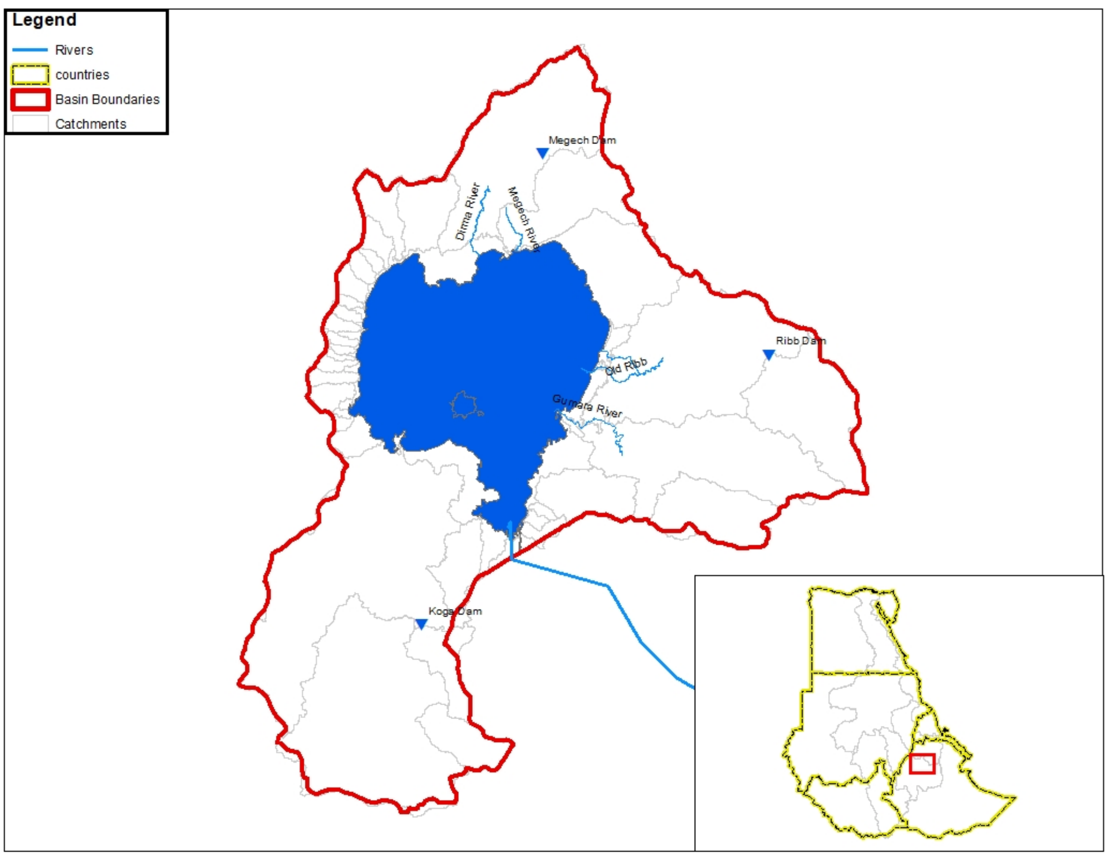

Figure 6 Lake Tana Sub catchments used within the NAM Rainfall-runoff model

Hydraulic Model:A 1D MIKE 11 hydraulic model was set up for the four major rivers in the sub basin is setup in hydraulic modelling platform. The following data were sourced to build the hydraulic model for Lake Tana basin (Figure 7 and 8).

- Cross sections of the four rivers, was sourced from surveyed data, HEC-RAS model of the lake and Airbus DEM

- River bed resistance, was sourced from HEC-RAS model of the Lake Tana basin

- Water level, flow data and Q-h relationship for gauges that were used in the data assimilation of the model

  Megech, Dirma, Gumera and Ribb stations were used for calibration, verification and validation of the model setup. These stations are not realltime stations, however a mechanism can be setup to report on daily basis to assist data assimilation in the model setup

- Height, volume, area relationships, dam water level, operational release, the Q-h relationship of the control structures (e.g. spillway) of the dams in the Lake Tana

  The dam include in the Lake Tana model setup is Ribb dam. Megech dam is not completed yet, but the structure is placed in the setup and it will be activated and required data (e.g LVA, bottom level..) updated once the construction is completed.

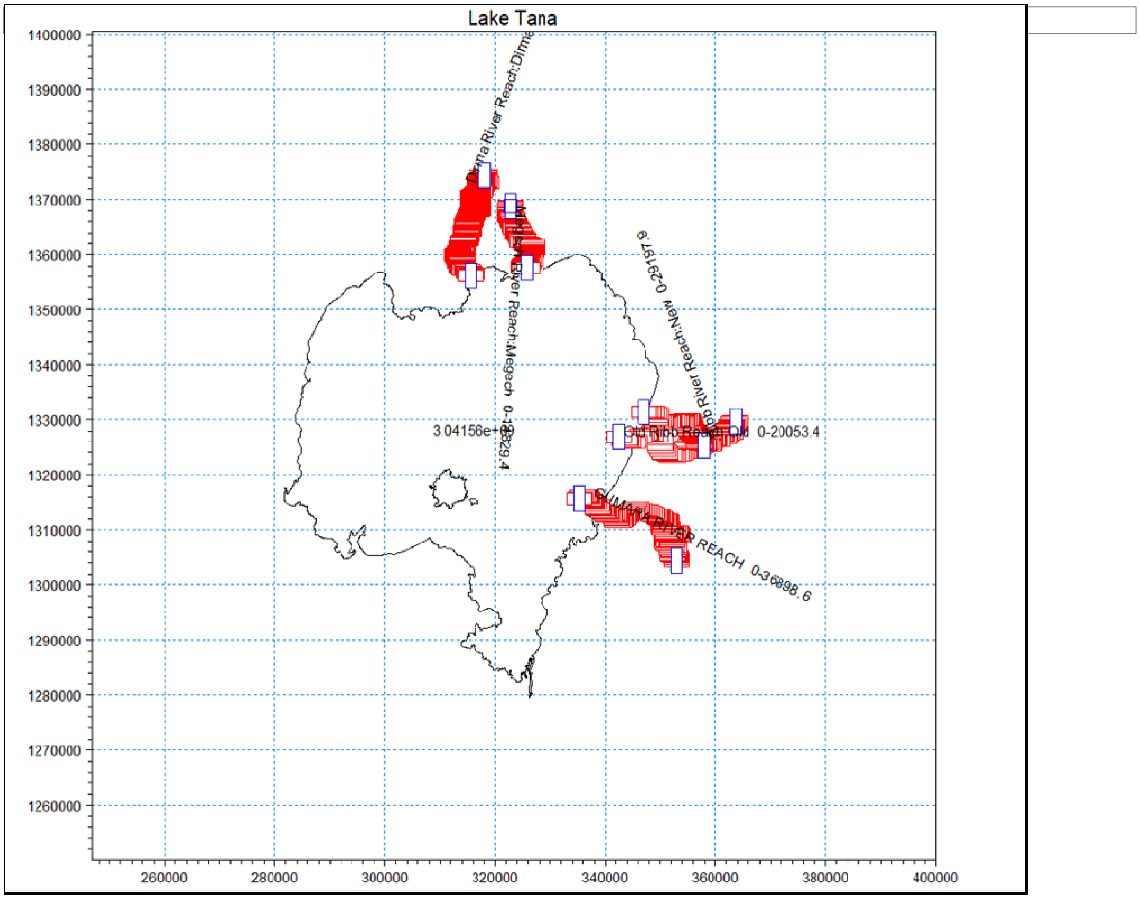

Figure 7 Lake Tana Sub basin network file in the MIKE 11hydraulic model

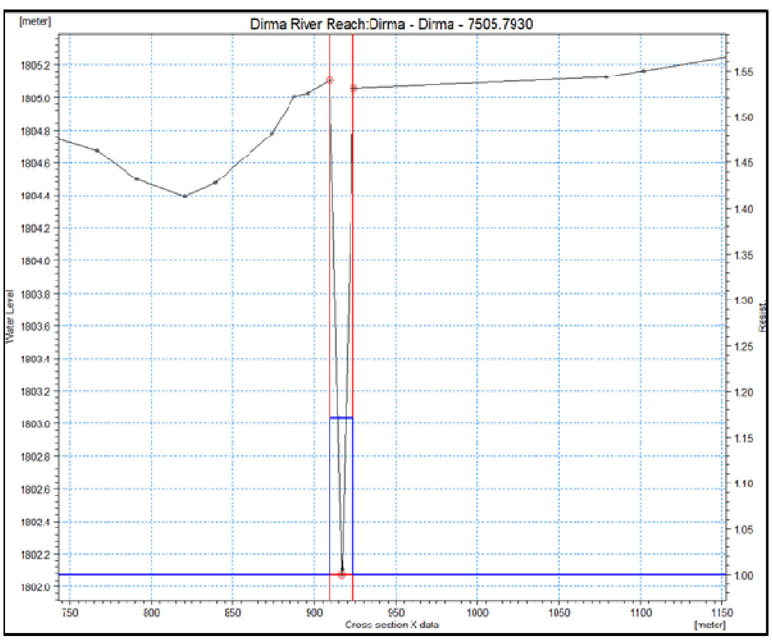

Figure 8 An example of the cross-section used in the DirmaRiver of the Lake Tana sub-basin

Baro Akobo Sobat Basin

Hydrologic Model: BAS sub watershed encompasses SobatRiver from South Sudan to White Nile confluence. The river segment from Sobat/White confluence to Khartoum is part of this watershed in the new model. Almost 80% of the sub watershed area is relatively low elevation and remaining area towards to the east of the sub basin is high elevation mountain range.

Hydraulic Model: The 1D 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, which is setup in MIKE 11 hydraulic modelling platform. The flow from Bahr el Ghazal is modelled as a boundary flow that is entering into the white river. The following data were sourced to build the hydraulic model for Baro-Akobo-Sobat sub basin(Figure 9 and 10).

- Cross sections of the white river, SobatRiver and the tributary river to sobat, is generated from Airbus DEM. The Cross section that are generated from the Airbus DEM seem to be reasonable where there is a gorge and not good in the flat part of the rivers. A new survey has been undertaken by ENTRO and is in progress to get new cross section. Once completed this will be used to improve the situation in flat areas.

- 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. The available stations at the Baro-Akobo-Sobat basin are stationed in the updtream of the Sobat river and two stations located at downstream of the White river. The stations in SobatRiver could not be used in the model as their in upper part of the catchment and it will not assist with calibration, verification and validation and data assimilation of the model. The stations upstream of Jebel Aulia Dam could be used to calibrate the overflow from the Baro-Akobo-sobat basin, however data is not available for this station.

- Height, volume, area relationships, dam water level, operational release, the Q-h relationship of the control structures (e.g. spillway) of the dams in the Baro-Akobo-sobat sub basin

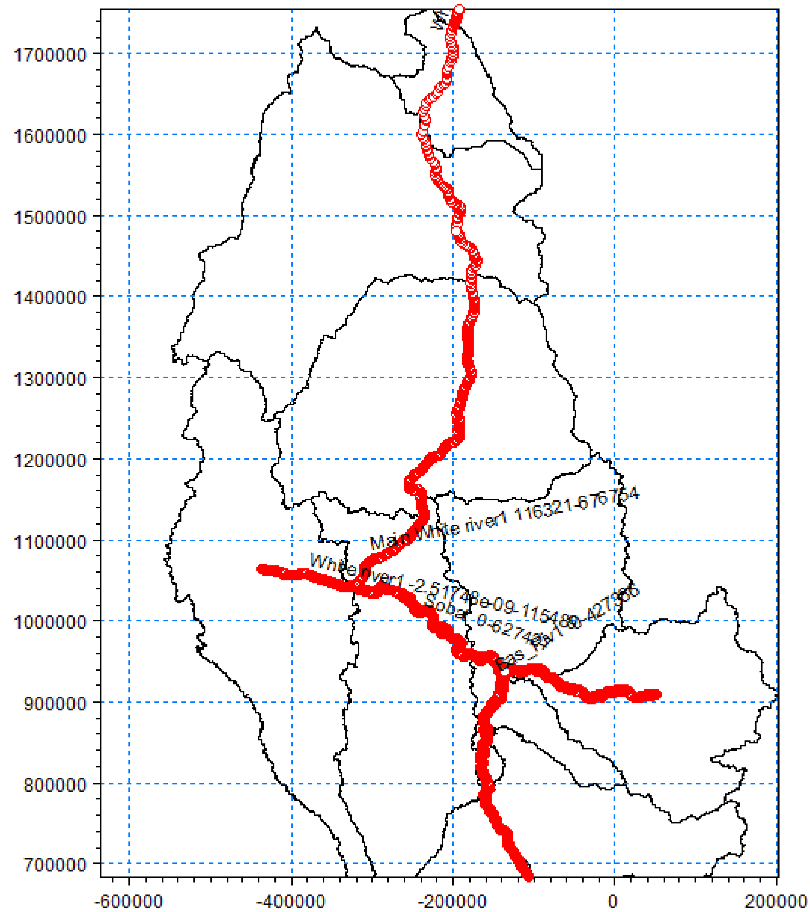

Figure 9Baro-Akobo-Sobat Sub basin network file in the MIKE 11hydraulic model

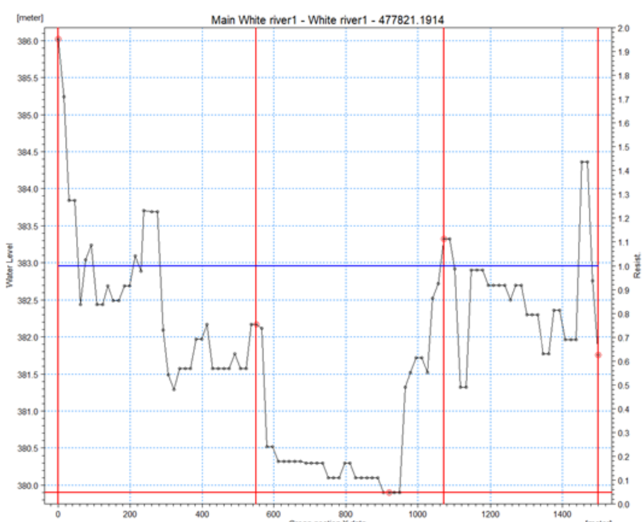

Figure 10 Example of the cross-section used in the White river of the Baro-Akobo-Sobat sub-basin

Blue Nile Basin

Hydrologic Model: Blue Nile sub watershed encompasses Blue Nile River from Lake Tana to Eldiem station at Ethiopia / Sudan border. Upper watershed is mountainous and with forest over, and lower part of the basin is from Eldiem to Khartoum is low grade. There is no usable hydrology model available for Blue Nile sub watershed and hence A NAM Hydrological model will be setup for the upper Blue Nile Basin and Mike 11 for the lower Blue Nile.

Hydraulic Model: The 1D hydraulic model of the Blue Nile River of the Blue Nile sub basin is setup in MIKE 11 hydraulic modelling platform. The following data were sourced to build the hydraulic model for Blue Nile sub basin(Figures 11 and 12).

- Cross sections of the Blue Nile river, is source Blue Nile sub basin HEC-RAS model
- River bed resistance, sourced from HEC-RAS model of the Blue Nile sub basin
- Water level, flow data and Q-h relationship for gauges that were used in the data assimilation of the model
    a. The stations that are identified to be used for calibration and validation of the model setup for the Blue Nile are:
        i. Eddiem station
        ii. Upstream and Downstream Roseires dam
        iii. Wad Elais station
        iv. Upstream and Downstream of Sennar Dam

    However, data for these stations was not provided.
- Height, volume, area relationships, dam water level, operational release, the Q-h relationship of the control structures (e.g. spillway) of the dams in the Blue Nile sub basin
    a. The two dams that are included in the model setup are Roseires and Sennar dam. The spillway Q-H relationships for these two dams was not provided as yet. The GERD is under construction, is included in the second version of the BN.

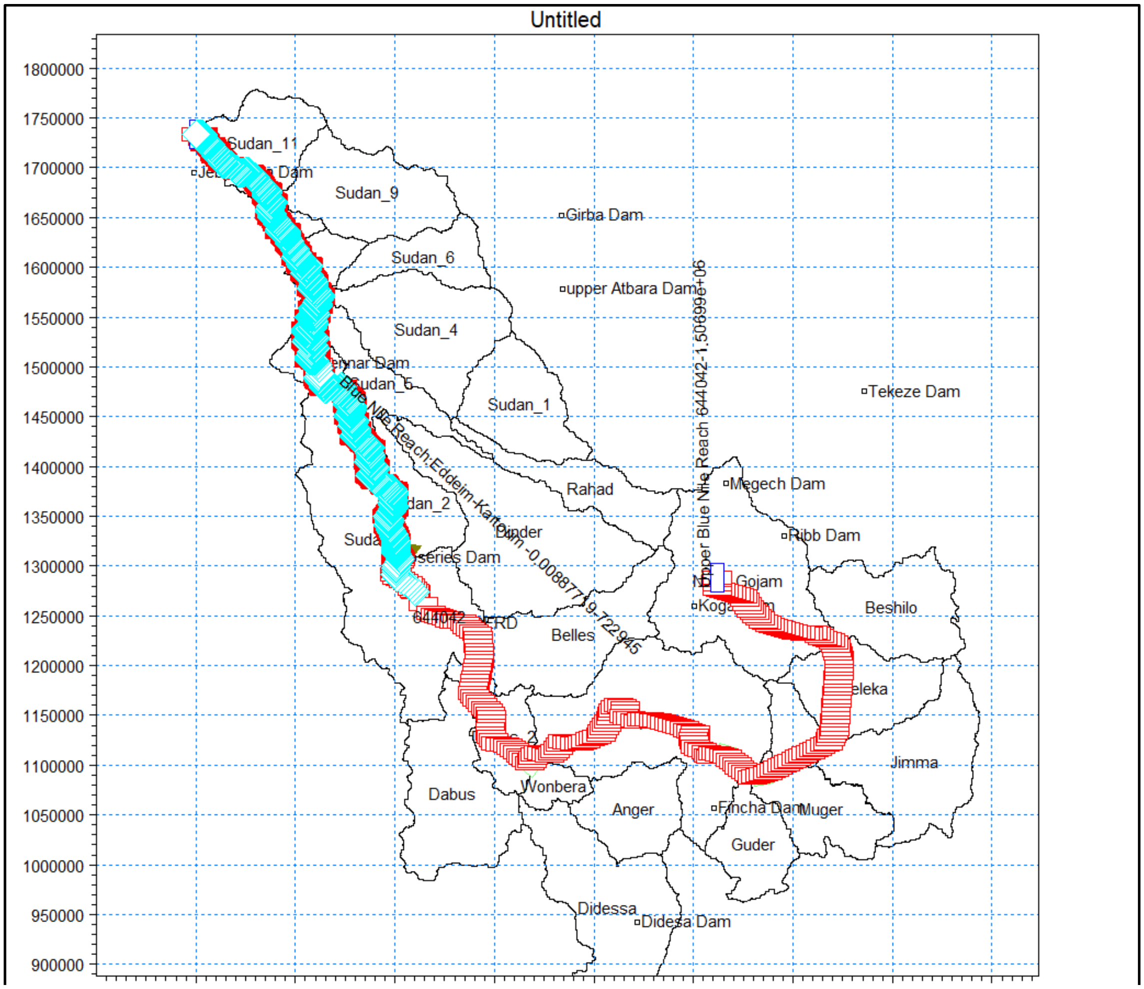

Figure 11 Blue Nile Sub basin network file in the MIKE 11hydraulic model

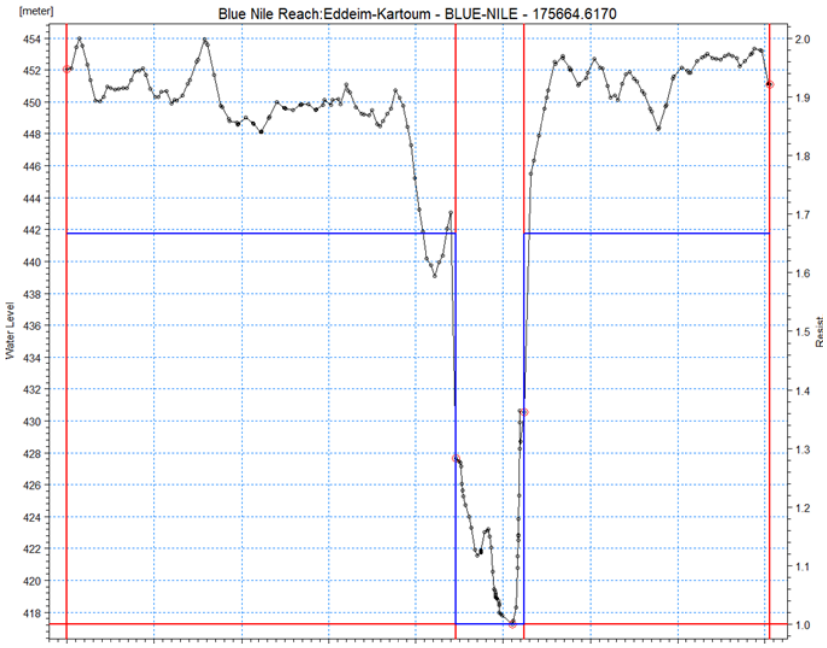

Figure 12 Example of the cross-section used in the Blue Nile

Tekeze-Setit-Atabara (TSA) Basin

Hydrologic Model:TSA basin head water starts from Mekele, Ethiopia and discharged in to Main Nile near Atbara. The upper watershed is hilly terrain with good forest cover and lower are is low grade land with little vegetation. A NAM model need to be developed for the entire sub basin.

Hydraulic Model: The 1D hydraulic model of the Atbara-Tekeze-Setit sub basin include two rivers namely TekezeRiver, and AtabaRiver, which is setup in MIKE 11 hydraulic modelling platform. The flows that are simulated from the sub-catchment are linked to the rivers at different positions. The following data were sourced to build the hydraulic model for Atbara-Tekeze-Setit sub basin (Figure 13 and 14).

- Cross sections of the TekezeRiver and Atbara River, is generated from Airbus DEM. The Cross section that are generated from the Airbus DEM seem to be reasonable where there is a gorge and not good in the flat part of the rivers.

- 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

  a. The stations that are selected to be used for calibration, verification and validation process of the model are upstream/downstream of Atabara dam, upstream/downstream of Girba dam, and Tekeze at Humera. However, data was not provided.

- Height, volume, area relationships, dam water level, operational release, the Q-h relationship of the control structures (e.g. spillway) of the dams in the Baro-Akobo-sobat sub basin

    a. The dams that are include in the model are Atabara and Girba, however the spillway Q-H relationship not provided.

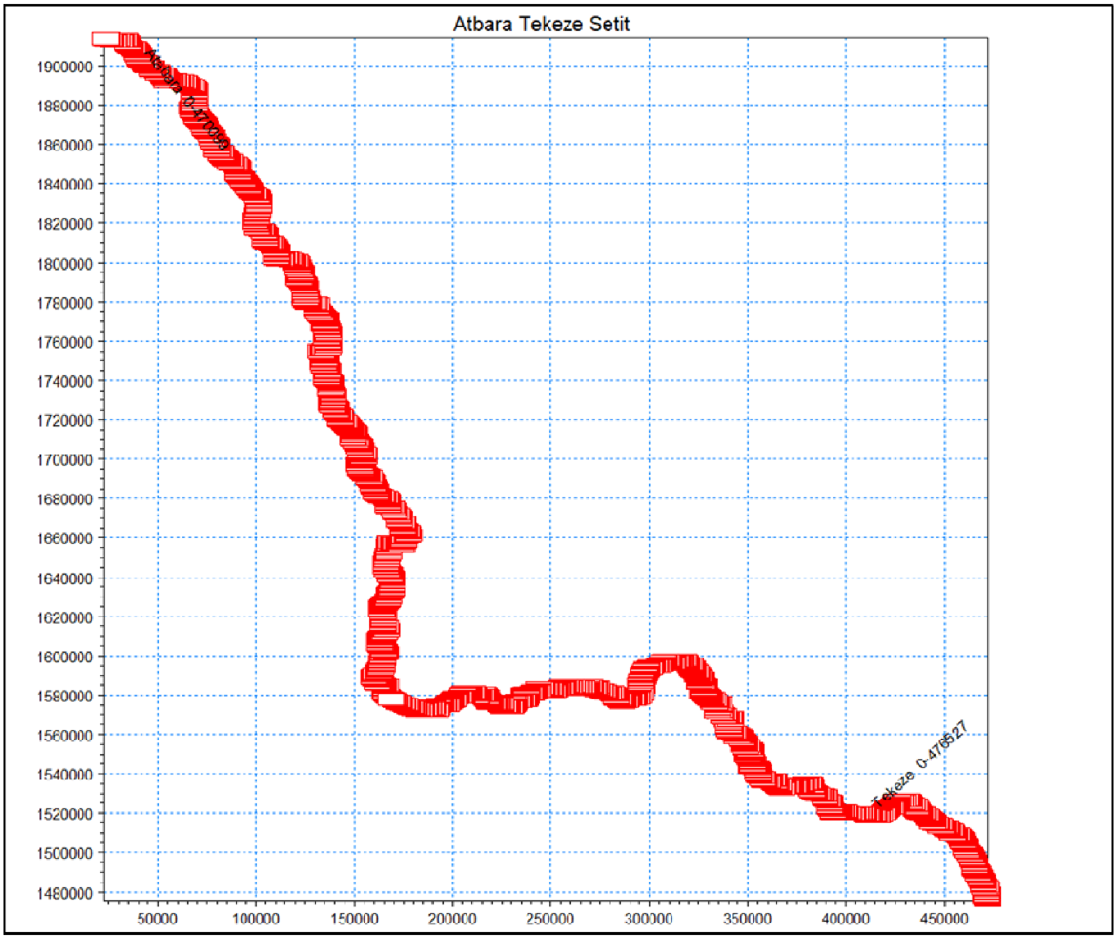

Figure 13Tekeze-Atbara-Setit sub basin network file in the MIKE 11hydraulic model

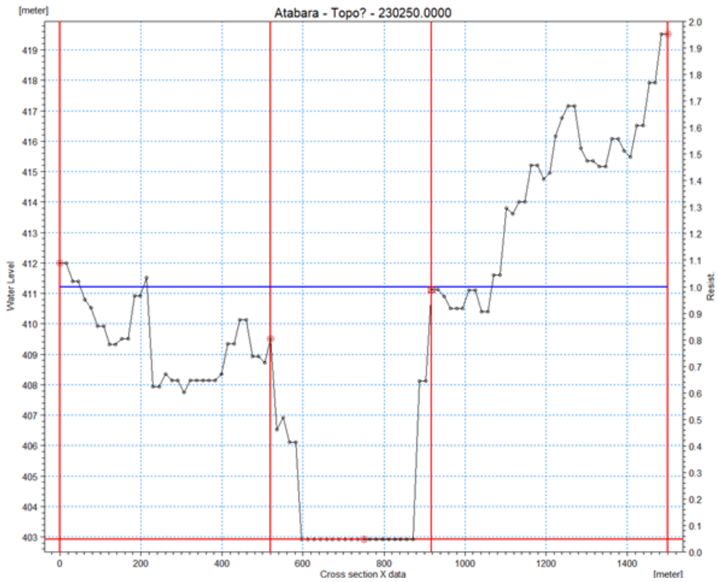

Figure 14 Example of the cross-section used in the Atbara river of the Tekeze-Atabara-Setit sub-basin

Main Nile

Hydrologic Model: The Main Nile sub watershed encompasses land mass between Blue Nile/White Nile confluence to City of Dongola. The area is mostly flat and arid environment with little rainfall. The flow contribution from this sub watershed is small compared to other areas, but Mike 11 model wasextended to include this region for consistency and for use of real time forecasting interface.

5.2 Calibration and Validation

In this study, discharge data was available for the Tana and BAS sub basins, therefore calibration was done for these two sub basins. In this process of calibration and validation process, it is important to note that the rainfall data that is used for the subcatchment in the rainfall-runoff model is a satellite generated data (values) NOAA RFE for calibration purpose and the WRF rainfall forecast data for the forecast period. Satellite data in general are good in showing the spatial distribution of the rain that falls over a catchment, however, it is not always accurate in estimate the rainfall values. Moreover, Satellite sometimes could miss an event and some cases it can report an event that has not occurred. Hence, it paramount important to verify the NOAA RFE rainfall data and the WRF data against an observed/ground truth rainfall data measured by raingauge.

Lake Tana Basin

The calibration and validation of the Lake Tana model was conducted at two stations of the four rives that are modelled in the setup, namelyGumera and Rib stations, as shown in Figure 15. The comparison of the simulated against the observed is shown Figures 16 and 17. The comparison of the simulated flow that are shown below against the observed flow data, generally show the simulated flow is underestimating the observed flow. Otherwise, the simulated flow at the Gamara and RibbRiver estimated the observed flow reasonably well. The two statistics that are used to measure the accuracy and reliability of the simulated are presented in Table 4, the statistics show that the simulated flow is reasonably accurate and reliable.

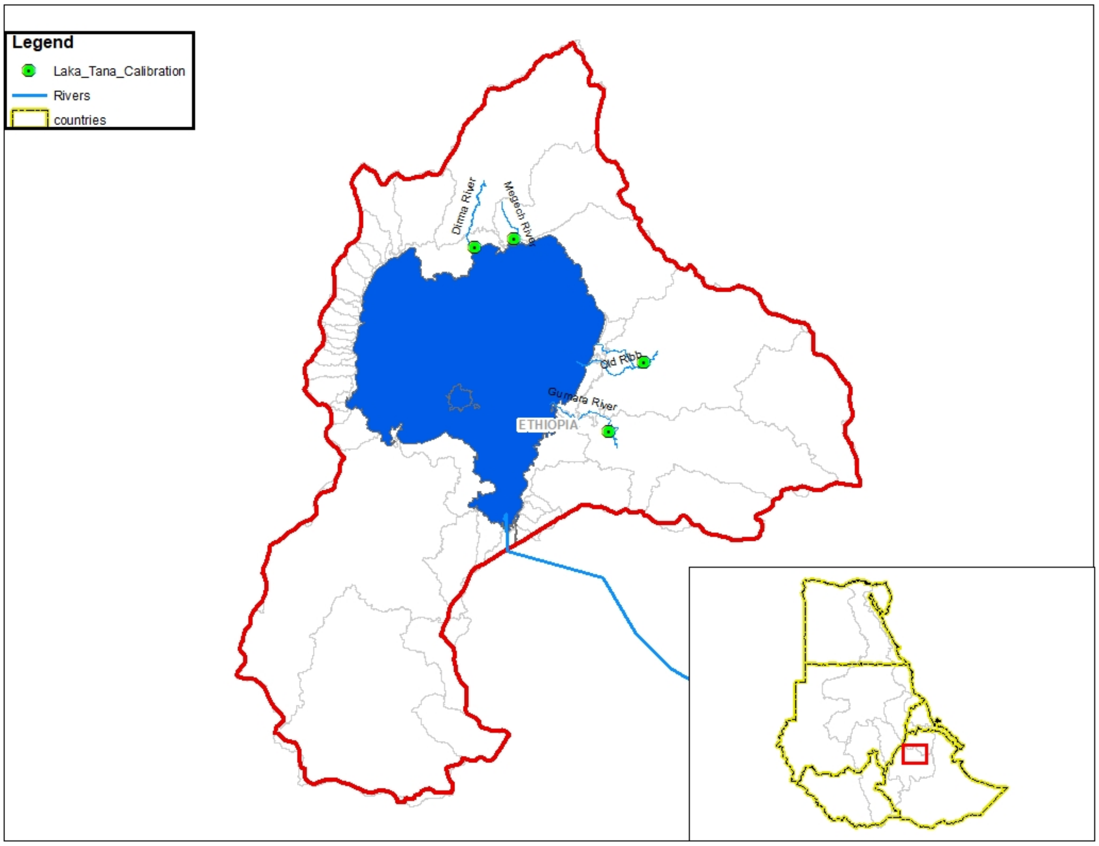

Figure 15 Calibration and validation points used for the Lake Tana MIKE 11 model

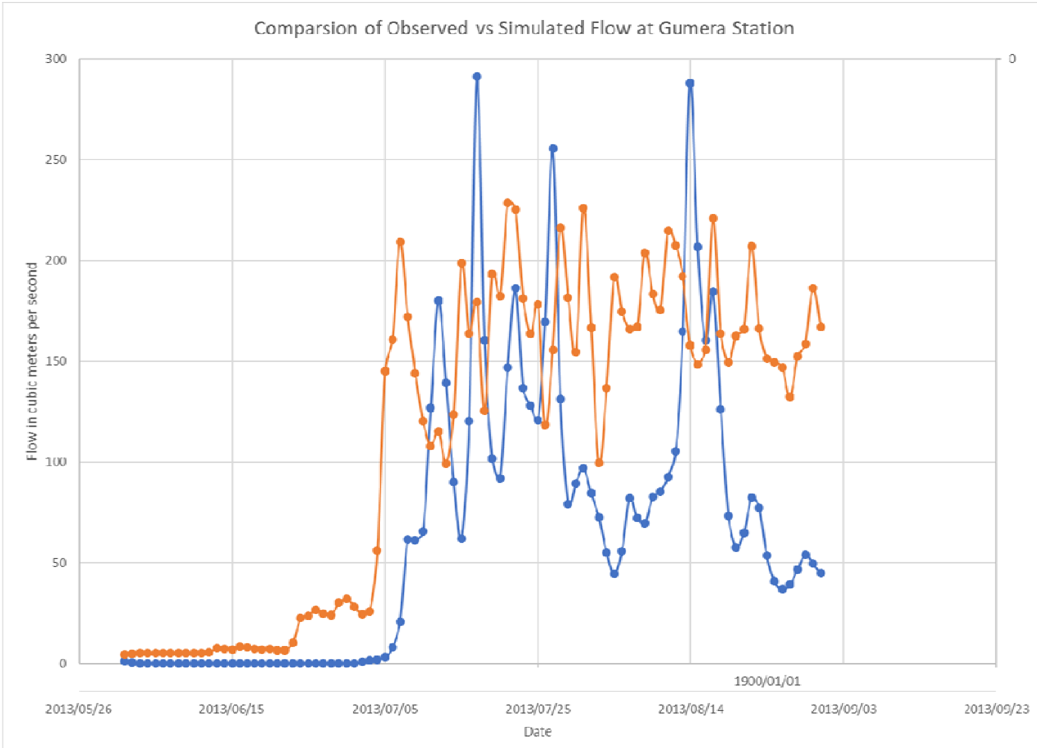

Figure 16 Comparison of Observed vs Simulated flow at Gumera station

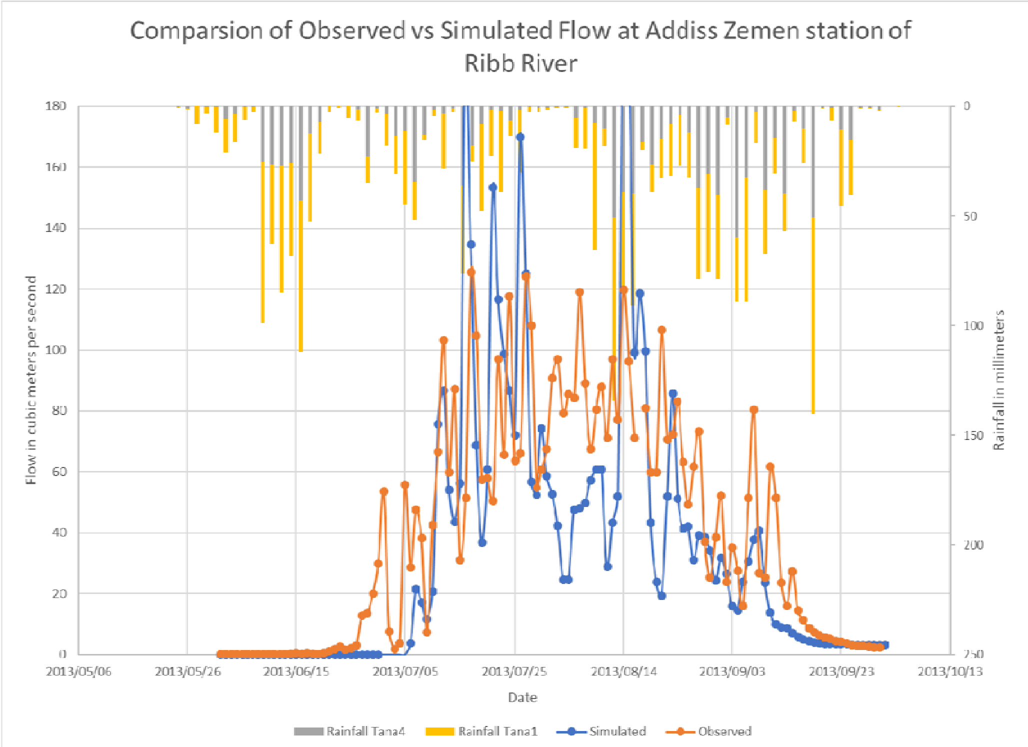

Figure 17 Comparison of Observed vs Simulated flow for RibbRiver atAddisszemen station

Table 4 Accuracy and Reliability Measurement of the Simulated Flow

River Name	Coefficient of determination (R^2)	Efficiency Index (EI)
Ribb River	0.5	0.61
Gumara	0.51	0.70

Baro Akobo Sobat Basin

The calibration and validation model of the Baro-AkoboSobatBasin model was done at Gambela stationfor 2013 year. The results of the comparison are shown in Figures 18 to 19. The simulated flow at Gambela station of SobatRiver represents the observed flow reasonable well with R^2 0.68 and efficiency index 0.89. As in the Lake Tana case, the simulated flow does under estimate the observed flow at Gambela station.

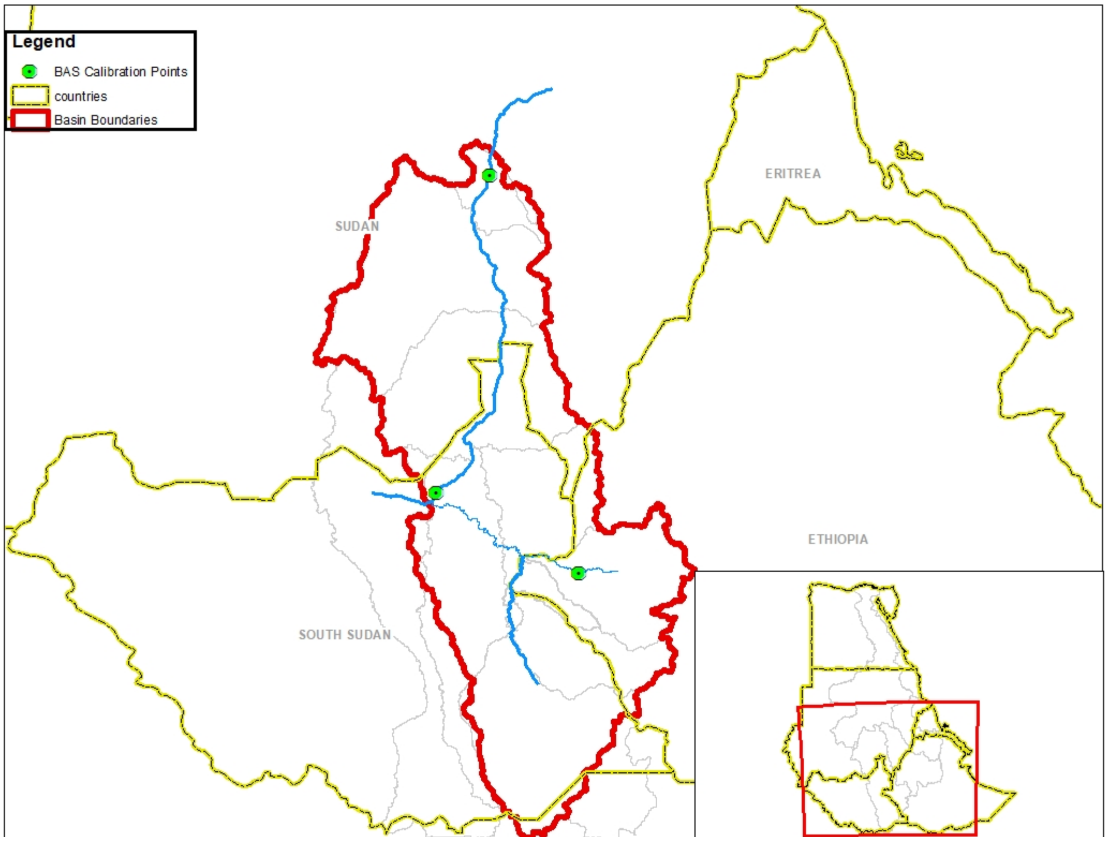

Figure 18 Calibration and validation points used for the Baro-Akobo Sobat Basin MIKE 11 model

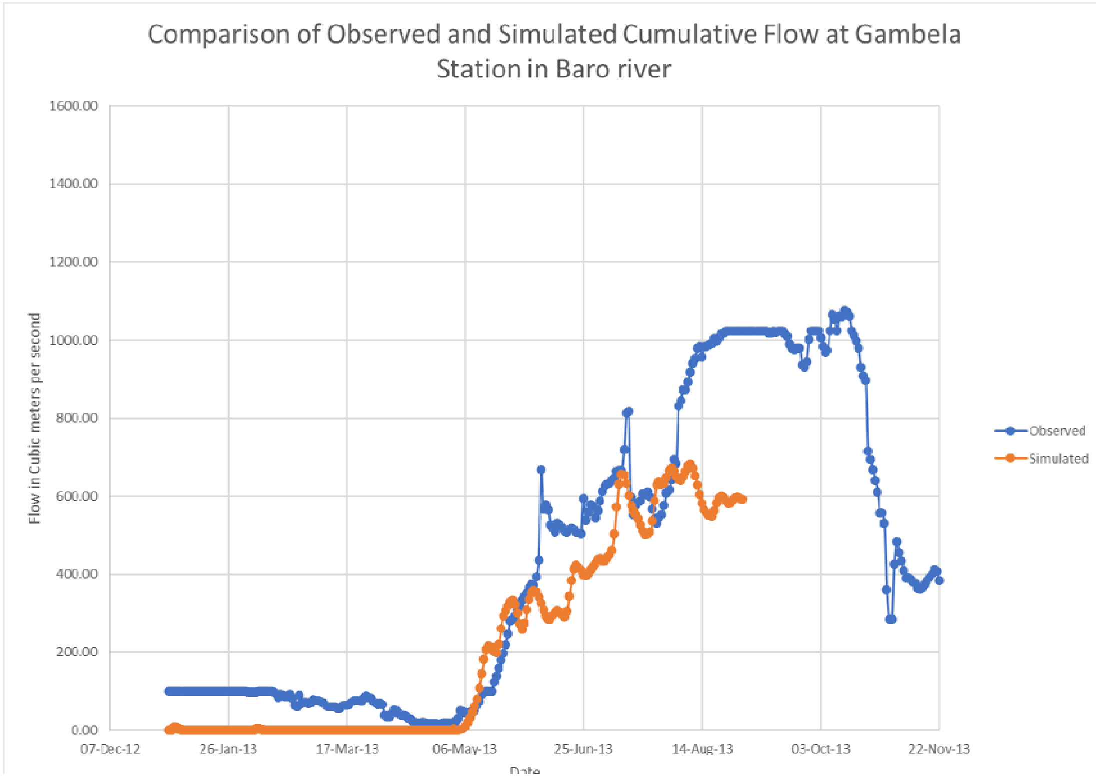

Figure 19 Comparison of Observed vs Simulated flow for Sobat River at Gambela station

6. FLOOD FORECASTING SYSTEM SET UP

MIKE Operations is a platform/framework used to setup an early warning system. The platform is designed for establishing customized (customer solutions) – generally referred to as decision support systems or information management systems - based on standardized products. The platform contains a back-end user interface where most of the early warning system setup is performed (e.g. model import, registration and scenario management, real-time data acquisition), a front-end user interface designed for client/customer to manage and interact with the early warning system.

Data Acquisition Process

Near real time, historical and forecasted data are acquired through the "Script and Job Manager" of the MIKE Operation backend and stored into a central database. The Job Manager is used to run scripts to do data processing as well as run models at specified times. The main monitoring data that are stored in the central database are as follows:

- Real time Rainfall Data (NOAA RFE, GEFS and WRF)

Modelling Integration

The NAM Rainfall-runoff and MIKE 1-D hydraulic models that were setup were registered and imported to the MIKE Operation platform through a "Scenario Manger", as shown in Figure 20. Scenarios are defined in the platform where all the input time series that expected to be updated by the near real-time and forecasted information are linked to appropriate time series in the model. In some cases, where the input timeseries are required to be built from more than one source(for example, combining observed and forecast rainfall into one timeseries), a hierarchy tool in the "Scenario manager" is used to build the input timeseries.

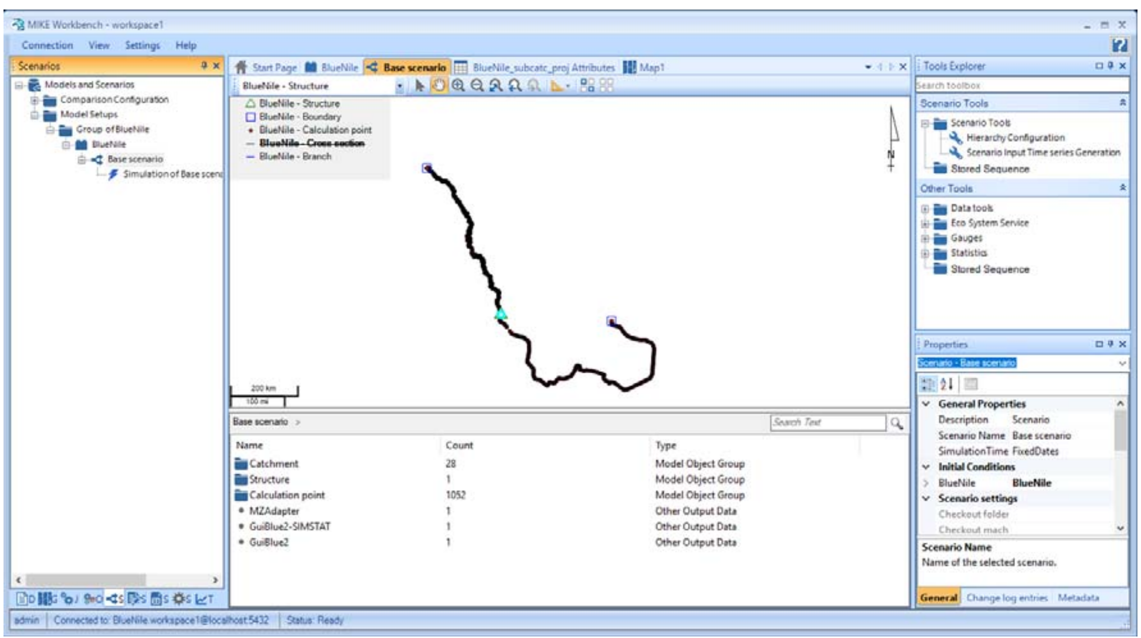

Figure 20 Blue Nile River Model Integration in MIKE Operation platform

Forecast Dissemination

Easter Nile EWFFS Desktop User interface

A simplified user interface which enables everyday users to configure specific elements within the model and to maintain the system has been developed(Figure 21). This is the "MIKE Operation Real-Time User Interface". It is quick and easy to teach potential users to operate the system effectively and thus ensures that system operators can effectively run and maintain the system. . It is designed to display real-time data, model time series input and model simulation results linked to spatial features.

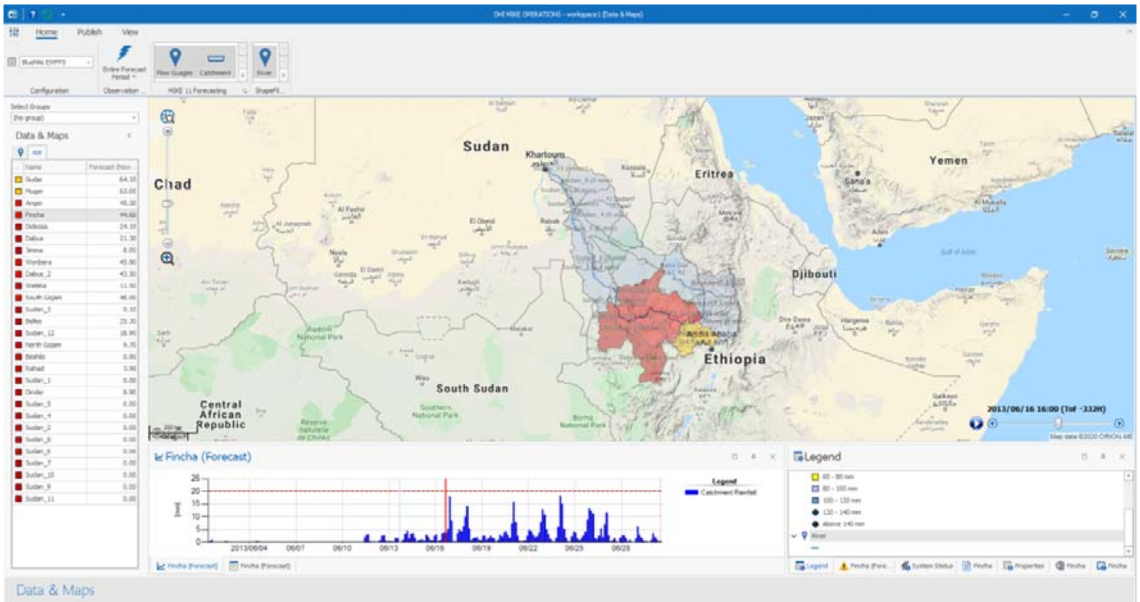

Figure 21 Blue Nile River basin EWFFS Desktop User interface

Easter Nile EWFFS Web Portal

The Easter Nile web portal (Figure 22) is a replica of the Easter Nile EWFFS desktop user interface. The web portal displays all information that is included in the desktop user interface. The web portal will be made available through internet to a wider stakeholder audience.

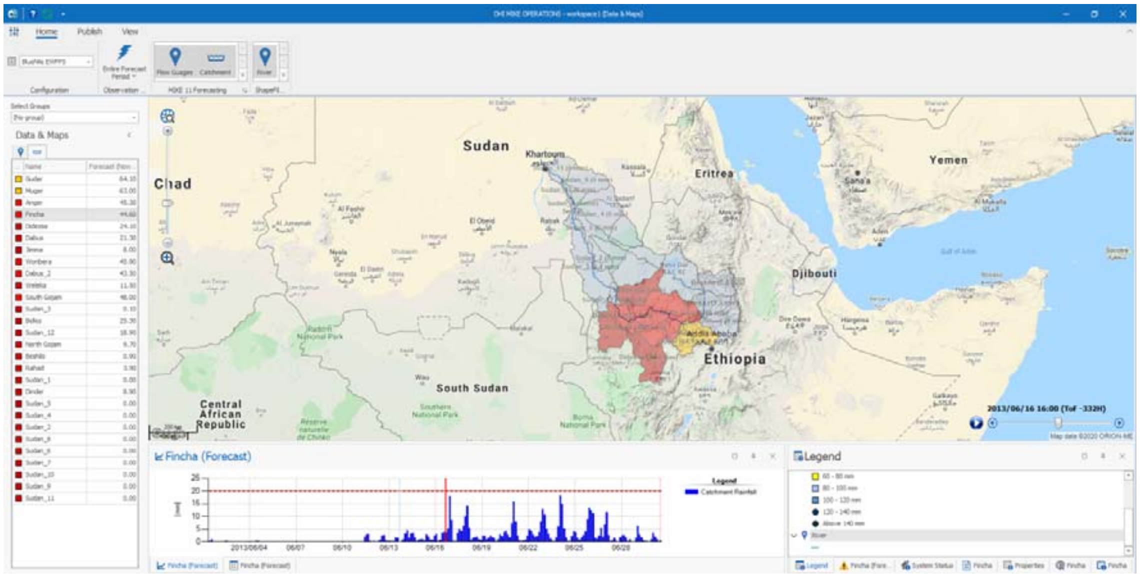

Figure 22 Blue Nile River basin EWFFS web portal

7. PROPOSED INSTITUTIONAL ARRANGEMENT AND COMMUNICATION METHODOLOGY FOR EN FLOOD EARLY WARNING

7.1 Proposed Institutional arrangement for running FEWS System

As flood forecasting and early warning activities has been an integral part of ENTRO it is recommended to institutionalize it in its structure even if it is unit under an appropriate section.

Currently, the EN flood forecasting activities are done during the rainy season of June to August for the three EN countries. During this period one staff is seconded from the each member states to ENTRO offices in Addis Ababa and they work on the modelling and issuing of forecasts. This means that very little activities is carried out outside this season since the seconded staff go back to their countries after the season is over. The best practice is that modelers work during the 'off season' to evaluate performance in previous season and work to improve on it for the coming season. This is a very critical activity and can take a considerable time to plan and execute. It includes assessment of model input accuracies, model results as well as communication and feedback of forecasts. Together with the lack of human resources for this activity is the fact that member states may send new staff who have not had experience with the ENFFEW system, thereby necessitating some training before starting the FFEW work.

In view of this, although it still encouraged to continue with the secondment of the staff to ENTRO, it is proposed to have at least one staff fully stationed at the ENTRO HQ to carry out this task, the operation and maintenance of the FFEW system and provide the required backstopping to the member states staff.

7.2 Communication Methodology

Currently ENTRO communicates the FFEW information once a day via email to water affairs related focal point ministry in the member states as well as several other institutions and individuals in their database. This process will be automated in the Mike Operation with interested individual or entities having the choice to receive email information only when certain thresholds is reached in their flood prone area of interest, as well as the information being available online via a web display.

Thus the proposed communication method in this case is Email and Web to reach those in countries and institutions with internet facility. It is then proposed that ENTRO discusses and encourages these institutions to actively use their network to reach those at risk and who lack access to the formal communication means. This is important since the social survey revealed that ENTRO FFEW information does not reach those at risk in time. The transmission of the information will be easier since the information in both the email and web will pinpoint whenever a flood is forecasted to occur the actual location and date of occurrence as well as magnitude/area affected. ENTRO should also, as part of the season's performance assessment, request from the users of its information feedback on how useful and accurate the information was and ways of improving it. This can be done as online questionnaire that takes a few minutes to complete

8. CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

As per objective and deliverables of this project, the following activities were successfully done.

- Country social assessment was completed. This study elaborated existing actors on data provision, use of early warning information and communication means. They were categorised as forecast data providers as well as forecast usersat regional and national level. The Regional institutions are ENTRO, ICPAC whereas National Meteorological and Hydrological institutions/Ministries are at National level and are key data providers.Forecast data users are the National Disaster risk Management agencies NGOs including UN agencies.

- An operational WRF system for the EN was set up and options for other forecast also established. The WRF covers the EN and provides 3hourly forecasts at 6km resolution for the next 3 days.The bias analysis was done for 2013, 2014 and 2018 hindcast simulations in order to understand the large-scale rainfall biases within the JJA season. The results verification for the years 2014 and 2015 indicates a general over-estimation of rainfall in central Ethiopia. These biases are less pronounced in South Sudan and Sudan for both simulations. Although the biases cannot be completely eliminated, the analysis indicates minimal biases in the flood prone areas and this indicates that WRF is a useful tool to provide to support rainfall forecasting for flood early warning in the EN region. As an alternative to the WRF rainfall forecasts, tools to acquire and process the GFS 25km rainfall forecast data were developed, this can be used when for some reasons the WRF products are not available. Near-real time rainfall data, QPE, is a crucial input for Model initialization. Tools for acquisition and analysis of TAMSAT, CHIPRS, CMORPH, ARC2, RFE2 and GsMAP rainfall estimates were developed for the EN to provide near real time QPEs.

- An operational ENFFEW system set up at ENTRO. The system consists of hydrologic and hydraulic models that were calibrated and validated as per the available data. The models are for the basins of EN namely, Lake Tana, Blue Nile, Tekeze-Atbara-Setit and the Baro-Akobo-Sobat sub catchments. The system is under the Mike Operation software and hosted at the ENTRO HQ. The Mike Operation runs the model automatically and send email messages to a list of provided email addresses once the flood threshold is exceeded for a particular location.

8.2 Recommendation

It is recommended that ENTRO undertakes to improve the system in future by undertaking the following

i. **Secure data and further calibrate and validate the models**: The developed models and the TAS and BN in particular will need to be further calibrated and validated to improve forecast accuracies. This is due to the fact that data for this sub basins were limited during development phase as well as that future changes in the basin will need to be included in the models.

   ENTRO is recommended to engage the member states in supporting them to setting up new stations at key location that is important for water resources management as well flood early warning with the understanding of that the member states will share the data with ENTRO even if it is not at real time basis.

ii. **Improve the infrastructure to optimize the system**: It is encouraged that ENTRO further improves the internet connection speeds and power backup systems in order to maintain the computing systems used for rainfall-flood forecasting operational. This is important since the ENFFEW system is supposed to run 24/7 and thus continuous power and internet connection for both data download and updating of the dissemination website is necessary. ENTRO can also consider as a stop gap measure as it works to improve the infrastructure to temporary hire cloud services for running the ENFFEW.

iii. **Enhance WRF capabilities:**It is important that ENTRO trains a pool of staff on use of dynamical models such as WRF in order to maintain and update the current system, as need arises. As ENFFEW system includes the WRF and is mainly managed and run by hydrologist, it is important that continuous training on its operation and maintenance. This is very critical to avoid service disruption at the critical flood seasons.

iv. **MoU with Data providers for forecasts and observed data:**ENTRO is encourage to networkand seek MOU with national hydrometinstitutions and regional climate centers in the region for exchange of meteorological data, both observed and forecasted as well as observed hydrological data. This will be useful in verification of model inputs and outputs and improvement of accuracies. It will also make it possible to extend the forecast range and support seasonal flood forecasting and preparation.

v. **Implementation of Flash flood guidelines:** It is anticipated thatdue to climate variability and increased urbanisation will lead to more human and material losses due to flash flood. As preliminary scoping work has been done to understand the flash flood in the region, it is important for ENTRO to embark on the implementation of guidelines recommended by the expert. The WRF model precipitation forecast data offers a good starting point in setting up a flash flood early warning/guidance system in the prioritized catchment.

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ANNEXES

- Flood Forum Report
- Meteorologist Report
- Hydrologist Report
- Flash Flood Assessment Report
- Sociologist Reports
    - Ethiopia
    - South Sudan
    - Sudan