EN-FFEW Enhancement Summary Report

Eastern Nile Technical Regional Office (ENTRO)
Addis Ababa Ethiopia

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Acronyms

CHIRPS	Climate Hazards Group InfraRed Precipitation with Stations
CIWA	Cooperation in International Waters in Africa (World Bank program)
CMORPH	CPC MORPHing technique (CPC: Climate Prediction Center)
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DSS	Decision Support System
EN	Eastern Nile
ENPM	Eastern Nile Planning Model Project
ENSAP	Eastern Nile Subsidiary Action Program
ENTRO	Eastern Nile Technical Regional Office
FFEWS	Flood Forecast and Early Warning System
FFGS	Flash Flood Guidance System
FPEW	Eastern Nile Flood Preparedness and Early Warning Project
GFS	NCEP’s Global Forecast System
GsMAP	Global Satellite Mapping of Precipitation
GUI	Graphical User Interface
HRC	Hydraulic Research Center of the USA
IDEN	Integrated Development of the Eastern Nile
IKP	Integrated Knowledge Portal
IMS	Information Management System
LIDAR	Portmanteau of light and radar; acronymlight detection and ranging
NAM	Nedbør-Afstrømnings-Model, DHI’srainfall runoff modelling tool
NB-DSS	Nile Basin Decision Support System
NBI	Nile Basin Initiative
NCEP	National Centers for Environmental Prediction
NCORE	Nile Cooperation for Result Project
NEL	Nile Equatorial Lakes
NELSAP	Nile Equatorial Lakes Subsidiary Action Program
NELSAP-CU	Nile Equatorial Lakes Subsidiary Action Program Coordination Unit
NETCDF	Network Common Data Format
NOAA	National Oceanic and Atmospheric Administration
NDRMC	National Disaster Risk Management Commission (Ethiopia)
NRT	Near Real Time
NWP	Numerical Weather Prediction
QPE	Quantitative Precipitation Estimate
QPF	Quantitative Precipitation Forecasting
RDRC	Regional Disaster Risk Management Committee (Ethiopia)

RFE2	NOAA's operational daily precipitation estimate method
SAP	Subsidiary Action Program
SRE	Satellite Rainfall Estimate
TAMSAT	Tropical Applications of Meteorology using SATellite data and ground-based observations
TSA	Tekeze-Setit-Atbara
UPS	Uninterruptible Power Supply / Uninterruptible Power Source
WMO	World Meteorological Organization
WPS	WRF Pre-processing System
WRF	Weather Research and Forecasting Model

Executive Summary

The Eastern Nile (EN) Flood Preparedness and Early Warning Project (FPEW) under the Integrated Development of the Eastern Nile (IDEN) is an ongoing project that is being implemented in two phases. The FPEW has created a regional Flood Forecast and Early Warning System (FFEWS) and has strengthened national offices both in terms of capacity and equipment.

During the implementation and application of the FFEWS substantial limitations became apparent and the following priority enhancements had been identified:

1. Expand the coverage of flood prone areas - e.g. parts in South Sudan andTekeze-Setit-Atbara (TSA) sub-basin
2. Revise and upscale the FFEWS based on a harmonized and coherent set of models and one integrated forecasting system
3. Updatethe list of stakeholdersfor flood alerts by conducting social surveys at country levels
4. Draw a road map for developing a flash flood forecasting system in the EN to expand the scope of the FFEWS accordingly

These priority enhancements are implemented with the following key outcomes:

A. Achievements:
    1. Flood vulnerabilities and preparedness in the communities affected by floods have been identified in national surveys.
    2. Institutional practices and collaborations at national levels have been identified.Issues related to data sharing, dissemination and communication have been fleshed out.
    3. The Eastern Nile Flood Forecast Early Warning System (EN-FFEWS) has been expanded and enhanced:
        a) The rain rainfall forecast component with the Weather Research and Forecasting (WRF) has been customized further.
        b) The hydrological and hydrodynamic forecast models have been harmonized with acoherent set of software toolsbased on DHI's software suite "MIKE by DHI".

B. Identified and/or resulting issues:
    1. Datasets, topographical and hydro-meteorological (historical and real-time) are not sufficiently available. This poses a significant limitation to the effectiveness of the forecast system.
    2. The EN-FFEWS is deployed on servers at ENTRO. Internet connectivity and reliability of electric power supply often pose a critical challenge to the reliability of the system.
    3. Data sharing mechanisms between stakeholders are either not in place or are insufficiently implemented.Reasons for these deficiencies are lack of capacities, budget limitations, and the absence of agreement frameworksbetween stakeholders.
    4. Flood information dissemination mechanisms are either not in place or are insufficiently implemented. In most flood affected communities flood awareness and preparedness is low. The communities are not adequately trained and mobilized.
    5. Flash flood forecasts are not included in the EN-FFEWS.

C. Recommendations on the way forward:

1. Arrangements for availing historical and real-time hydro-meteorological datasets, e.g. memoranda of understanding between stakeholders, need to be in place. ENTRO needs to play a proactive role to make that possible.
2. Significant efforts are necessary to improve the availability ofhydro-meteorological observations on the ground and topographical data.ENTRO needs to facilitate national activities in this direction.
3. When new and improved datasets become available the forecast models need to be revised, calibrated, and validated further, to improve the quality of the results.
4. The forecast system should be migrated to the cloud. This would make flood forecasts and flood information communication reliable.
5. National flood forecast centers need to be strengthened in their flood early warning and communication capacities. For this dedicated staff for the collaborative operation of the EN-FFEWS needs to be identified.ENTRO needs to facilitate national activities in this direction.
6. Flood awareness as well as effective flood response preparedness and capability in flood affected communities must be increased. The technical and administrative implementations at national levels need to be facilitated by ENTRO.
7. Flash flood forecasts need to be integrated into the EN-FFEWS.

The works to enhance the EN-FFEWS have substantially improved the forecast system and have given insights into the situation on the ground regarding flood information communication as well as flood response preparedness and resilience. On this basis, the above recommendations for further improvements and enhancements have been given. These need to be taken into consideration in the next project phases of the FPEW to strengthen and scale up the forecast system, to strengthen institutional capacities at national levels and to improve flood community awareness and preparedness on the ground.

1 Introduction

Ten African Counties (Burundi, D.R. Congo, Egypt, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda) have established an intergovernmental partnership, the Nile Basin Initiative (NBI), to develop the Nile River cooperatively. NBI provides an all-inclusive regional platform for multi stakeholder dialogue, information sharing as well as joint management and development of water and related resources in the Nile Basin. The member countries launched two Subsidiary Action Programs (SAP), namely (1) the Eastern Nile Subsidiary Action Program (ENSAP) and (2) the Nile Equatorial Lakes Subsidiary Action Program (NELSAP). These subsidiary action programs initiate concrete joint investments and action on the ground at sub-basin levels.

- The Nile Equatorial Lakes Subsidiary Action Program Coordination Unit (NELSAP-CU) based in Kigali, Rwanda is the executive arm of the NELSAP.
- The Eastern Nile Technical Regional Office (ENTRO) based in Addis Ababa, Ethiopia is the executive arm of the ENSAP.

The Integrated Development of the Eastern Nile (IDEN) is an ENSAP project agreed by the member countries in 2002. IDEN consists of several subprojects, one of which focuses on flood preparedness and early warning - the Eastern Nile (EN) Flood Preparedness and Early Warning Project (FPEW) – as floods in the Eastern Nile basins have significant impacts on livelihoods and economies in the region: The estimated average annual flood damages on the Blue Nile and Main Nile in Sudan and in the floodplains adjoining Lake Tana in Ethiopia exceed 30 Million US$. The 2006 flood in Ethiopia resulted in a loss of 700 peoples' lives and a displacement of 242,000 people. The extent of the 2005 flood damages to the agricultural sector in Sudan impacted 115,000 ha of agricultural crops. The 1998 flood in Sudan caused a direct flood damage of 24.3 Million US$.

The FPEW aims at reducing human suffering caused by frequent flooding, while preserving environmental benefits of floods.

1.1 Background

The FPEW’s emphasis is 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 is being implemented in two phases:

- 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 phase II).FPEW I was concluded in 2010.
- FPEW II is ongoing and focuses on structural measures and upscaling of the pilot interventions of FPEW I. The project proposal for FPEW II was finalized in 2007 and distributed to different stakeholders and donors to secure funding. But funding could not be obtained. However, ENTRO initiated with Eastern Nile countries and 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 FPEW has created a regional Flood Forecast and Early Warning System (FFEWS) and has strengthened national offices both in terms of capacity and equipment.

1.2 Rationale

During the implementation and application of the FFEWSsubstantial limitationsbecame apparent. These were discussed in the 3rdAnnual Eastern Nile Flood Forum in August 2018. In the forum the need for improvements was pointed out and priority enhancements were identified. Accordingly,the following priority enhancements, were to be implemented:

1. Expand the coverage of flood prone areas - e.g. parts in South Sudan andTekeze-Setit-Atbara (TSA) sub-basin
2. Revise and upscale the FFEWS based on a harmonized and coherent set of models and one integrated forecasting system – the implemented system was using different modelling tools, forecasting systems and different methods of dissemination for the different flood prone areas.
3. Updatethe list of stakeholdersfor flood alerts by conducting social surveysat country levels
4. Draw a road map for developing a flash flood forecasting system in the EN to expand the scope of the FFEWS accordingly

These priority enhancements have been implemented. The works have been funded by CIWA. This summary report summarizes the key outcomesof these enhancements. It also summarizes recommendations for the way forward.

2 Floods the Eastern Nile Region

Floods have significant impacts in the Eastern Nile region, and both riverine floods and flash floods are common in the region (seeoverview map in Figure 1)

These flood prone areas lie in four distinct EN-basins:

1. The**Lake Tana** basin is located upstream of the Blue Nile river. Head waters of the catchments in this basin are steep hills with good forest cover. Flows coming from surrounding hills converge in plains to eventually enter Lake Tana. Four rivers identified as important water ways to the lake are Dirma, Gumera, Megech and Rib.
2. The **Blue Nile**basin encompasses the catchments that drain into the Blue Nile river between Lake Tana and Khartoum. Relevant sub-basins in this basin are those of the rivers Dinder and Rahad. The upper catchments in Ethiopia are mountainous and with forest over, whereas the lower parts of the basin in Sudan are rather flat and with less vegetation cover.
3. The **Tekeze-Setit-Atabara** basin head is in the northern highlands of Ethiopia. Its outlet is at the confluence of the Atbara river and the Main Nile near Atbara. The upper catchments are in hilly terrain with forest cover and the lower parts of the basin are flat and have little vegetation.
4. The **Baro-Akobo-Sobat**basin encompasses the catchments of the Baro and Akobo rivers upstream as well as those of the SobatRiver in South Sudan to White Nile confluence. Most of the catchments that drain into the Akobo and Sobat rivers are flat. The upstream catchments of the Baro towards to the east of the basin are high elevation mountain ranges with good forest cover. The lower part of the Baro however is flat.

Figure 1: Eastern Nileflood prone areas

2.1 Flood Vulnerabilities and Preparedness in Ethiopia

In the Eastern Nile part of **Ethiopia**, the flood vulnerable areas are the flood plains at Lake Tana, the Gambella plain, and the Humera area of the Tekeze basin(near Ethio-Sudan border), as well as flash floods at different locations.

- Lake Tana: Flooding is a recurrent threat occurring almost every year in the Lake Tana area caused by the overflowing of the Dirma, GilgelAbay, Gumera, Megech and Rib rivers and the spillover of Lake Tana.
- Gambella Plains: The flood 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 rural areas and several settlements affected by larger floods including the city of Gambella.
- Tekeze near Humera: The flat area at Humera (near the Ethio-Sudan border) is flooded from overflow of the Tekezeriver over its banks. This occurs during extreme rainfall conditions in the upper catchment of the Tekeze basin.

When floods are forecasted, the National Disaster Risk Management Commission (NDRMC) communicates the flood alert to stakeholders by telephone and email. The NDRMC communicates the issued flood alert to the Regional Commission Offices by e-mail. The flood alert is then discussed by the Regional Disaster Risk Management Committee (RDRC). The regional DRMC communicates the flood alert to Zone and Woreda offices by telephone. The Woreda in turn communicates to the Kebele administration by telephone, which is responsible for the dissemination of warnings at community level.

The disaster risk management activities at Woreda level are carried out along with agricultural activities by the Woreda agricultural office. Early warning communication at this level is poor because early warning practices are not well “owned”.Some rural Kebeles – like 16 rural Kebeles in Jore woredain the Gambella region – do not have access to modern communication technology. In these kinds of areas, the local people may not have personal radios or sirens may not be functional. Such circumstances make disseminating alerts even more 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.LiboKemkem in the Amhara region). A survey found that the is no evidence of monitoring mechanisms to check whether warning messages reach communitymembers and/or are understood and interpreted correctly.

Response activities to flood early warning at community level can be categorized as follows:

1. Some respond positively to warnings by taking the necessary preparedness actions to save their lives and property.
2. Others are reluctant and do not respond to the flood warnings – e.g. Fogera Woreda in Amhara region
3. 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 Gambella region cannot resettle in safer areas because the flat land is easily inundated.

2.2 Flood Vulnerabilities and Preparedness in the Republic of 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. Most people there live and work in settlements in flood prone areas because their livelihoods depend mainly on farming in flood plains, fishing, and/or livestock. The city of Malakal at the confluence of the Sobat and the White Nile is also affected. Most floods occur annually.Estimates indicate that flash floods affect about one million people regularly.

The main vulnerable settlement areas are the following:

1. 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.

2. Malakal: The vulnerable flood prone area, 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.

2.3 Flood Vulnerabilities and Preparedness in 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.Flash flood occur more often than riverine floods.

A survey found 2,900 villages in flood prone areas. These are distributed along the Blue Nile, Dinder, Al-Rahad, Al-Gash and Tekeze-Atbara-Setit. The houses are in floodplains that are more susceptible to high flood impacts as well as highly vulnerable to economic, physical/ infrastructural, and attitudinal dimensions. These communities couldmitigate flood impacts if they are warned at least 3 days before the flood occurs, like during the floods of 2018 and 2019.Sample household surveys in the following pilot riverine flood prone were carried out:

1. Um Benein village is located on the western bank of the Blue Nile within Singa locality with an estimated population of 10,000 persons.
2. El Sabonabi village is located on the western bank of the Blue Nile within Singa locality. The total population is about 15,000 persons (750 families).
3. Tuti island village is in the heart of Khartoum state at the confluence of the Blue Nile and the White Niles. Its total area is about 8 km2. The total number of houses on the island is 1,820. The total population is about 20,000.
4. Wawisi village is located east of the River Nile, about 100 km north of Khartoum, within of Sharq Al Nil locality, Khartoum state. The total population is about 6,000 (about 800 families).
5. Wad Ramly consists of five villages and is located east of the River Nile, about 102km north of Khartoum, within of Sharq Al Nil locality, Khartoum state. The total population is about 40,000 (about 14000 families).
6. Sidon city belongs to the Sidon administrative unit, Lamar locality, River Nile State. It is located 60 km from Lamar, at the eastern bank of Atbara River. 700 families live there.
7. Alabka village belongs to the Sidon administrative unit, Damar locality, River Nile State. It is located 60 km from Damar, at the western bank of Atbara River. 460 families live there.

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

1. Inadequate training initiativesto enhance local capacities to mitigate and cope with seasonal floods
2. Not enough time to evacuate if necessary
3. No reliable forecasts or measurements -no fixed thresholds for warnings and alerts
4. 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 isrequired to save livelihoods and assets from flood disasters. This needs to be weighed against the fact that longer lead timesresult in less reliable forecasts.

3 The Eastern Nile Flood Forecast Early Warning System

The Eastern Nile Flood Forecast Early Warning System (EN-FFEWS)is an integrated real-time forecasting and early warning system that supports ENTRO, as well as regional and national stakeholders in flood forecasting and early warning. This enhanced system is operational and running.The EN-FFEWS is currently deployed on a server at ENTRO and options to migrate the system to the Cloud are being investigated.

One component of the EN-FFEWS is a customized version for the EN of the Weather Research and Forecasting (WRF) model. The other component builds upon DHI's decision support system, MIKE Operations with integrated modelling tools to simulate hydrological and hydrodynamic processes.

Currently, the EN-FFEWSis hosted on a server at ENTRO.

3.1 Meteorological Forecasts

In the EN-FFEWS rainfall is forecasted with the Weather Research and Forecasting (WRF) model. The model is a regional customization for the EN with global input from NCEP's GFS to provide initial and boundary conditions.WRF produces 3-day forecasts with a spatial resolution of 6 km, and the forecasts are updated daily.The temporal resolution of the rainfall forecasts is hourly.

The meteorological forecast process starts with a scheduled download of NCEP's Global Forecast System (GFS) to provide initial and boundary conditions. Once the data is successfully downloaded, it is seamlessly ingested in the WRF Pre-processing System (WPS), which extracts the relevant variables to initial the forecast for the region. The outputs of WPS are passed to the WRF proper, which upon completion of the simulation, generates a three-day forecast as NETCDF-outputs. These outputs are archived for input to the hydrological models(see chapter 3.2) and are further processed to plot daily total rainfall maps. This process takes about3 hours.

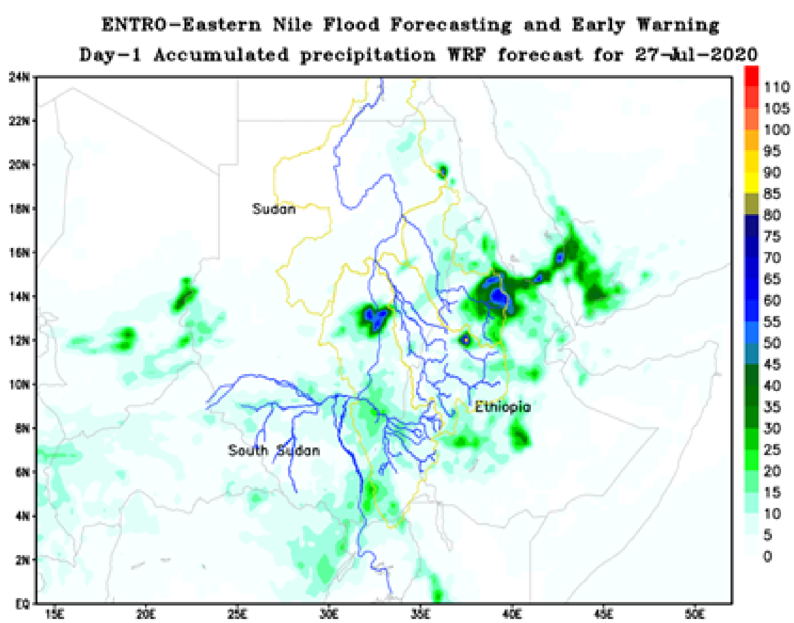


Figure 2: Sample daily total rainfall map showing WRF forecast

To ensure that the hydrological forecasts don't suffer lack ofrainfall inputs, there are alternative provisions for using 25km GFS rainfall forecasts for three days lead time - incase WRF doesn't run. The process is automatedand allows downloading, processing, and packaging of the GFS 25km hourly data.An advantage of utilizing the GFS data is that it can be obtained frommultiple servers that support automatic remote access and regional sub-setting of the data.

Furthermore, the meteorological forecast component provides access to near-real-time (NRT) satellite rainfall estimates for quantitative precipitation estimations (QPE). For this purpose, tools for acquisition and analysis ofTAMSAT, CHIPRS, CMORPH, ARC2, RFE2 and GsMAP rainfall estimates were developed. The tools allow the operator of the system to save selected datasets as NETCDF file and plot rainfall maps for a specified period. These datasets areavailable with 1-day lag and can be used to quantify biases of the rainfall forecasts.

Applications so far with the meteorological forecast component show that internet connection at ENTRO is at times insufficient – connection speed is slow, and connection is often interrupted. Furthermore, computing performance of the server that hosts the meteorological forecast component should be increased, as generally NWP models require high-performance computers forefficient operation.

3.2 Hydrological Forecasts

In the EN-FFEWSrunoffs in the catchments of the four basins and flows at key locations in the river network are forecasted with the hydrological modelling tool NAM of DHI.NAM is the Danish abbreviation of “Nedbør-Afstrømnings-Model” which translates into Englishas “Rainfall-Runoff-Model”.NAM simulates the terrestrial phase of the hydrological cycle. It allows developing deterministic and lumped hydrological catchment-based models. NAM can be applied independently, or it can be used to generate lateral contributionsto river networks. In this way, it is possible to model an individual catchment as well as a groupof sub-catchments constituting a larger basin with a more complex river network.

For each EN-basin a hydrological model has been developed with NAM. The development of the hydrological models was carried out based on different earth observation products to hydrologically characterize and delineate the catchments in the basins[1]. Model setup and calibration was conducted with historical rainfall and observed evaporation data that was sourced from satellite products. Supplementing this source of information with ground observations of rainfall and evaporation was not possible because such datasets were not available during the development of the models. Therefore,the models were calibrated with historical WRF rainfall datasets. This would reduce errors that result from using rainfall forecasts with the WRF.

Table 1: Key Numbers of the Hydrological Models of the EN-Basins

Basin	Number of Catchments	CatchmentArea Range [km2]	Number of Flow Forecast Locations
Lake Tana	14	62 – 2,049	13
Blue Nile	28	890 – 32,167	7
Tekeze-Setit-Atabara	13	3,847 – 33,599	5
Baro-Akobo-Sobat	10	9,235 – 112,727	10

The real-time inputs for forecasting runoffs in the catchments and flows at key locations in the river network come from meteorological forecasts with the WRF (see chapter 3.1). The forecasted flows are archived for further analyses in the integrated forecast system (see chapter 3.4). The input to the hydrodynamic models (see chapter 3.3) is direct.

[1]The Baro-Akobo-Sobat basin has been expanded: The catchments draining into the river segment from the confluence of Sobat and White Nile to Khartoum have been added to this basin in the newly developed hydrological model. The flow from Bahr el Ghazal is modelled as a boundary flow that is entering into the White Nile.

Usually, flood forecasting systemsmake use of ground-based telemetric point rainfalldata. As mentioned above, the hydrological models developed for the EN-FFEWS only use satellite-based rainfall estimates. In the EN-basin, there are very few manual rainfallmeasuring stations, not dense enough to represent accurate areal catchment rainfalls. The rainfall measuring stations are not well distributed over the basin. Furthermore, noneof the measuring stations are telemetric and transfer data in near-real-time.

3.3 Flood Forecasts

In the EN-FFEWS flood water levels at key locations in the flood prone areas in the river network of the basins are forecasted with MIKE 11. MIKE 11 is DHI's 1-dimensional hydrodynamic modelling tool to simulate flows and water levels in river reaches.

Observed flow and gauge levels, where there is an observed flow or gauge levels the information was used for calibration and data assimilation. There is no telemetric realtime data that can used for the data assimilation, however, there are manual flow gauges that report on daily basis. An effort will be made to develop a mechanism for these gauges to report to the central database, and the data to be used for data assimilation.

For each EN-basin, hydrodynamic models have been developed for the flood prone areas that are affected by riverine floods (see chapter 2).The development of the hydrodynamic models was carried out basedon topographic information from digital elevation models (DEM) with a resolution of 25 m (Airbus DEM). Most cross section in the hydrodynamic models are derived from this DEM. Where available, cross sections from other hydrodynamic models and survey data have been used to supplement. In flat areas, cross sections derived from DEM don't represent the river geometry appropriately, which in turn can affect the quality of the simulated flood levels in such areas.

The hydrodynamic models were calibrated with historical water levels and flowsat selected gauging stations.

Table 2: Key Numbers of the Hydrodynamic Models of the EN-Basins

Basin	Number of River Reaches	Total Length of River Reaches [km]	Total Number of Cross Sections
Lake Tana	4	133	533
Blue Nile	2	2,230	1,072
Tekeze-Setit-Atabara	2	947	489
Baro-Akobo-Sobat	3	2,038	240

The final MIKE 11 setup is developed jointly with the rainfall-runoff model that is developed to enable integration between the models. Secondly, the MIKE 11 data assimilation module (MIKE 11 DA), extensively used in flood forecasting modelling applications, is setup at points where it is assumed that near-real-time information can be sourced.Data assimilation is a method to condition the model predictions of water levels at selected locations to observed data.

The inputs to the hydrodynamic forecasts of flood water levels are flows from hydrological forecasts (see chapter 3.2).The forecasted water levels are archived for further analyses in the integrated forecast system (see chapter 3.4).

Near-real-time flow gauges are fundamental part of a flood forecasting system,they are required to constantly update the accuracy of the prediction and measure theperformance of the flood simulations by the flood forecasting system. They are used in dataassimilation process of the hydraulic modelling of the system. The near-real-time observed waterlevels and flows are used to calculate errors at data assimilation points and recalibrate the model flood prediction to improve model performance. Currently, due to the absence of such gauges in the EN this is not possible in the EN-FFEWS. But the system has been prepared to make this easily possible when data from telemetric stations in the EN-basins becomes available in the future.

3.4 Integrated Forecast System

The EN-FFEWS is setup in the MIKE Operations platform, DHI's decision support system which is the generic version of the Nile Basin Decision Support System (NB-DSS). MIKEOperations is a platform that has the purpose to integrate operation and planning tools ormodels with near-real-time, forecasted and historical observed data. Furthermore, it produces reports from model results as well as raw and processed data to assist managers andtechnical personnel to make decisions – for planning or real time operation purposes in water resources development and management.

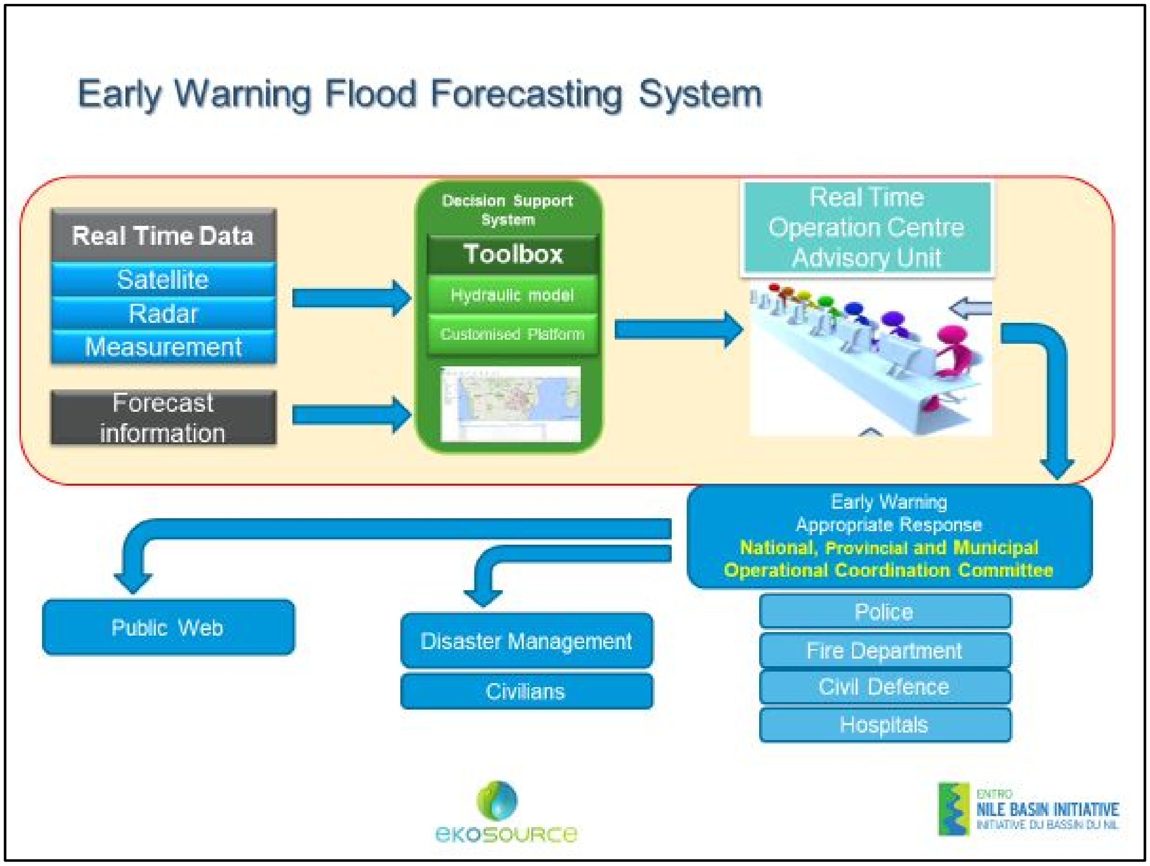
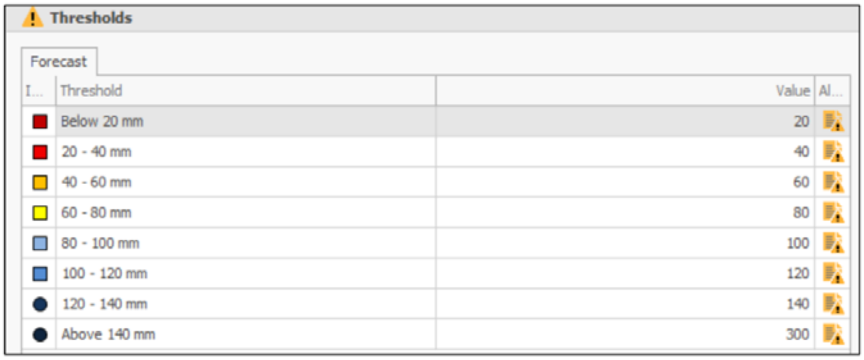


Figure3: Architecture of the EN-FFEWS

The architecture of the EN-FFEWS is shown in Figure3, where near-real-time and forecasted dataare regularly imported from different sources to the central database through scheduled dataimport jobs. The scheduled interval for these jobs depends on how frequently the data ismade available at the source. In the data acquisition process the system reads, pre-processes and makes the following real time rainfall datasets available for subsequent processes (such as hydrological modelling or interactive analyses supported with the GUI of the platform): NOAA RFE2, GFS and WRF.



Thresholds

Forecast

I...	Threshold	Value	Al...
	Below 20 mm	20	
	20 - 40 mm	40	
	40 - 60 mm	60	
	60 - 80 mm	80	
	80 - 100 mm	100	
	100 - 120 mm	120	
	120 - 140 mm	140	
	Above 140 mm	300	

Figure 4: Example of thresholds defined for rainfall in the EN-FFEWS

The rainfall-runoff and hydrodynamic models have been integrated in MIKE Operations so that simulation runs are triggered from the platform. The input timeseriesare regularly updated using the real-time and forecasted data. The NAM rainfall-runoff models and the MIKE 11 hydrodynamic models for the 4 basins of the EN run every 6 hours. When a model run is completed, results are summarised to be analysed in the GUI of MIKEOperations and in the Eastern Nile web portal. If simulated or observed water level values exceed pre-defined threshold values, warning triggers are sent to the appropriate entities by SMS or e-mail.

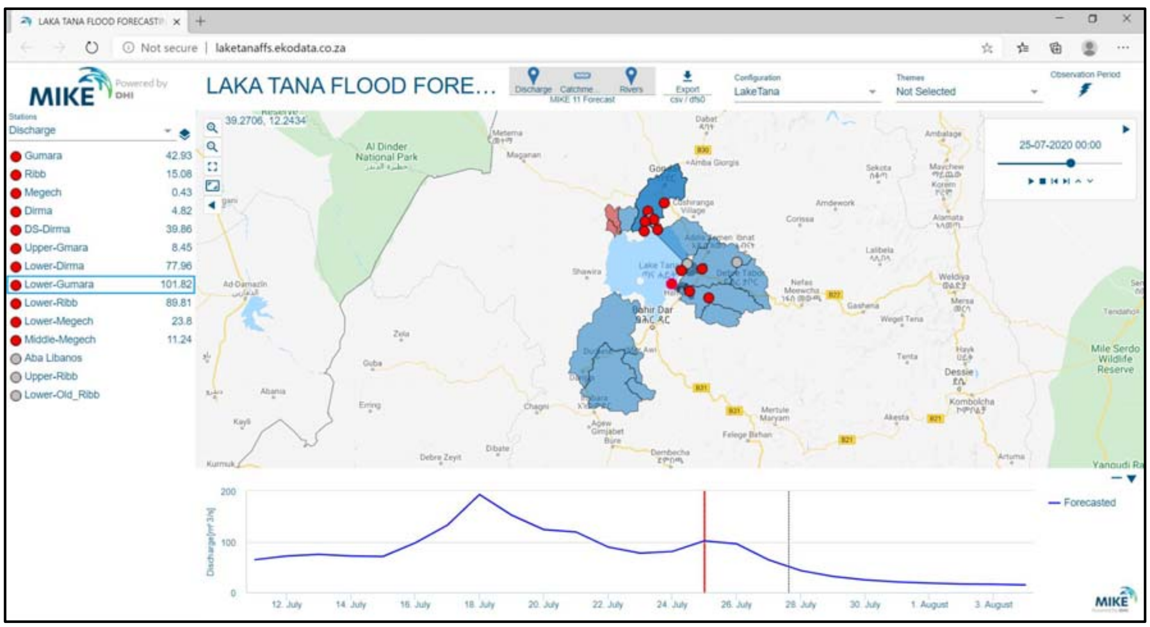


Figure 5: Lake Tana basin web GUI in the EN-FFEWS

The GUI of MIKE Operations enables operators of the system to investigate and analyze forecast outputs – e.g. real-time data, model time series input and model simulation results in interactive maps. Furthermore, operators of the system can configure what type of forecast information is to be disseminated to whom under which circumstances (e.g. exceedance of threshold values of flows at selected locations). The GUI also enables operators to run and maintain the system.

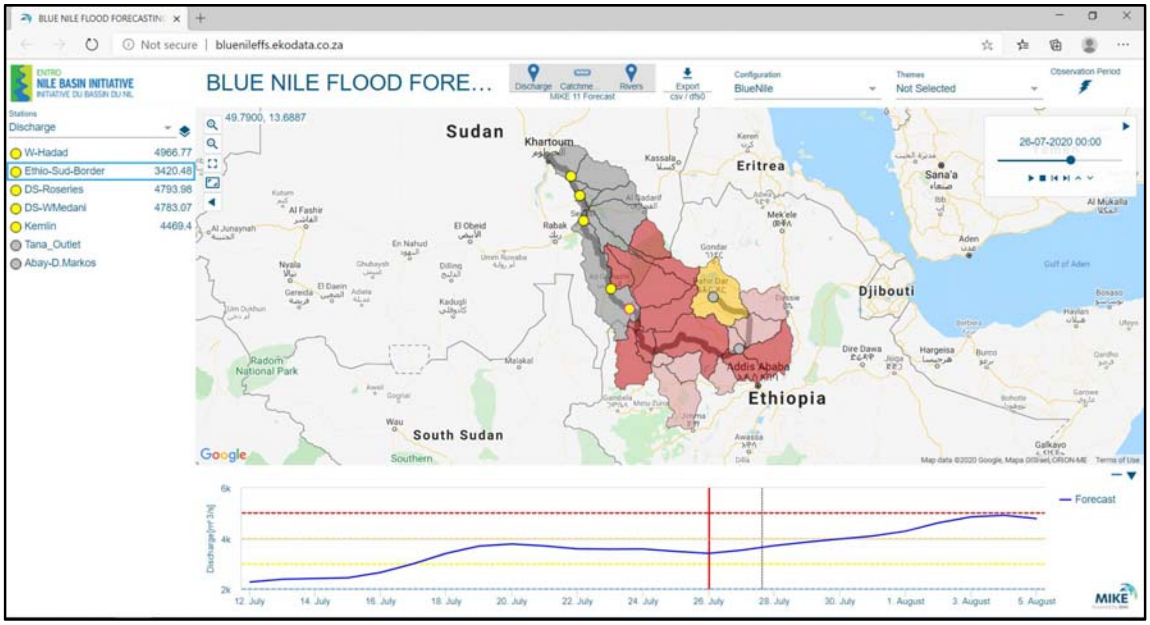


Figure 6: Blue Nile river basin webGUI in the EN-FFEWS

The EN-FFEWS web portal is a replica of the EN-FFEWS desktop GUI. The web portal displays all information that is included in the desktop GUI.The web portal allows to a wider stakeholder audience viewing forecasts in the internet.

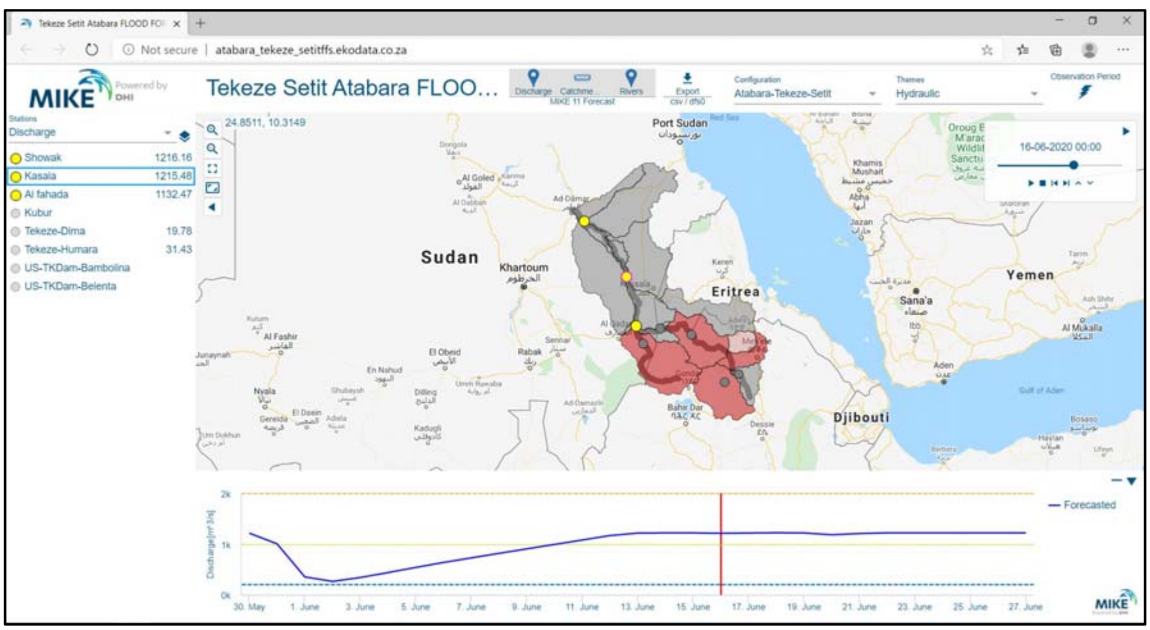


Figure 7: Tekeze-Setit-Atabara basin webGUI in the EN-FFEWS

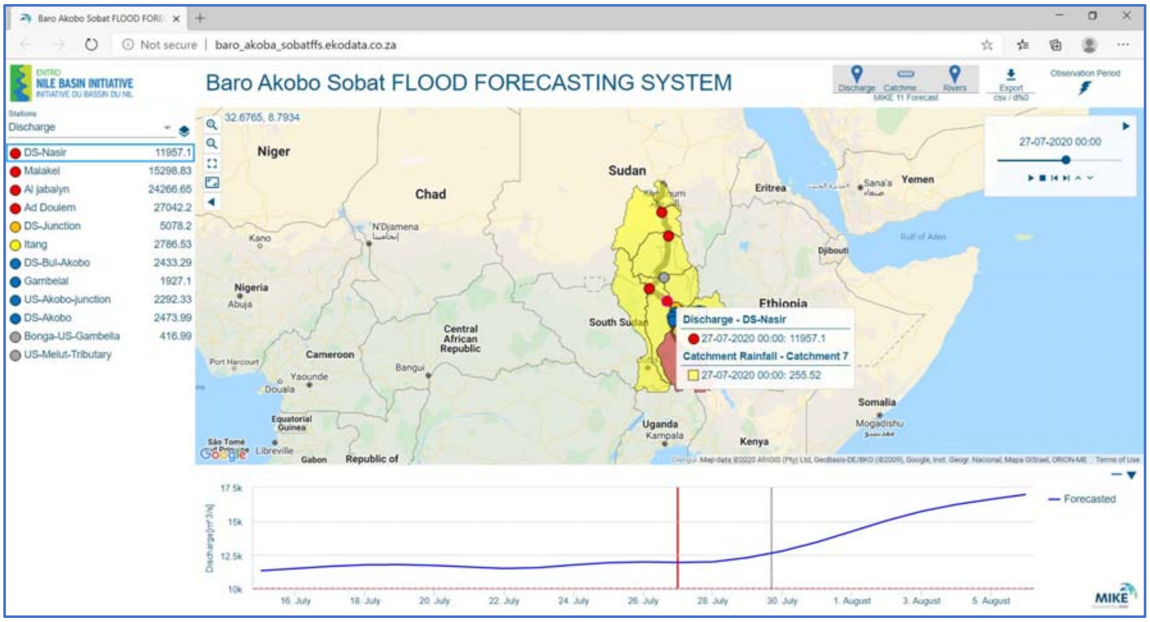


Figure 8: Baro-Akobo-Sobat basin webGUI in the EN-FFEWS

4 Stakeholders and the Role of the EN-FFEWS

There are two types of roles of stakeholders of a FFEWS in general:

1. Entities that **provide datasets** to the FFEWS, either real-time datasets like weather forecasts that are relevant for flood forecasts or rather static datasets ranging from contact information for dissemination of alerts to historical timeseries of flows and flood water levels to support model improvements.
2. Entities that **receive flood related information** ranging from flood reports to real-time flood warnings through different dissemination channels like e-mail, SMS, telephone, or VHF radio.

4.1 Sharing of Informationfor Flood Forecasts

Sharing of flood relevant information requires the involvement ofinstitutionsat national levels, such as national meteorology agencies, ministries, or basin authorities. It should also involve entities at district levels because contact information of affected and feedback from flood response activities can improve the effectiveness of the FFEWS. Ultimately the information recipient is the entity that is responsible for the FFEWS, e.g. ENTRO, and the general purpose of information sharing is to make the FFEWS effective and more reliable.

Table 3: Sharing of flood forecast relevant information

Information Type	Typical Sharing Entity	Type of Sharing	Purpose
Weather forecast	National meteorology agency	real-time	Ameliorate meteorological forecast
Hydro-meteorological data	Ministry of water, river basin authority	near-real-time	Adjust flood forecasts with data assimilation Build data repository for future model

Information Type	Typical Sharing Entity	Type of Sharing	Purpose
			improvements
Historical hydro-meteorological data	Ministry of water, river basin authority	once off and when new datasets are available	Build sound data repository for models
Topography survey data	Ministry of water, river basin authority	once off and when new datasets are available	Improve hydrodynamic models with more accurate cross sections
Contact details of stakeholders	District authority, selected ministries, disaster management institution	once off and when new datasets are available	Ensure that dissemination paths are effective
Observations of extreme flood events on the ground	Designated locals in the districts, infrastructure operators	when an extreme flood occurs	Photos at landmarks, such as bridges support performance evaluation of models and forecasts
Feedback report on flood emergency response	District authority, disaster management institution, infrastructure operators	regularly during the flood season	Evaluate effectiveness of dissemination system

Recent surveys in the EN-basin countries Ethiopia, South Sudan and Sudan have identified that data sharing mechanisms as in Table 3are either not in place or are insufficiently implemented. Reasons for these significant deficiencies are lack of capacities (e.g. proficient and designated staff in the respective institutions), insufficient budgets, and the absence of agreement frameworks such as memoranda of understanding between stakeholders (including ENTRO).

4.2 Dissemination of Flood Forecasts and Early Warnings

Different types of the society and the economy are affected by floods (see chapter 2). If they receive reliable flood information in due time they can reduce and mitigate flood damages. FFEWS are important for effectuating the dissemination of reliable flood information, which in turn is the prerequisite for adequate response and actions to mitigate impacts.

Table 4: Flood information requirements for different target groups

Target Group	Flood Information Type	Typical Dissemination Path	Dissemination Frequency	Typical Information Use
Selected ministries, river basin authority	Flood bulletin	e-mail	After every flood season	Understand and evaluate past flood season
Disaster management	Flood forecast as detailed as	e-mail, SMS, web page	When a critical flood is	Mobilize flood response in

Target Group	Flood Information Type	Typical Dissemination Path	Dissemination Frequency	Typical Information Use
institution	necessary		forecasted	affected districts
Infrastructure operator	Flood forecast as detailed as necessary	e-mail, SMS, web page	When a critical flood is forecasted	Mobilize flood response at infrastructure location
Affected community	Concise and simple flood alert	SMS, subsequently designated focal persons disseminate alerts through local means (e.g. VHF radio, megaphone)	When a critical flood is forecasted	Mobilize local flood response action according to practiced action plan
General public and media	Concise standardized flood forecast report	web page, e-mail to selected media outlets	When a critical flood is forecasted	Create public awareness

The recent surveys referred to in chapter 4.1 also showflood information dissemination mechanisms like those in Table 4are either not in place or are insufficiently implemented. Implementing these types of information dissemination is technologically feasible. However, to be effective, e.g. ensure that affected communities respond adequately, training and mobilization at community levels is important. The surveys indicate that in many cases the awareness of locals is low due to lack of regular communication with and information by local and national authorities.

5 Recommended Further Enhancements of the EN-FFEWS

With the current enhancement of theEN-FFEWS ENTRO has established a coherent flood forecast system with harmonized models. This will make operation and maintenance of the system efficient because capacity building efforts and costs of technical staff at regional and national levels can be streamlined easily. However, there are residual issues that need to be tackled in order to further improve and enhance the EN-FFEWS.

5.1 Data

Reliability of forecasts is essential to ensure stakeholder trust. Reliable forecasts need good quality models which in turn need good quality datasets. There are two types of data sets that are currently of inferior quality in the EN-FFEWS and that need to be improved:

1. **Hydro-meteorological observations on the ground**: Historical and real time timeseries of rainfall at spatially well distributed weather stations, river flows and water levels at key gauging stations need to be improved and made available.
2. **Topographical data**: The cross sections in the hydrodynamic models are currently derived from DEMs. In the flat flood prone areas these need to be replaced with cross sections from surveys (terrestrial or LIDAR as far as necessary).

Evidently, it is important to assess the resource implications. But most importantly, data sharing agreements (e.g. memoranda of understanding) need to be in place so that it can be made sure that national datasets can be shared with ENTRO and as far as necessary between the countries as well.

5.2 The Models

When new and improved datasets (see chapter 5.1) become available the hydrological and hydrodynamic models need to be revised, calibrated and validated further, to improve the quality of the results. This in turn is importantto ensure stakeholder trust as mentioned in chapter 5.1.

Specifically, when revisiting the hydrological and hydrodynamic models one needs to investigate the rationale behind the expansion of the Baro-Akobo-Sobat basin.The catchments draining into the river segment from the confluence of Sobat and White Nile to Khartoum have been added to this basin in the newly developed hydrological model. The flow from Bahr el Ghazal is modelled as a boundary flow that is entering into the White Nile. The implications of this approach on the forecasts need to be explored and appropriate adjustments, if necessary, must be made.

5.3 Software and IT-System

The current system, comprising two sub-system WRF and MIKE Operations is deployed on servers at ENTRO. Internet connectivity and reliability of electric power supply often pose a critical challenge to the reliability of the EN-FFEWS. In the mid-term it should be expected that the computational capacities could constrain system performance.

Therefore, migrating the system to the cloud needs to be considered as a measure to overcome these challenges. Migrating the system to the cloud will incur recurring costs – e.g. yearly fees to the cloud service provider. However, this step comes with the following advantages:

1. **Robustness**: The system runs continuously 24/7 without any interruption because electric power supply, internet connection and data security mechanisms of the hosting servers comply with the highest international standards.
2. **Connectivity**: The EN-FFEWS interfaces with different types of information management systems (IMS) and automatically access these data sets periodically. These systems comprise sources of global data sets such as results from earth observations and weather forecasts - usually these data sets are bulky (several GB) and require robust and fast internet connection. The necessary "back-end to back-end connection" is fast and reliable, which is particularly important in a flood forecasting context.
3. **Data security**: Inherently cloud solutions facilitate securing data through different technical solutions depending on the specific client requirements for data security. The necessary mechanisms and processes for that, such as regular back-ups, can be implemented and configured efficiently and flexibly in a cloud-environment.
4. **Monitoring**: The system performance can easily be monitored remotely by the operator of the system. The cloud solution makes it easier for any authorized user to monitor the performance remotely.
5. **Flexible remote access**: Collaborative works of regional and national technical staff, specifically during the flood season, become more efficient as the operators can work at their respective working environments.
6. **Well-defined costs**: Cloud hosting services incur costs - through yearly payments to be made to the cloud service provider. Budget can easily be fixedbecause criteria and conditions are clear. The current implementation arrangements also incurs costs - primary costs such as maintenance costs for the servers – including costs for UPS and air condition of the server room – as well as secondary costs resulting from different types of damages due to failures of the system. With a cloud solution these direct and indirect costs would be avoided.

7. **Smooth scalability**: The system can be upscaled easily if additional computational resources become necessary. This would incur marginal additional recurring cost.

5.4 Institutional Arrangements

Currently, the EN flood forecasting activities are carried out during the rainy season, from June to August. During this period one staff from each country, Ethiopia, South Sudan, and Sudan, is seconded to ENTRO offices in Addis Ababa. The collaborative works comprise modelling and issuing of forecasts. Supposedly, the staff works much less on flood forecasting related matters outside this season.

Best practice however would be that the technical staff work during the ‘off season’ to evaluate performance of the previous season and work to improve on it for the coming season. This is an important activity and can require considerable time to plan and execute. It includes assessments of model input accuracies, model results as well as communication and feedback of forecasts.

With the recommended migration of the system to the cloud (see chapter 5.3) implementing this would make this work expansion efficient, as collaborative works could be conducted remotely. And regular training of national technical staff would be necessary. For this, it is necessary that ENTRO have at least one designated operator of the EN-FFEWS, the operator’s responsibilities comprising operation and maintenance of the EN-FFEWS and providing the necessary backstopping to the national technical staff.

Along with this, the national flood forecast centers need to be strengthened.

ENTRO is encouraged to network and seek memoranda of understanding with national data providers for forecasts and observed data. These data providers comprise hydro-met institutions,regional climate centersfor exchange of observed and forecasted meteorological data.

5.5 Dissemination of Warnings and Communication

Until the EN-FFEWS was enhanced, ENTRO has been disseminating FFEWinformation once a day via e-mail to national ministries – water affairsrelated national focal points –and to several other institutions andindividuals that are registered in a database.

This process has been automated withMIKE Operations withinterested entities having the choice to receive information only whencertain thresholds are reached in selected flood prone areas of interest. In addition, latest flood informationis available online via a web portal.

The information dissemination chain however needs to ensure that the affected communities are informed timely and appropriately. The EN-FFEWS also supports automatic dissemination of warnings via SMS. The technical and administrative means to implement this need to be pursued. Furthermore, it is important that the national institutions actively reach out to those at risk and who lack access to formal communication means making use of supplementary local information dissemination means (e.g. VHF radio, megaphone).

This will ensure increased flood awareness and effective flood response preparedness in the affected communities.Dissemination and communication of warnings must reach those at risk. Clear messages containing simple, useful information are critical to enable proper responses that will help safeguard lives and livelihoods.Along with this, regional, national and community level communication systems must be identified, and appropriate authoritative voices established. The use of multiple communication channels is necessary to ensure as many people as possible are warned.

Response capability of the affected communities is essential. Communities need to understand their risks; respect the warning service and know how to react. Education and preparedness programs play a key role. It is also important that disaster management plans are in place, well-practiced and tested. The communities should be well informed on options for safe behavior, available escape routes, and how best to avoid damage and loss to property.This could be achieved through launching awareness campaigns and designing risk communication strategies to enhance the flood risk perceptions of the communities. The local institutions would have to be engaged with the communities to implement effective disaster risk reduction plans.

ENTRO should also, as part of the season's performance assessment,request feedback on how useful and accurate the flood forecast informationwas and ways of improving communication.

6 Integrating Flash Flood Forecasts

The EN-FFEWS has been developed to forecast floods in the main river courses in the EN. However, there are also locations in the EN where flash floods prevail (see Figure 9). Two types of flash floods prevail in the EN basin: (1)river flash floods, and (2) storm flash floods. River flash floods are already covered in the EN-FFEWS.However, storm flash floodsare not included. Storm flash floods are short in duration and are caused by local heavy rainfalls.

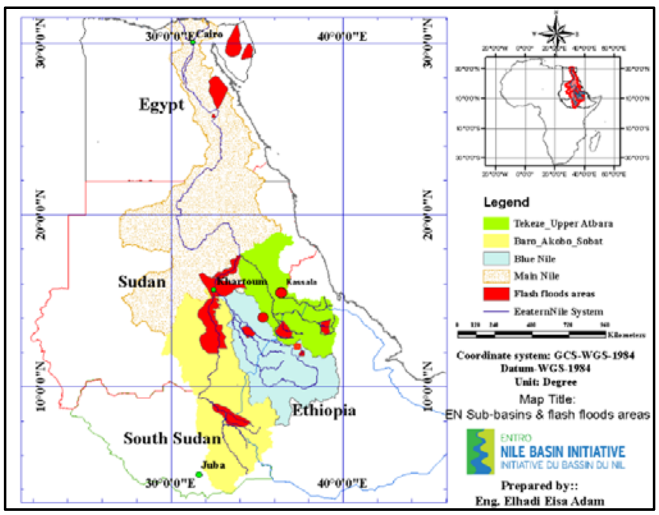


Figure 9: Flash floods sites in the EN basins

The following sections discuss how the EN-FFEWS can and should be expanded to forecaststorm flash floods in the EN basins.

6.1 Acquisition of Rainfall Data

Rainfall data – real-time observations and/or rainfall forecasts – must be available in a FFEWS in due time to have sufficient time for warnings and responses. As the hydrologic processes are fast – in the range between a few minutes and a few hours – obtaining the adequate rainfall dataset can become challenging. The following data source types are candidate input data sources for flash flood forecasts:

1. **Ground stations**:Inputs to flash flood forecasting systems are rainfall as well as river flows and water levels. Because of the short time (less than six hours)between the observed rainfall or upstream river water level and the flood at the point of interest, reporting and recording systems should be automated/telemetric.
2. **Radar**: As many flash floods result from thunderstorm rainfall, the accurate assessment of areal rainfall is a major problem in flash flood forecasting. The catchments are often small, and many of them are in mountainous areas where orographic effects increase the areal variability of rainfall. Radar can be useful in assessing areal rainfall because it gives an aerial perspective and has the facility to estimate areal rainfall quickly.

3. **Satellite Rainfall Estimates** (SREs): Satellite data may also be used for estimating rainfall amounts and areal distribution.SREs are increasingly being used in regions with poor coverage of ground rainfall stations. The EN-FFEWS has tools for acquisition and analysis of selected SRE products (see chapter 3.1), thus providing near real time QPEs. This can significantly enhance the flash flood forecasting capability of the system.
4. **Quantitative Precipitation Forecasting** (QPF): As a flash floodsare by definition floodsthat occur after a short time between the causative event (usually heavy rainfall) and the flood at the point of interest, QPF is a useful tool for both the meteorologist and the hydrologist. QPF shows both the areal distribution and the amount of the rainfall expected to occur over a given period.The WRF is already implemented in the EN-FFEWS for quantitative precipitation forecasting (QPF). WRF is suitable for both local and regional flash flood forecasting systems, as literature reviews by ENTRO indicate.

Currently, there aren’t any operational telemetric ground stations or radarsin the EN basins. Hence, viable input data sources for flash flood forecasting with the EN-FFEWS are SRE and QPF products. The operational SRE products and the QPF product WRF in the EN-FFEWS can and should be used as input data sources for flash flood forecasts in the EN-FFEWS.

6.2 ForecastingApproach

The flash flood forecasting methodology and approach should be the same as for riverine floods – like already implemented in the EN-FFEWS:

The hydrologic models are fed with rainfall information from WRF in real-time. Alternatively, a selected set of the QPEs/SREs in the system can be used. Then, the hydrologic and hydrodynamic simulations are performed for selected flood locations in real-time and if forecasted values (flows and/or water levels) exceed certain thresholds,warnings are disseminated to predefined stakeholders, such as authorities or selected members of affected communities through established and configured dissemination channels (e.g. through ENTRO’s web portal or as SMS).

For this, the scheduled jobs in the system that invoke cascades of model runs including pre-processing and post-processing will have to be adapted according to the frequency of availability of new input datasets (e.g. QPEs and QPFs). The schedules will also have to take into consideration the necessary lead times for warning and flood emergency responses in the affected communities.

The approach for dissemination of warnings and communication for flash floods is identical with the methodology and approach explained in chapter 5.5.

6.3 Further Important Actions

ENTRO can approach the WMOand HRCfor possible implementation of theFlash Flood Guidance System (FFGS), a system developed by WMO to strengthen the capabilities of national meteorological and hydrological services to issue timely and accurate flash flood warnings and to integrate these in their operational activities.

The FFGS is a forecaster’s tool designed to provide hydrological and meteorological forecasters with readily and accessible quality controlled precipitation estimates from weather radars and satellites, precipitation measurements (rain gauges), forecast data from NWP models, and other information to produce timely and accurate flash flood warnings worldwide. The general implementation approach is designed to support capacity building in the regions and aims at the reduction of flash flood hazard impacts to life.

The FFGSis a possible opportunity to further enhance the EN-FFEWS.

7 Conclusion

The works to enhance the EN-FFEWS have substantially improved the forecast system and have given insights into the situation on the ground regarding flood information communication as well as flood response preparedness and resilience. On this basis, recommendations for further improvements and enhancements have been given:

1. Arrangements for availing historical and real-time hydro-meteorological datasets, e.g. memoranda of understanding between stakeholders, need to be in place. ENTRO needs to play a proactive role to make that possible.
2. Significant efforts are necessary to improve the availability of hydro-meteorological observations on the ground and topographical data. ENTRO needs to facilitate national activities in this direction.
3. When new and improved datasets become available the forecast models need to be revised, calibrated, and validated further, to improve the quality of the results.
4. The forecast system should be migrated to the cloud. This would make flood forecasts and flood information communication reliable.
5. National flood forecast centers need to be strengthened in their flood early warning and communication capacities. For this,designated staff for the collaborative operation of the EN-FFEWS needs to be identified. ENTRO needs to facilitate national activities in this direction.
6. Flood awareness as well as effective flood response preparedness and capability in flood affected communities must be increased. The technical and administrative implementations at national levels need to be facilitated by ENTRO.
7. Flash flood forecasts need to be integrated into the EN-FFEWS.

These recommendations need to be taken into consideration in the next project phases of the FPEW for which ENTRO has identified the need to enhance preparedness/resilience against flood disastersthrough flood risk mitigation planning and establishment of a strong regional flood forecastingand early warning system. In the next project phases, it is envisaged to prepare a project aiming at the following:

- Strengthen the EN FFEWS
- Upscale the lessons learned of EN region to establish and a flood forecasting and early warning system for the NEL region
- Operationalize a FFEWS for Nile basin
- Enhance a comprehensive regional approach to flood management
- Strengthen the capacity for flood forecasting of the national level through institutional strengthening and capacity building of national ministries for conducting flood forecasting
- Improved flood preparedness through community awareness for the EN region
- Enhanced regional collaboration and cooperation during flood events
- Assess flood risk in the basin through flood maps for selected areas

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