ENTRO
NILE BASIN INITIATIVE
INITIATIVE DU BASSIN DU NIL

EN Flood Forecasting and Early Warning System

Seasonal Report

October 2023

EXECUTIVE SUMMARY

The flood is one of the mean disasters that affect millions of people within Eastern Nile Region countries resulting in losses every year. Flood forecasting and Early Warning Systems (FFEWS) - one of the floods risk management measures - are currently operational in every rainy season for Eastern Nile country. Eastern Nile Flood Forecast and Early Warning (EN-FFEW) service is a key component of ENTRO activities that has been continuously conducted every flood season (July through September) since 2010. The EN-FFEW activities strengthened regional collaboration through sharing of information, strengthening of national flood forecasting institutions and overall reduced the risks of flood devastation for 2.2 million people living in flood-prone areas in the Nile basins of Ethiopia, South Sudan, and Sudan. The EN flood forecast activities during this 2023 flood season, July to end of September, and flood forecasting and modeling processes using WRF climate model and Mike hydrological/hydraulic models carried out at ENTRO Cloud server as presented in this report. For the importance of FFEWS for disaster risk reduction in Eastern Nile Region a survey done in juba in South Sudan to Understand the gaps and challenges. This report contributes to bridging these gaps by analyzing the responses to a comprehensive survey with mullite questions for different institutions and community on various components of FFEWS (risk knowledge, monitoring and forecasting, warning dissemination and communication, and response capabilities). The mean goal for this survey is to improve the FFEWS within the Eastern Nile Countries to provide clear standards and a roadmap for improving FFEWS' effectiveness, and to improve coordination between institutions responsible for flood forecasting and those responsible for communicating warnings and community preparedness and awareness.

Table of Contents

List of Figures

List of Tables

1. BACKGROUND

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.

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.

Since the establishment of FFEW, it has been an important part of ENTRO's activity that has continuously been conducted since 2010 for every flood season (July-September). The FFEW has helped the Eastern Nile countries in reducing the loss of life and money by preparing flood forecast bulletins for the Lake Tana (Blue Nile -Ethiopia), the Blue Nile-Main Nile (Sudan), and Baro-Akobo-Sobat (BAS) sub-basins flood- prone areas. The FFEW activity has strengthened national offices in terms of capacity and overall reduced the risk of flood devastation for 2.2 million people in the region to present. During the implementation and application of the FFEWS, substantial limitations became apparent and the following priority enhancements had been identified. These are; Expand the coverage of flood-prone areas.

1.1. Eastern Nile Flood-prone Areas

The Lake Tana basin is located upstream of the Blue Nile River. The Headwaters 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 waterways to the lake are Dirma, Gumera, Megech, and Ribb.

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 cover, whereas the lower parts of the basin in Sudan are rather flat and with less vegetation cover.

Baro-Akobo-Sobat basin encompasses the catchments of the Baro and Akobo rivers upstream as well as those of the Sobat River in South Sudan to the White Nile confluence. Most of the catchments that drain into the Akobo and Sobat rivers are flat surfaces. The upstream catchments of the Baro towards the east of the basin are high elevation mountain ranges with good forest cover, the lower part of the Baro however is flat.

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 cover.

2. OBJECTIVE

The main objective is to enhance regional collaboration and improve national capacity in mitigation, forecasting, early warning, emergency preparedness, and response to floods in the EN basin countries.

Specific objectives:

- To enhance regional collaboration and improves national capacity in the mitigation, forecasting, early warning, emergency preparedness and response to floods in the EN basin countries.
- To make rainfall forecasts over EN region based on three days' lead-time and address the patterns of the rainfall which might cause flooding.
- To make flood forecast over the model areas in the EN basin, these are the lake Tana, Blue Nile, BAS and TSA River systems.
- To produce flood reports: daily reports and seasonal report, and disseminate to users, decision makers, different stakeholders and officials in the region.

3. CAPACITY BUILDING AND TRAINING

ENTRO provides a 1-month training and capacity building on weather numerical forecasting model (WRF model) for rainfall forecasting and hydrologic, hydraulic and Mike operation models (Mike models). This started with a background introduction on WRF modeling processes, Mike Zero system, how to produce 3-days lead time rainfall forecasts for the EN basin and consider the patterns of precipitation that could lead to flooding for Lake Tana, Blue Nile, BAS, and TSA in the EN basins, and prepare daily flood forecast bulletin for dissemination to users: decision-makers, other stakeholders, and regional officials. Below is summary of the tailored trainings provided:

- WRF modeling - Numerical Weather Prediction model:
    - Introduction to WRF modeling system and applications.
    - Basic Linux commands and Linux shell scripts (Linux Operating System).
    - WRF modeling and producing WRF maps and NetCDF data for Mike model.
- Mike Models (Mike Zero, NAM, Mike 11 and Mike Operation):
    - Introduction on Mike models used in EN flood forecasting.
    - NAM hydrological modeling system and model setup with an AOI.
    - Mike 11 modeling system for the AOI.
    - Mike workbench and Mike Operation works.
    - Requirements accessing of the FFEW system on the Cloud server.
    - Producing daily forecast reports (bulletins).

4. RAINFALL FORECASTING USING WRF MODEL

In this WRF ENTRO, we have multiple nested grid configurations. Coarse grid spacing is required to allow useful simulation of synoptic and mesoscale dynamics, while fine grid spacing is required to allow the simulation of convective-scale features over the EN and MD basins. To successfully simulate the convective storm over the basin, we used two nested domains, the mother domain covers

the most of Easter Nile (-1.5°S to 24.5°N and 19°E to 52°E), and the parent domains are covering the model domain (0°N to 24°N and 20°E to 50E) as shown in the figure 1.

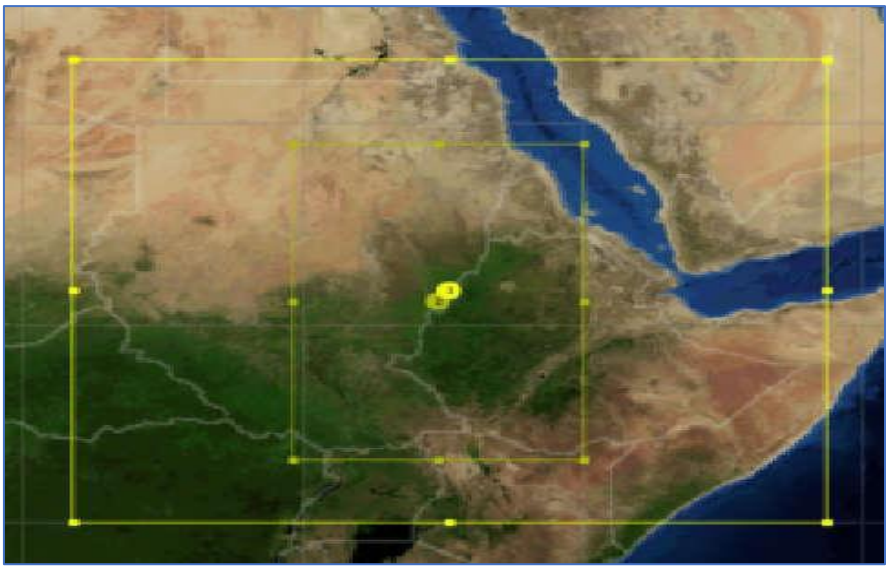

Figure 1: WRF model configuration for EN (outer box) and Model (inner box) domains.

The configuration of the model was done based on literature which helps to select schemes which are suitable for the EN region, and summary of the configuration is presented in table.

Table 1: **S**ummary of WRF model configuration

Parameter	**Parent domain**	**nested domain**
Region	EN, Eastern Nile Domain	MD, Model Domain
Grid resolution	18km	6km
No. of Vertical levels	28	
Period	72hr (3 days)	
Integration time step	240s	
Dynamic solver	ARW	
Boundary condition	GFS	Second nested domain
Microphysics	The (Lin,1983) scheme, WRF SM6CS scheme (Hong, 2006) and the (Morrison, 2009) scheme.	
cumulus parameterization	Kain-Fritsch (Kain, 2004)	Turning off (0) @ 6km
Atmospheric convection	Betts–Miller–Janjic scheme (Betts, 1986; Janjić, 1994)	
Surface layer	Mellor-Yamada-Janjic scheme (Janić, 2001; Mellor, 1982)	
Lund surface model	Noah LSM	
Land cover classification	USGS	
Planet boundary layer	Yonsei University (Hong, 2006)	

Therefore, the forecast products for EN region using the configured WRF model which were produced in the house of ENTRO in daily basis in 3-days (72 hours) lead time.

5. Eastern Nile FLOOD FORECASTING

The EN flood forecasting and early warning system, a single platform is used for each model area to produce flood forecasts daily. The flood forecast system consists of configured and integrated Mike models (Mike suits) to flood forecasting processes

5.1. Mike Modeling

Mike suits are a Mike zero packages of which NAM hydrological model, Mike 11 hydraulic model and Mike Operation models, and the Postgres-SQL database server installed and configured on the Cloud and run smoothly to produce daily forecasts. On top of this, Mike Operation (Mike Workbench) served as visualization tool of the forecast products which is easily understand by uses at different level. Nevertheless, for training purpose, exercise and transfer the knowledge, these packages were installed on the local computers.

- The average rainfall plots and tables that shows the expected rainfall per each sub - catchment where floodwater was generated using WRF forecast as input
- The runoff flow hydrographs and tables that shows the expected peak floods
- Forecast results were then interpreted before dissemination to users, decision makers, local administration and responsible legal bodies.

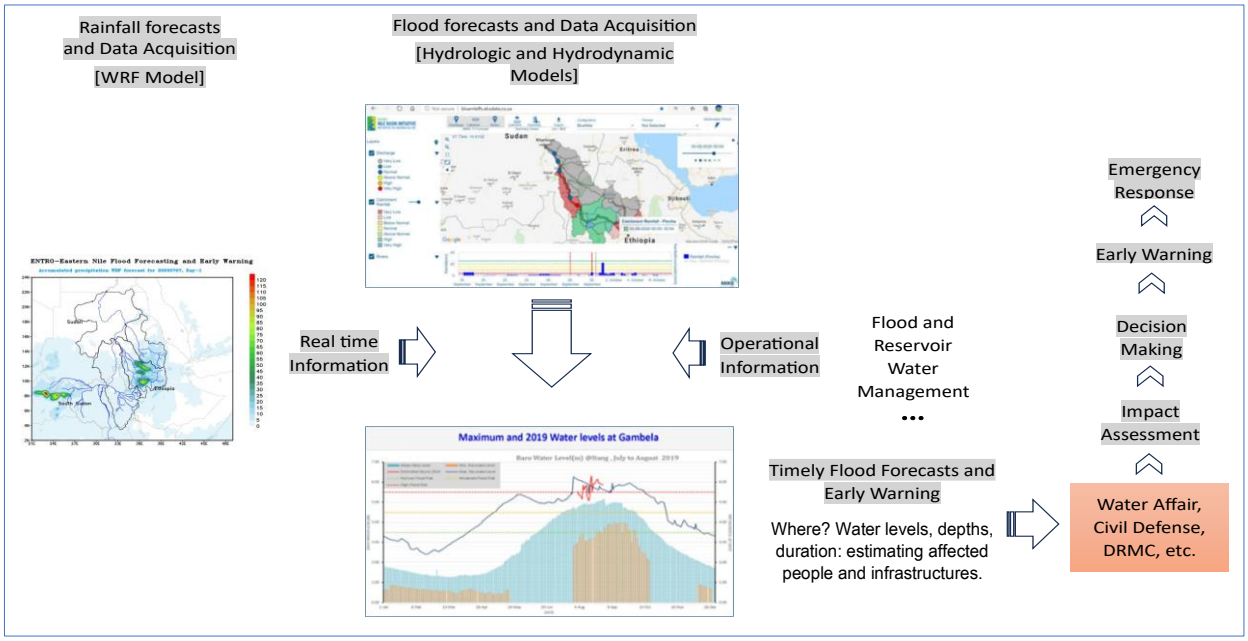

Figure 2: Eastern Nile flood forecast processes.

5.1.1. Lake Tana in Ethiopia

In the Lake Tana forecasting system, the sub-catchments from upstream of Dirma, Megech, Ribb, and Gumara river systems including all sub-catchments in upper land to the flood prone areas of Denbia and Fogera to inlet of lake Tana were monitored. Then runoff routing for each river were utilized to produce flood forecast and early warning information for the local communities. The under note described instance forecast information in line with the catchment average rainfall that

trigger a peak runoff over Tana_1 and Tana_4 sub-catchments have significant contribution for Ribb river, Tana_1, Tana_2, Tana_3 and Tana_4 sub-catchments for Gumara river and have contributions of flooding over Fogera floodplain. Similarly, the runoff over Denbia floodplain from Megech (Tana_5) and Dirma catchment have contributions over Denbia floodplain, see figures below.

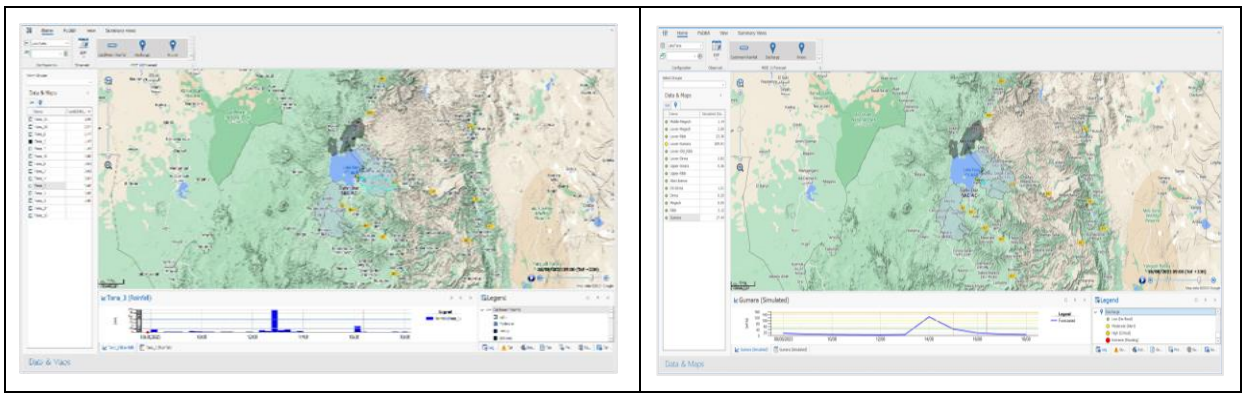

Figure 3: Lake Tana rainfall (left) and runoff (right) forecasts.

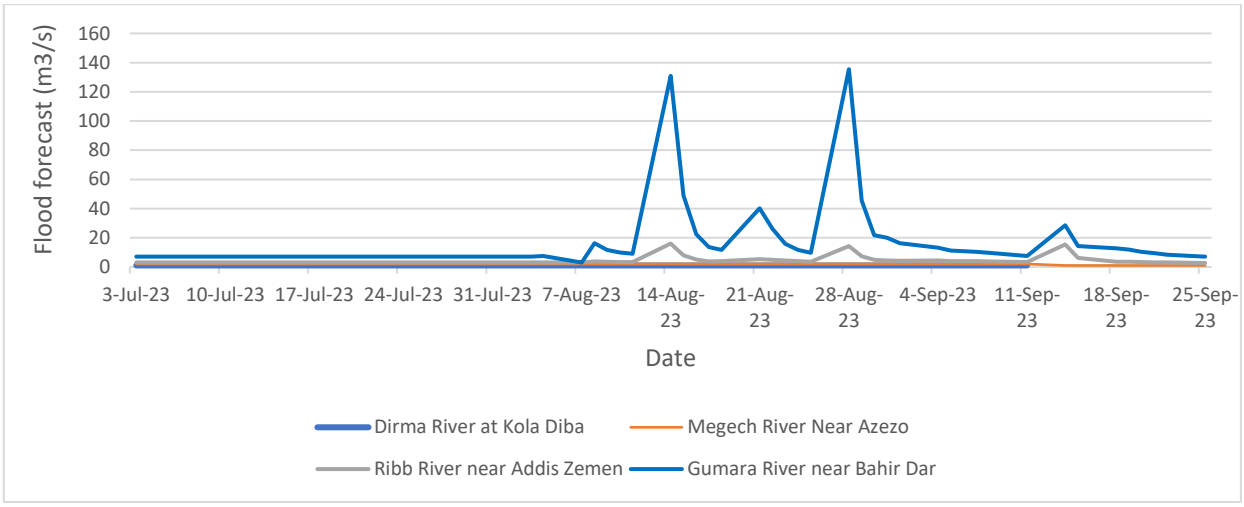

Figure 4: Lake Tana rivers runoff forecasts.

5.1.2. Blue Nile Forecast in Sudan

The Blue Nile forecasting system, the sub-catchments from upstream of the border at El Deim gauging station including all sub-catchments in Ethiopian highlands to the far downstream at Khartoum were monitored. Then runoff routing the Blue Nile between El Deim and Khartoum information were utilized to produce flood forecast information. In the previous flood seasons, the flood forecasts for Blue Nile and main Nile were monitored using Sudan-FEWS since 1992 to 2019. During 2020 to 2023 flood season, FEWS Sudan not run at ENTRO and replaced by the commonly developed FFEW platform using Mike suit, to run the EN flood forecasts. Below describes instance forecast information in the Blue Nile catchments in such a way that the average rainfall from each sub-catchment trigger peak runoff from the upland sub catchments, in Ethiopia highland has significant flows contributions in the Blue Nile River system.

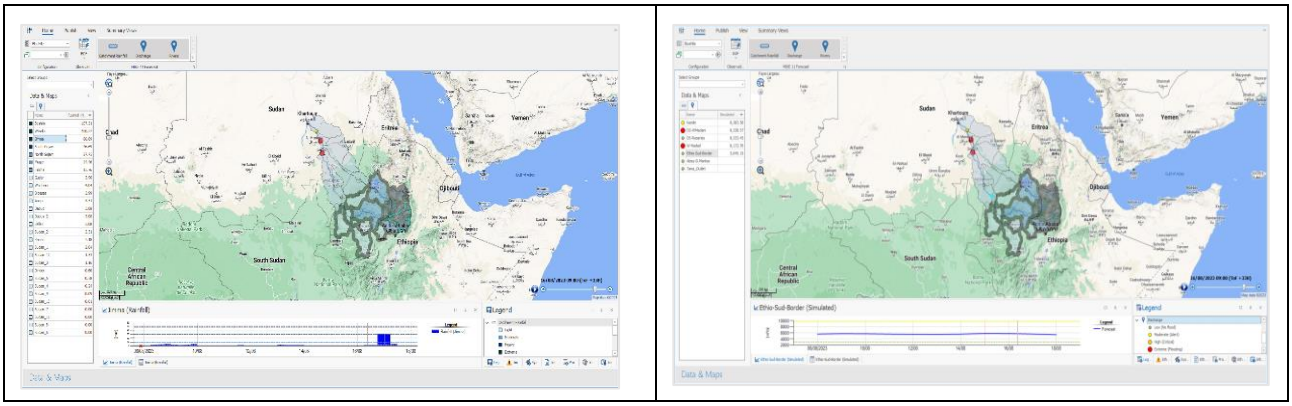

Figure 5: Blue Nile rainfall (left) and runoff (right) forecasts.

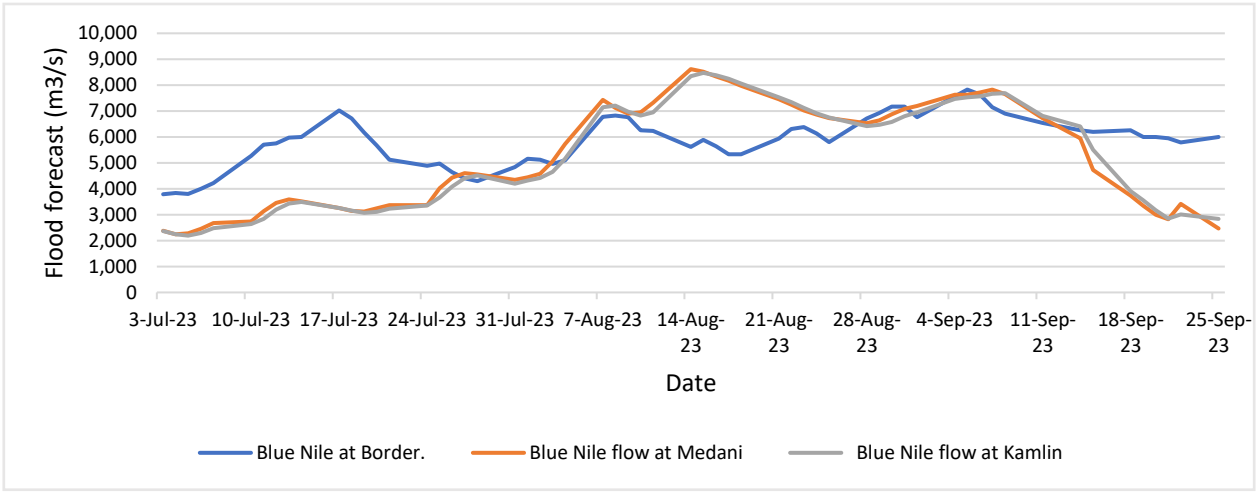

Figure 6: Blue Nile rivers runoff forecasts.

5.1.3. BAS Forecast in Ethiopia and South Sudan

the BAS forecasting system, the sub-catchments from upstream of the Baro River at Gambela gauging station, to Sobat River in Malakal and far downstream at Khartoum areas were monitored. Then runoff routing from upstream of Gambela to downstream at Khartoum areas were utilized to produce flood forecast and early warning information for the early warning uses. The flood forecast information for BAS is described in the under notes to show instance forecast information. The average catchment rainfall from the upland sub-catchments has significant runoff contributions at the catchment outlet points in the downstream. The average rainfall induced from Catchment 3 triggers moderate runoff in the Baro river at Gambela and routed to downstream Itang, and Sobat after joining the Akobo River, see figures below.

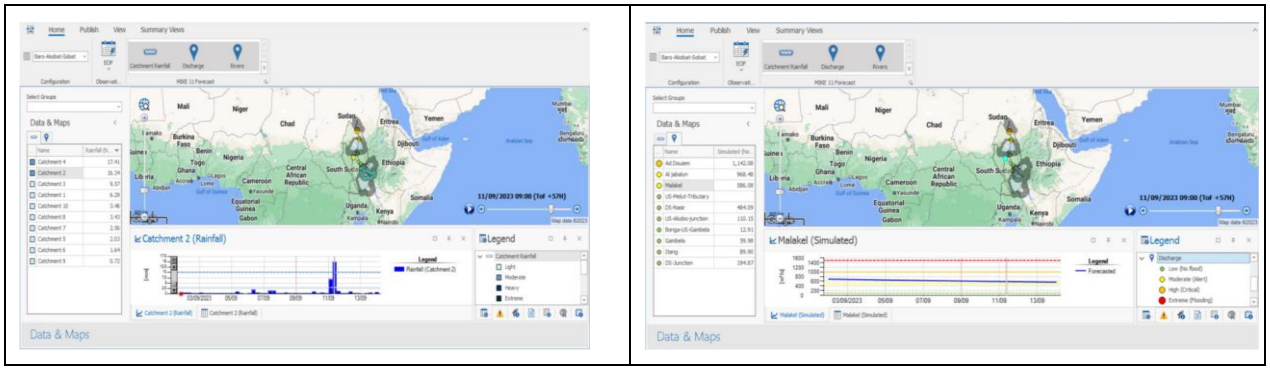

Figure 7: BAS rainfall (left) and runoff (right) forecasts.

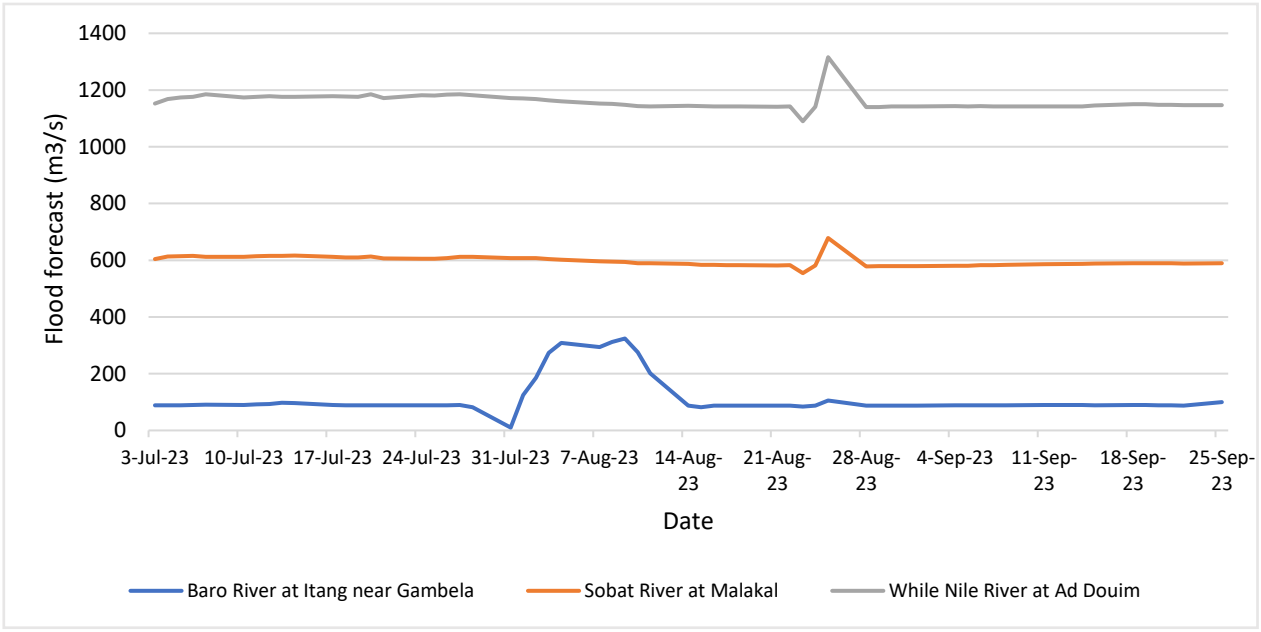

Figure 8: BAS rivers runoff forecasts.

5.1.4. TSA Forecast, Ethiopia, and Sudan

the TSA forecasting system, the sub-catchments from upstream of the Tekeze gauging station the upland areas in Ethiopian highlands to downstream at Atbara areas were monitored. Then runoff routing from upstream through Tekeze dam to downstream at Atbara area were utilized to produce flood forecast and early warning information for the early warning uses. The flood forecast for TSA is also presented in the figures below which describes instance forecast information. Therefore, the average rainfall that may trigger peak runoff from the upland sub catchments has peak river flow contributions to Tekeze river at Dima and at Metema, and other downstream river gauging stations along with the river course before and after the junction at Showak, and it may impact the local communities living along the river course and river banks and infrastructures in the localities and downstream areas.

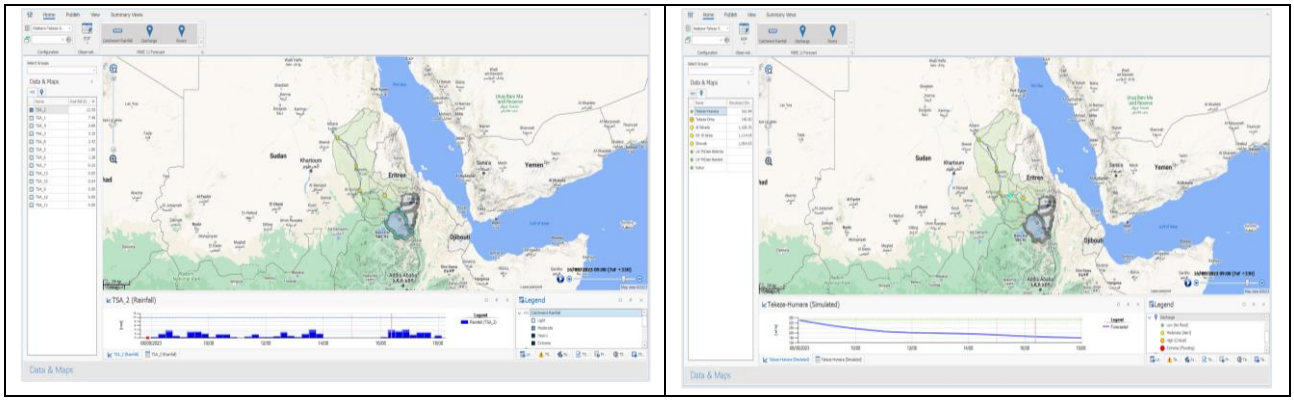

Figure 9: TSA rainfall (left) and runoff (right) forecasts.

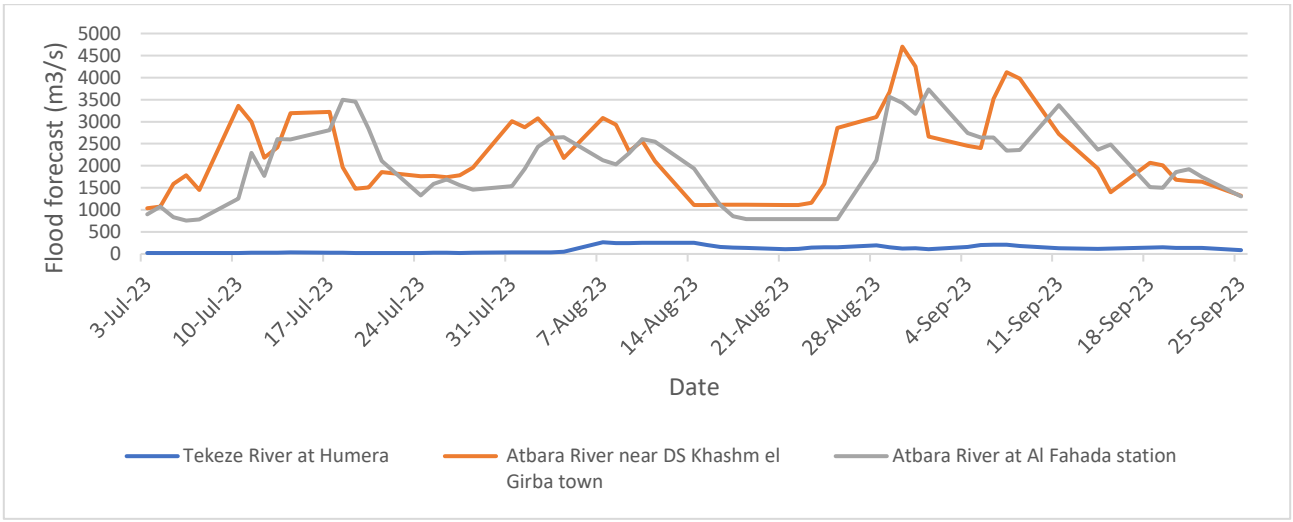

Figure 10: TSA rivers runoff forecasts.

6. COMPARATIVE ANALYSIS OF FLOOD FORECAST

The Comparative analysis of flood forecast in 2023 EN flood forecast, a comparative assessment was done is South Sudan and we observed recently the country install five telemetry or automated river gauging stations a long White Nile in Nimule and two in Malakal and at sobat river which may contribute to data records available for the forecast period. Nevertheless, the thresholds at key river gauging stations were determined from the model for some river gauging station.

7. MAXIMUM RAINFALL AND RUNOFF FOR 2023 FLOOD SEASON

Table 2: Maximum Rainfall recorded from July to September 2023.

Catchments	Lake Tana	Blue Nile	BAS	TSA
Forecast day	Day1 RFF	Day1 RFF	Day1 RFF	Day1 RFF
Month and days	July 18, 31 and Aug 1, 2023	Jul 6 &7, Aug 14 and Sep 4, 2023	July 6, 2023	July 31, Aug 1, and Sep 25, 2023
Maximum rainfall (mm)	65	110	80	110

Table 3: Maximum Runoff recorded from July to September 2023.

Stations	Dirma	Megech	Ribb	Gumara	Abbay/ Blue Nile at Border	Gambela / Itang	Atbara
Date	Jul-Sep, 2023	Jul-Sep, 2023	Sep 14, 2023	Aug 28, 2023	Sep 5, 2023	Aug 9, 2023	Aug 7, 2023
Maximum Discharge (m^3/s)	1	1	14.4	121.2	7,828	324	265

8. 2023 FLOOD IMPACTS ASSESSMENT

In Ethiopia, the 2023 flood season flood affects many local people in Gambela flood prone areas although no sufficient data was obtained from these areas. However, I found a preliminary satellite-derived flood assessment for Gambela Region, Ethiopia, dated 28 June 2023. The report indicates that the region experienced inundated agricultural areas and affected roads. (Derived, 2023)

- Inundated agricultural areas observed in the eastern part of Abobo village as of 21 June 2023
- Widespread affected roads observed in Abobo village as of 21 June 2023;
- No major damage observed in the settlement zone of Abobo village as of 21 June 2023.
- The Regional Disaster Risk Management Service announced that more than 25,000 residents have been displaced from their homes because of the floods in nine districts, including Gambella town.
- The state government has announced that it is facilitating immediate support for the evacuees by talking to the relevant stakeholders. From the Gambella Region Government Communications Affairs Office (September 20/2023), the director of early warning response of the disaster risk management service of the region, Seifu Wolde, said that due to the heavy rains that fell in the highlands of the country.

The representative of the head of state and the deputy head of the peace and security office, Mr. Umod, said that the water level is increasing day by day and may cause more danger. He said that the state government is working to gather information to support the flood-affected and displaced people. *Source*: MoWE of Ethiopia flood impact assessment report for 2023.

In South Sudan, JRS's refugee and internally displaced person camps in Maban, South Sudan, sustained significant damage because of heavy rain and severe floods last week. Many people are now looking for dry ground because the floodwaters have wrecked homes, highways, and schools. More than 200,000 individuals are believed to have been impacted by water levels reaching above a meter in the area, which has resulted in significant displacement of the local host and refugee communities. Additionally, the communities' capacity to properly begin their recovery has been hampered by considerable loss to livelihood resources, food crops, and animals. (JRS Eastern Africa, 18 September 2023).

In Sudan, On the first week of August 2023, a flash flood hits the city of Al-Jabalain in White Nile State - Al-Jabalain locality, because of heavy rains downpours for hours in the eastern highlands of the town. A massive water run down the southern and western parts of the city it swept away and

destroyed everything in its path so that the residents of these areas found themselves within the moments homeless. Many houses have been destroyed as well families lost their properties in ten areas. Total HHs affected 632 (416 HH totally damaged and 216 HH partially damaged). In Northern State 6,670 families were affected by flash floods, 1,580 houses were totally affected, 5,090 houses were partially affected, and 2,250 latrines were destroyed by flash floods. (GO, Aug, 2023).

9. CHALLENGES

There are various technical challenges at national, regional and local levels to operating FEWS: data collection and integration, synthesis, management, the hydrologic modeling process, and, warning dissemination and communication networks, among others.

The major challenges faced by operational systems is the lack of technical expertise and manpower. Trained personnel with flood forecasting expertise and adequate forecast group staffing are required by the FFCs to effectively issue timely warnings in the National level.

Many technical issues faced by operational systems relate to financial challenges. Owing to funding limitations, sustainability of FFC is a major challenge that leads to discontinuous operation of warning systems.

Limitation in the number of hydro- meteorological stations, in BAS and TSA catchments areas which is the challenges for the verification and calibration of numerical WRF model to enhance the accuracy of the rainfall forecasts.

Limitation in the telemetry gauging stations for verification and calibration and improvement of the forecast as long some of the stations has been installed in South Sudan can improve the forecast by the in key point in flood forecast.

The difficult to understanding the EN_FFEW flood forecast information as been mentioned by some users and also the information is not reaching the end users it is crucial, according to survey respondents, done in South Sudan.

10. CONCLUSION

Each flood season for the EN region, the EN forecast system uses combined forecast models (WRF and MIKE) to create reliable flood forecast products. Flooding is one of the worst types of natural disasters. In order to save lives and lessen property damage, forecasting runoff in a timely and precise manner is crucial. It is critical to strengthen the institutions responsible for disaster management. Additionally, in order to minimize flood damage in urban areas, an integrated flash flood forecasting and warning system must be prepared. This system must consider the meteorological, hydraulic, and hydrologic characteristics of streams. More than 25,000 people were forced out of their houses as a result of the flooding on September 14, 2023 in the Gambela Region, which included Gambella City. According to the ENTRO forecast, the BAS basin will see heavy rainfall before three days on September 11, 2023, and flooding is also anticipated throughout this time frame. This demonstrated that the ENTRO flood forecast information does not reach the end users or flood vulnerable communities, resulting in a gap in the dissemination of information at the national level and a gap in

the dissemination of information for end users. The model forecast close to the ground reality on Blue Nile but on the BAS, TSA and Lake Tana is need further improvement. Special in lake Tana the forecast show underestimate.

11. RECOMMENDATIONS

Each flood season for the EN region, the EN forecast system uses coupled forecast models (WRF and MIKE) to create accurate flood forecast products. However, it is crucial and strongly advised to regularly validate and verify forecast results with ground data, both for rainfall and runoff data, in order to access (and exchange) observation data (real-time data, if applicable, from telemetry system) and enhance the EN forecast products.

- Improving the forecasting system to connect national flood monitoring and forecasting systems to global networks.
- Strengthen the regional protocol for the exchange of hydro-meteorological data and information.
- To improve the efficiency and reduce time lags, FFCs may consider better data management systems that involve shifting from manual data collection and transfer systems to telemetric gauge stations that can help in maintaining long records of continuous data.
- For the communities in flood-prone areas, preparation and communication have to be improved. This involvement enhances awareness and understanding of the implications of natural hazards.
- As climate and the weather cycles continue to change, it may be expected that Eastern Nile countries should upgrade their FEWS centers from basic to advanced, taking advantage of the availability of tools that provide better quality data in real-time, access to global flood forecasting systems to supplement national FEWS, better computing techniques and resources, and new communication channels for better connection with end users.
- Creating social media content or collaboration with existing social media like TV, Radio, etc.
- After a rain season the assessment is highly recommended how much this information is rich to the communities and how much really the flood affected communities survived from the risk of flood by using ENTRO flood forecast and early warning information.
- From our fieldwork in South Sudan, we observed that the forecast information that ENTRO produced for early warning did not reach the target communities. As a result, ENTRO and all official stakeholders within Eastern Nile are working to improve the manner in which forecast information is disseminated and to raise awareness of how to understand early warning messages.
- Early Warnings reaching isolated or underserved populations. It is crucial to include the local authorities in the communities because some of these people own phones, radios, or televisions, or have reliable power for these services.
- The need for an active partner network with yearly meetings is to overcome the communication gaps between national agencies.

- Adaptation technologies for building resilience to climate change encouraged hazards in the water sector.
- In Lake Tana, TSA and BAS catchments riverine flood forecast need calibration and validation.

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