EN Flood Forecast and Early Warning Program

SEASONAL REPORT

EN-Flood Monitoring Team

October, 2020

Executive Summary

The EN flood forecast activities during 2020 flood season, mid of June to end of September, and flood forecasting and modeling processes carried out at ENTRO using the enhanced models and tools is presented in this report.

EN Rainfall Forecast

In the 2020 EN rainfall forecast system provides a platform to share early warning forecast information and services with Eastern Nile communities, the current and seasonal weather conditions over the Eastern Nile region was monitored continuously to understand the potential weather impacts. In this processes, WRF numerical weather model and other regional and global NWP models were used. In this 2020 flood season the convective activities forecasts were made over Eastern Nile resulting in the riverine flood over the flood susceptible areas in Ethiopia, South Sudan and Sudan. In general, in this 2020 flood season light to moderate to heavy and of course extreme rainfall magnitude were observed over the Eastern Nile.

EN Flood Forecast

The 2020 moderate to heavy rainfall events in the EN basin leaves back flood related threats in in the region, such as Khartoum and other states in Sudan, Lake Tana and Gambela in Ethiopia, Jonglei in South Sudan and other flood prone locations due to extreme runoff triggered for incident rainfalls especially in Ethiopian highlands. Therefore, rainfall forecast from WRF weather model was used in the Configured Hydrologic Modeling System (NAM) to produce runoff forecasts. The Hydraulic model (Mike-11) then used to route the runoff forecasts to produce runoff at different river gauging locations. Finally, the forecast products were visualized by any users using a Mike Operation web based GUI. In addition, summary of forecast products were analyzed, interpreted and disseminated to users as summary forecast report to the decision makers at different institutions and to the local communities.

***Lake Tana**, Ethiopia: In the Lake Tana flood forecast system, the river runoff produced at Dirma, Megech, Ribb and Gumara river gauging stations. The peak runoff from these river systems and other ungauged sub-catchments impacted the flood prone areas in lake Tana, Denbia floodplain (Dirma and Megech rivers) and Fogera flooodplain (Ribb and Gumara rivers). This was due to the moderate to heavy rainfall events in the upland areas and direct rainfall intensities over the flood prone areas that resulted in bank full/ over topping runoff.*

***Blue Nile**, Sudan: In the 2020 flood season, heavy rainfall over the Ethiopian highlands, in upper Blue Nile, the water levels in some key river stations have exceeded the flooding levels and the highest records ever. As a result, there were some flooding incidents occurred along the Blue and Main Nile river systems. The flood forecast has been done using Mike 11 forecast models using the WRF rainfall .*

***BAS**, Ethiopia and South Sudan: Baro-Akobo-Sobat region is one of the flood prone area due to its flat topography where the overflow of major rivers of BAS (Baro, Gilo, Alwero and Akobo, and Pibor) causes to increase the water level and inundates the areas during flood season. Therefore, the main purpose of this forecast was to produce a functional flood forecast information for early warning activities for BAS by integrating Mike models.*

***TSA**, Ethiopia and Sudan: Tekeze-Setit-Atbara region is one of the flood prone area, it was part of flood monitoring location in this 2020 flood season, due to its flat topography where the overflow of major rivers in TSA causes to increase the water level and inundates the areas during flood season.*

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1. Introduction

Flood forecasting and early warning system is the provision of advanced early warning of circumstances that are likely to affect and causes risk of flooding to life, properties and infrastructure. The main purpose of the Eastern Nile Flood Forecasting and Monitoring Program is to save life by allowing people to have early warning forecast information and provide emergency services to prepare for flooding and prone impacts. The second purpose is to reduce the damages from flooding. Flood is a significant issue due its impacts in many countries once the flood water covers the surface of land temporarily, it threatened people who live in flood vulnerable areas. Owing to the adverse nature of flooding events and the frequency of floods, the flood forecasting and early warning system was operational in Eastern Nile basin countries since 2010 to the current 2020 flood season. The FFEW activities strengthened regional collaboration and in overall reduced the risks of flood devastation for 2.2 million people in the region to present, despite preserving its environmental benefits.

In doing the flood forecasting processes, the rainfall forecast was carried out in daily basis over the Eastern Nile basins using WRF rainfall forecasting model emphasizing on the flood prone areas. The WRF model outputs were utilized as an input to the flood forecasting model for each model areas of lake Tana, Blue Nile, Baro-Akobo-Sobat (BAS) and Tekeze-Setit-Atbara (TSA) sub-basins. In addition, WRF rainfall forecasting model were compared with other regional and global numerical weather prediction models for the output verification based on the 3-days lead-times forecasts. Furthermore, the MIKE Operation uses GUI to visualize the forecast information and analyze forecast products generated by the hydrological and hydraulic models.

1.1. Background

The Nile Basin Initiative (NBI) is a partnership of the riparian states of the River Nile. The NBI seeks to develop the river in a cooperative manner, share substantial socio-economic benefits, and promote regional peace and security. The NBI started with a participatory process of dialogue among the riparian that resulted in their agreeing on a shared vision to “achieve sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile Basin water resources”, and a Strategic Action Program to translate this vision into concrete activities and projects.

The Eastern Nile Subsidiary Action Program (ENSAP) of the NBI is launched by Egypt, Ethiopia and the Sudan to initiate concrete joint investments and action on the ground in the Eastern Nile sub-basin in the areas of power generations and interconnection, irrigation and drainage, flood preparedness and early warning, watershed management, development of planning models and joint multipurpose programs. ENSAP is governed by the Eastern Nile Council of Ministers (ENCOM) and implemented through the technical arm of the ENSAP, Eastern Nile Technical Regional Office (ENTRO) in Ethiopia, Addis Ababa. ENTRO assists member states to identify, plan and prepare joint investment projects and supports strengthening country capacities for effective implementations.

The Eastern Nile Flood Preparedness and Early Warning (FPEW) project is one of those projects under ENSAP programs implemented by ENTRO that involves in the management of floodplain areas; flood mitigation planning; flood forecast and early warning; and emergency responses and preparedness at regional, national and local community levels in the EN countries. The goal is to carry out flood forecasts and disseminate flood information to different users in the EN basin. Some of the pilot flood-prone areas where ENTRO gives emphasis and provides flood forecasting and early warning services are Lake Tana, Baro-Akobo-Sobat, and Blue Nile, and Tekeze-Setit-Atbara River systems. In this regard, ENTRO seeks to reduce human sufferings caused by frequent flooding in these pilot flood-prone areas despite the fact that preserving the environmental benefits of floods.

The areas of implementation of FFEW system is in the upper Blue Nile around Lake Tana sub-basin in Ethiopia, Blue Nile in Ethiopia and Sudan, BAS both in Ethiopia and South Sudan, and TSA in Ethiopia and Sudan. Standardized flood forecasting procedure were made in the house of ENTRO since 2011 to the current 2020 flood season, daily forecasts and seasonal reports were produced and disseminated accordingly to the flood communities in the EN region.

1.2. EN flood monitoring program

Eastern Nile flood season monitoring program is one of the most important programs in the EN countries to mitigate the recurrent flood risks. In the past decades, there were many severe floods were occurred more frequently in EN region which was caused many losses and significant destruction of infrastructures. The 2006 flood in Ethiopia, for example, resulted in 242,000 people displaced and many were died. On the other hand, the 1998 flood in Sudan caused a direct flood damage of about US$ 24.3 million, and recently due to the 20202 flood season, thousands were displaced and many hundreds were died both due to flash floods and riverine flooding in Sudan, Khartoum and other counties, in South Sudan and around Gambella and lake Tana areas in Ethiopia, which also affects life and damage of properties.

Due to the impacts of extreme climatic and weather events which figuratively drive to the need for trans-boundary cooperation in the processes of monitoring the impacts from such climate related impacts. Increased populations in the region and the movement of human population into floodplains have increased the vulnerability of these populations to flood prone areas. Then, following the disastrous floods and to sustain the flood forecasting and monitoring program, the EN flood forecasting and early warning system enhancement has been done for a significant benefits to the region. This will improve the forecast products and then helps to reduce the integrated impact and damages from flooding.

1.3. Objectives

The main objective is 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.

The specific objectives are:

- 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
- Generate flood reports; daily reports and seasonal report, and disseminate to users - decision makers and different stakeholders in the region

2. Methodology

2.1. EN Rainfall forecast

In the EN rainfall forecasts, the WRF weather model was utilized to produce a 3-days lead time rainfall forecast data and information. The WRF model together with other global weather prediction models.

2.2. EN flood forecast

In flood forecast processes for each model areas of Lake Tana, Blue Nile, BAS and TSA, the methodologies for flood forecasting and modeling, combined hydro-meteorological models from Mike suits were used. The hydrological and hydraulic models (NAM and Mike 11 models including Mike operation) were used in which flood control and early warning strategies were applicable. In addition, there was a discussion on the model output results and the communication features of data exchanges and information dissemination.

3. EN Rainfall Forecast Processes

The rainfall received by Ethiopian highland and upper Blue Nile catchment are resulted in flooding, both riverine and flash floods, in Ethiopia, South Sudan and the Sudan and produce devastating effect on life, livelihoods, and properties since the major riverine flows generated in the Ethiopian highlands during each flood season, June through September. Floods are the most devastating natural disaster striking eastern Nile region each year due to both flash floods and river floods which has been growing exponentially. This is a consequence of the increasing frequency of heavy rain, changes in downstream and a continuously increasing concentration of population and assets in flood prone areas. The flood forecasting over eastern Nile region is an important tool in reducing vulnerabilities and flood risks. The EN seasonal flood monitoring program is serving the EN region to improve the capacity of hydro-meteorological services jointly to deliver timely and more accurate forecast products and services required in the flood forecasting and warning systems.

3.1. WRF Model setup

- **Installation and Configuration of the WRF model**

The WRF model is installed on the ENTRO Desktop and workstation (server) and . The WRF UEMS which is an end to end WRF system is installed.

- **Domain setup**

In this domain setup for the EN WRF forecast system, multiple of nested grid configuration was made. In this case, 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 domain and model area domain (MD) basins. To successfully simulate the convective storm over the basin, the two domains are nested, the mother domain covers the Easter Nile (-1.5°S to 24.5°N and 19°E to 52°E), and the parent domains are covers the model domain (0°N to 24°N and 20°E to 50E) respectively as presented in Figure 1.

The time steps for the WRF simulations for grid EN and MD model domain is 10m, and 5m, respectively. For all numerical experiments, the model has been initialized and nudged at the lateral boundary using GFS, data sets, for 3-days lead time forecast. The WRF model is running the Kain-Fritsch cumulus scheme for the mother domain (18 x18 km) without cumulus parameterization and the nested domain (6 x 6 km) is running the cumulus parameterization is turning off. Since the grid space is less than 6km the cumulus parameterization has to be turning off (Jeworrek, 2019).

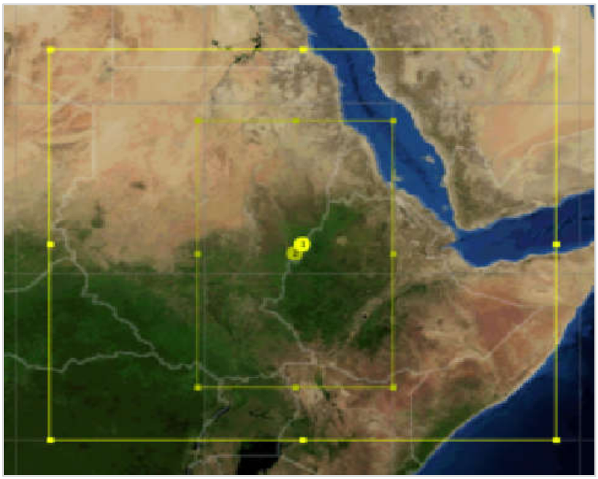


Figure 1. WRF Model domain size for EN and Model Domain

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 1.

Table 1. Summary 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
Microphysis	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 (or 72 hours) lead time. The sample EN rainfall forecast made on the 30th of September 2020 is presented in Figure 2 below.

Day-1 Forecast Day-2 Forecast Day-3 Forecast

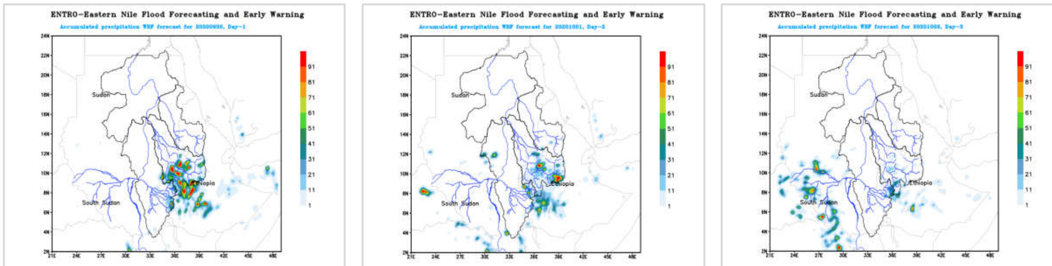


Figure 2. EN sample WRF weather forecast product (2020-09-30, SEP30-OCT02)

4. EN Flood Forecast Processes

The EN flood forecasting and early warning system, uses a single platform for each model area and produces flood forecast information in daily bases. The main outputs of forecast model results are:

- The average rainfall plots and tables that shows the expected rainfall per each sub-catchment where floodwater were generated
- The runoff flow hydrographs and tables that shows the expected peak floods which were generated using NAM and Mike 11, Mike Operation models
- Forecast results were then interpreted before dissemination to users the decision maker, local administration and responsible legal bodies.

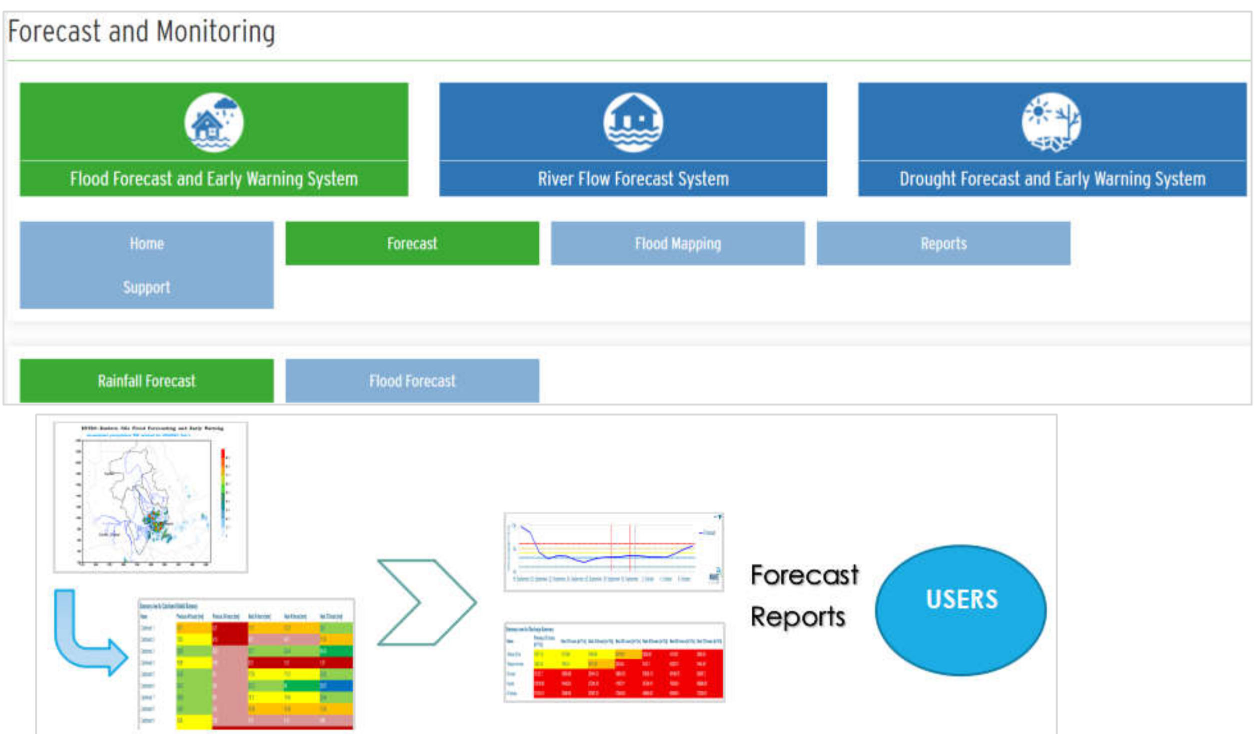
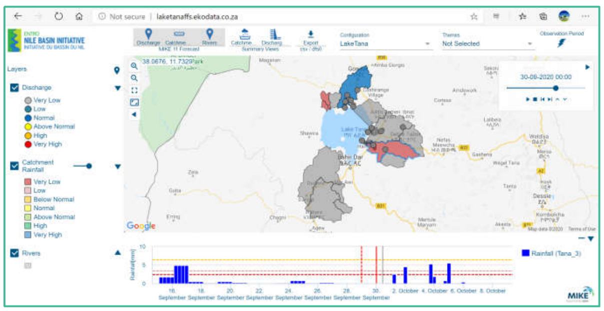


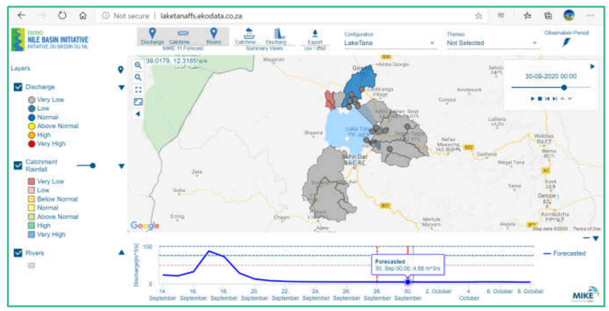
Figure 3. Combined model results and overall forecast processes

4.1. Lake Tana, 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 rivers 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 and Tana_3 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 upland catchment have contributions over Denbia floodplain, see figures below.



Rainfall forecast for Tana_3



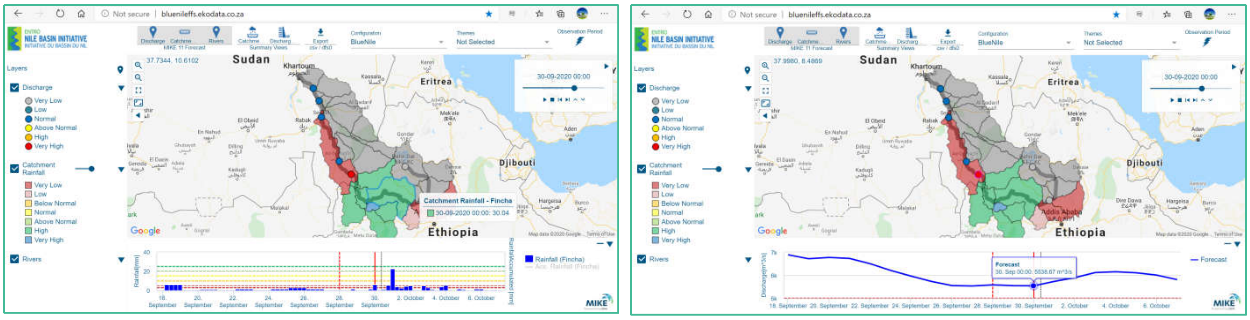
Runoff forecast at Gumara station

Figure 4. Estimated mean rainfall (left) and river flows (right) for Lake Tana

4.2. Blue Nile Forecast, Sudan

In 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 and early warning information. In the previous flood seasons, the flood forecasts for Blue Nile and main Nile was monitored using Sudan-FEWS following the floods of 1988 and it became operational since 1992 to 2019. In the 2020 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. In this forecast, the runoff at Roseries receives from upstream and routes downstream through Sennar, Madani and other downstream river gauging stations increases and may impact the local communities living along the river courses and river banks, and of course infrastructures over flood susceptible areas.

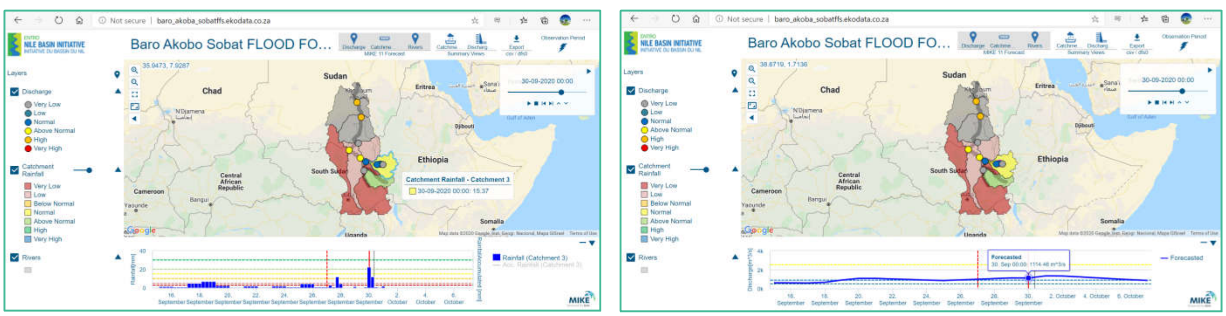


Rainfall forecast for Fincha | Runoff forecast at Ethiopia-Sudan Border

Figure 5. Estimated mean rainfall (left) and river flows (right) for Blue Nile

4.3. BAS Forecast, Ethiopia and S. Sudan

In the BAS forecasting system, the sub-catchments from upstream of the Baro river at Gambella gauging station, to Sobat areas and far downstream at Khartoum areas areas were monitored. Then runoff routing from upstream of Gambella 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 to get moderate runoff in the Baro river at Gambella and routed to downstream Itang, and Sobat after joining the Akobo river, see figures below. This may have less impact on the local communities living along the river courses and river banks and the flood prone areas. Please also aware that the heavy rainfall is expected in the White Nile and may affect people in the area.

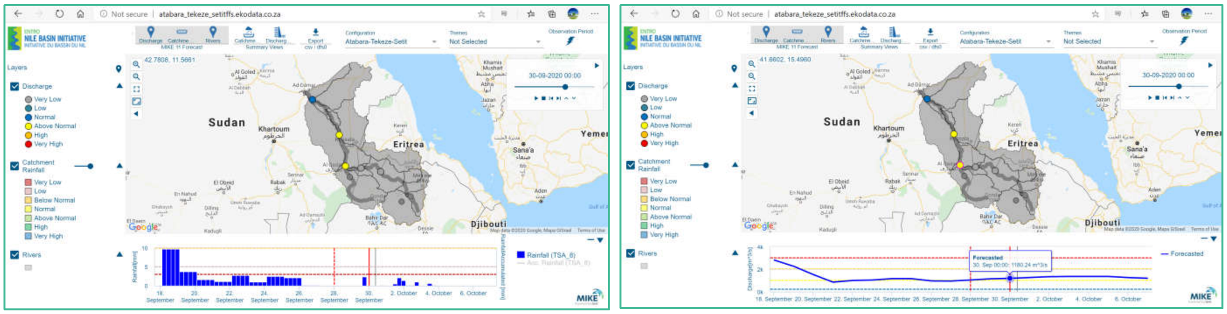


Rainfall forecast for Catchment 3 | Runoff forecast at Gambella station

Figure 6. Estimated mean rainfall (left) and river flows (right) for BAS

4.4. TSA Forecast, Ethiopia and Sudan

In 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.



Rainfall forecast for TSA_8 Runoff forecast at Showak station

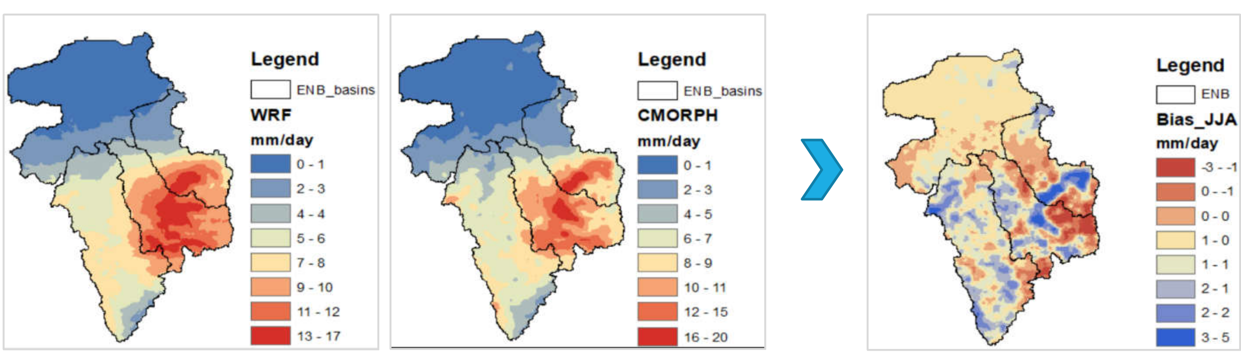
Figure 7. Estimated mean rainfall (left) and river flows (right) for TSA

5. Flood Forecast Skill Assessments

5.1. EN Rainfall forecast

The rainfall distribution in the EN basin were determined form the WRF forecast model and uses the output data for Lake Tana, Blue Nile, BAS and TSA model areas to generate the corresponding runoff or flood forecasts and analysis.

Therefore, to examine the skill of the WRF model forecasts, historical observed rainfall data from twenty automatic weather gauging stations, Satellite-based estimated rainfall from CMORPH with 8km spatial resolution, and 30 minute temporal resolutions (ftp://ftp.cpc.ncep.noaa.gov/precip/CMORPH_RT/ICDR/8km-30min) and GSmap gauge (ftp://rainmap:Niskur+1404@hokusai.eorc.jaxa.jp/realtime_ver/v7/hourly_G) data sets were used. These data sets were re-gridded to 0.06° to have similar resolution as WRF output spatial resolution to verify its forecast skills. This was considered at the locations where a meteorological station data access to validate the temporal forecast skills for three days lead time during the 2020 flood season, beginning of June to end of August. As a result, the WRF model forecast shows overestimated, however, in spatial distribution with observed CMORPH satellite rainfall but shows significant forecast/observation bias. In this case, the large bias couldn't be resulted from WRF model simulation skill only but due to CMORPH satellite rainfall estimation algorithms or resolution difference.



a/ WRF forecast b/ CEMORPH c/ Bias

Figure 8. Plots of WRF forecast and CMORPH rainfall data and their bias

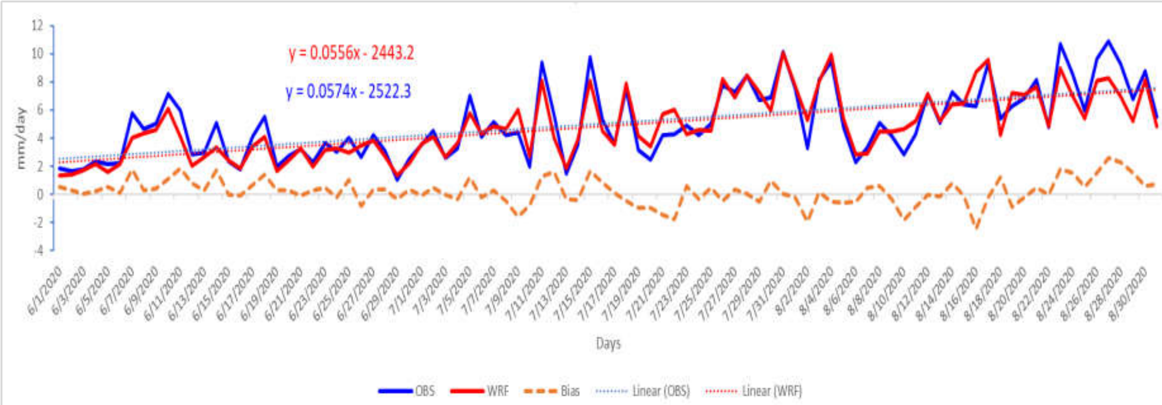


Figure 9. Time series, area mean WRF, observed and their bias rainfall, JJA of 2020

In summary, the 2020 rainfall season, June through September, was the wettest season having above normal rainfall in many area of the EN basin. Due to the heavy rainfall events (above normal rainfall), the cumulative rainfall was at least 100 mm per day based on the long-term average across the region and results in big flooding. The bigger surpluses were observed in the highlands of Ethiopia and over eastern Sudan. This wetness was due to frequent and well-above-average rainfall during August and early September and of course impacts from the climate change shifts in the Continent and the Easter Africa region in particular. Therefore, in this flood season, heavy downpours fell and triggered flooding, which was resulted in widespread flooding impacts in many areas, https://www.cpc.ncep.noaa.gov/.

5.2. EN Flood forecasts

In the 2020 EN flood forecast, a comparative assessment was get ride-off since no observed or automated river gauging records available for the forecast period. Nevertheless, the thresholds at key river gauging stations were determined from the historical records for some river gauging station as presented in the Table 1 below. The thresholds are rather used to indicate the levels of peak runoff forecast during model run and the corresponding impacts associated with it.

Table 2. Thresholds for some and accessible river flows

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

Therefore, for Lake Tana, Blue Nile, BAS and TSA model areas, the performances of the model and the runoff forecasts produced were not assessed due to unavailability of the observed data for each model area. On the other hand, it was tried to test the model performance indirectly using rainfall-runoff correlation approach but still it demands statistical modeling approach and it was get ride of instead.

6. Flood Impacts Assessments in 2020

In Ethiopia, the 2020 flood season affects more than one million people country wide. However, in the EN system of the country, over 19,232 people were affected in Gambella area, and more than 1,000 people were affected in Lake Tana end of July, many thousands in August and September 2020 and of which 2 deaths were registered from the September flooding. http://floodlist.com/tag/Ethiopia; https://reliefweb.int/updates.

In Sudan, flood kills more than 99 and affected more than 500,000 people and damaged more than 100,000 homes. In this 2020 year, flooding rates exceeded in history including the 1946 and 1988 records. South Darfur, North and West Kordofan, Al Jazirah, Khartoum, Kassala, Blue Nile, and the Red Sea States of Sudan for instance affected by the extreme floodin: https://reliefweb.int/updates, https://www.cpc.ncep.noaa.gov/, http://floodlist.com/tag/sudan and https://www.theguardian.com/world/2020/sep/05/sudan-declares-state-of-emergency-record-flooding, etc.

In South Sudan, during July to September 2020, both flash floods and riverine flooding induced from heavy rainfall affected many people. For instance, more than 5,000 people have been displaced due to floods in Bor South and Twic East counties in Jonglei, more than 600,000 people have been affected in areas along with the White Nile since July, where Jonglei and Lakes are the worst affected states, http://floodlist.com/tag/south-sudan.

7. Challenges and Lessons Learn

7.1. EN Rainfall Forecast

In the EN rainfall forecasts, limited observed data access and limited number of hydro-meteorological stations, in BAS and TSA model areas and of course automatic stations in all modeling areas of the EN region become a challenge for the verification and calibration of numerical WRF weather modeling to enhance the accuracy of the forecasts. In addition, limitations related to the computational resources, internet and power instability while running the model and during exchange of forecast information with the forecasts users. Nonetheless, the internet problem was hands over and resolved with the unlimited 4G internet services during downloading the climate parameters and dissemination of the forecast information.

7.2. EN Flood forecasts

Receiving feedback from forecast users mechanisms were none is a challenging feature in real time modeling processes since it is considered as one of a significant improvement area during the enhancement of the forecast. Although an effort was made to produce consistently and daily forecast and early warning information, still no mechanism made to check if the message is filtering to the intended and responsible person at the EN flood community for some reasons.

Since, surveying of ground data and the public information are important source of information, there is the chance improve and utilized the forecasting products. Therefore, these interrelated challenges and limitations shall be considered to generate a reliable forecast results and smooth dissemination of flood information for users.

The lack of topographic data, such as detailed topographic survey data, lake of hydro-met data from key gauging stations (need of establishing additional new gauging stations), limited capacity of flood forecasting and early warning systems are the challenges.

8. Forecast Enhancement and Way Forward

8.1. Model Enhancement

Currently, the flood forecasting and early warning systems have been enhanced to produce more reliable results. The enhancement of flood forecasting model will improve the capabilities of modeling results and helpful to reduced flood impacts by delivering in time forecasts and services for users. The current model configuration will incorporate and update the up-coming infrastructures to support the flood related risks in the future.

8.2. Communication Enhancement

The ENTRO web page is a good means and help to provide flood information and share the knowledge base between and among users. Short mobile messaging (SMS) service, Internet based map services and user groups access to solve problems of unexpected communication channel breakdown and provide means for exchange of information and features on the ground, such as water level rise/ fall and accessibility during flooding. It also helps to receive, Geo-referenced water level data from floodplains, discharge data at river gauging stations, pictures that shows the current situation around settlements. These would be used for qualitative assessments having an input for further enhancement and expansion of the flood forecasting and early warning system for the EN communities. In general, in the 2020 flood season, the forecast products produced in daily bases in the house of ENTRO, and disseminated as daily forecast reports and presented online for users, on the cloud.

8.3. Recommendations

In EN forecast system, combined forecast models are used to produce reliable flood forecast products for the region each flood season. However, regular validation and verification of forecast results with the ground data, both for rainfall and runoff data are important to improve the forecasts using the real-time data.

Since the WRF weather forecast model has more than1000 physics options, additional schemes tests and parameterization is recommended to improve the model output results. Currently, a six km spatial resolution model domain setup was used, however, it is recommended to test the model with different spatial resolution setups which will improve the skill of model performance.

It is also highly recommended to incorporate automatic weather stations and upper air data to improve the WRF forecasting system instead of using the GFS and GCMs data sources alone. Similarly, automatic river stations (telemetry systems) are important to include and use them for the verification of the flood forecast information with the ground truthing.

It is advisable to enhance and modernize the WRF numerical weather model, verify results and use of it for the flood forecast and used for the hydrologic model. Since, ENTRO works for the benefits of the region and sharing of knowledge and information with ministries, universities and different institutions, the data should be fair enough to be shared.

The local communities have good awareness about the recurrent flood challenges, and hence regular updates of flood risks and its potential damages should be forwarded them to protect themselves, their properties and infrastructure from devastating flooding.

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