SEASONAL REPORT

2022 FFEW SYSTEM

SEPTEMBER, 2022

Executive Summary

The EN flood forecast activities during 2022 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.

EN Rainfall Forecast

In the 2022 EN rainfall forecast system, 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 were used. The convective activities and rainfall forecasts in the EN trigger riverine flood over the flood susceptible areas in Ethiopia, South Sudan and Sudan. In 2022 flood season, light to moderate to heavy rainfall and of course extreme rainfall magnitude were observed in general over the Eastern Nile.

EN Flood Forecast

The 2022 moderate to heavy rainfall events in the EN basin leaves back flood related threats in the region, such as Khartoum and Algazera states in Sudan, and Gambela areas in Ethiopia, Jonglei in South Sudan and other flood prone areas due to extreme runoff triggered from rainfall incidents especially in Ethiopian highlands. Therefore, rainfall forecast from WRF weather model was used in the Configured rainfall-runoff model (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 interface. In addition, summary of forecast products was 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: The flood forecast at Dirma, Megech, Ribb and Gumara River gauging stations were produced. 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 floodplain (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 moderate runoff.*

Blue Nile*, Sudan: In the 2022 flood season, heavy rainfall over the Ethiopian highlands, in upper Blue Nile, the water levels in some key river gauging stations have exceeded the flooding levels and the highest records. There were some flooding incidents occurred along the Blue and Main Nile River systems that has been produced using Mike 11 forecast models.*

BAS, *Ethiopia and South Sudan: Baro-Akobo-Sobat region is one of the flood prone areas 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 each flood season. Therefore, flood forecast was produced for early warning activities in the BAS system.*

TSA*, Ethiopia and Sudan: Tekeze-Setit-Atbara region is one of the flood prone areas, and some parts of this catchment affected by floods due to its flat topography nature. Thus, as other modeling areas, flood forecast was produced for the area and disseminated for users, such as the rainfall peaks (both spatial and depth), and runoff levels at key river gaging stations such as Showak station for instance.*

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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 from 2010 to the current 2022 flood season. The FFEW activities strengthened regional collaboration and 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 on a 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 Mike 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 produced by the hydrological (NAM) and hydraulic (Mike 11) 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 procedures were made in the house of ENTRO since 2011 to the current 2022 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 2022 flood season, thousands were displaced and many hundreds were died both due to flash floods and riverine flooding in Sudan, Algazera states. In Ethiopia Gambala region more than 75,000 people displeased and 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 benefit 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.

Specific objectives:

- 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

2. FLOOD FORECASTING PROCESSES

2.1 General forecasting system

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.

In flood forecast processes for each model areas of Lake Tana, Blue Nile, BAS and TSA, the methodologies for flood forecasting and modelling, 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.

2.2 EN Rainfall Forecasting

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.

2.2.1 WRF Model setup

Before producing the rainfall forecast activities: the model configuration and domain setup was done.

Installation and Configuration

The WRF model was 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 covering the model domain (0°N to 24°N and 20°E to 50E) respectively as presented in Figure1.

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).

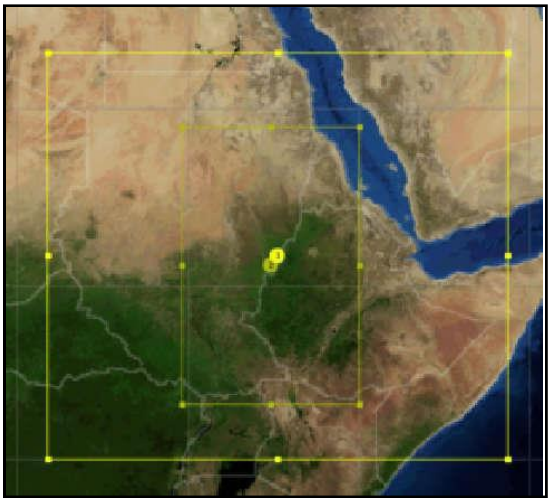


Figure 1: WRF model domain sizes for EN (outer box) and Model (inner box) domains

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 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 15th of August 2022 is presented in Figure 2 below.

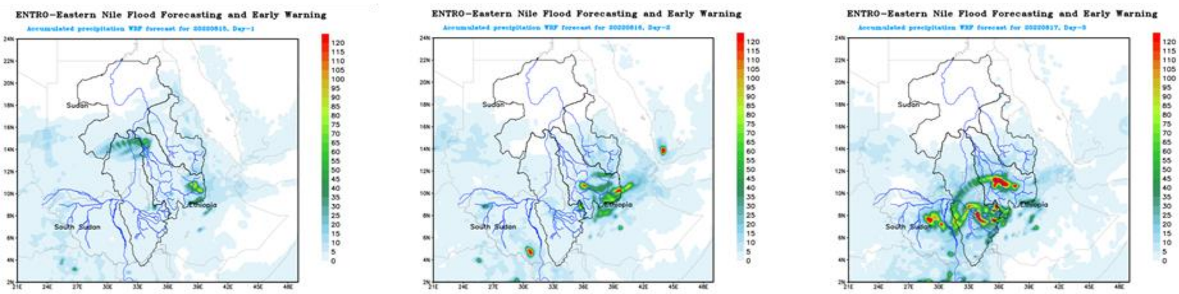


Figure 2: Sample WRF rainfall forecast made on 15AUG2022 for 3-days lead time (15, 16 and 17)

2.3 EN Flood Forecasting

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

Mike model configuration and usage

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 machine.

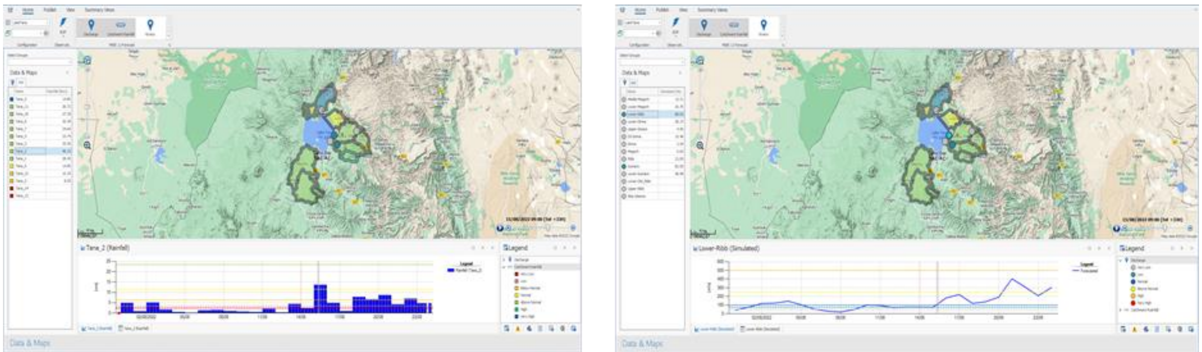
Some of the forecast outputs using NAM (rainfall-runoff model) and Mike11 (river routing), Mike Operation (visualization) are:

- 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 3: IKP interface (upper) and model results and overall forecast processes (lower)

2.3.1 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 w ere 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.



a/ Rainfall forecast for Tana_2 b/ Runoff forecast at Lower Ribb station station

Figure 4: Estimated mean rainfall (left) and river flows (Right) for Lake Tana

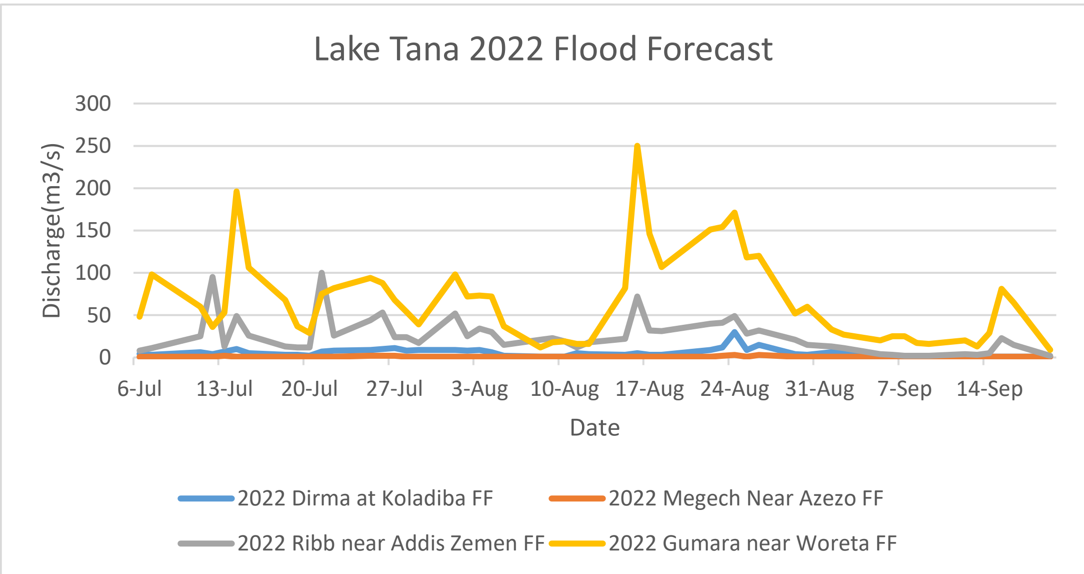
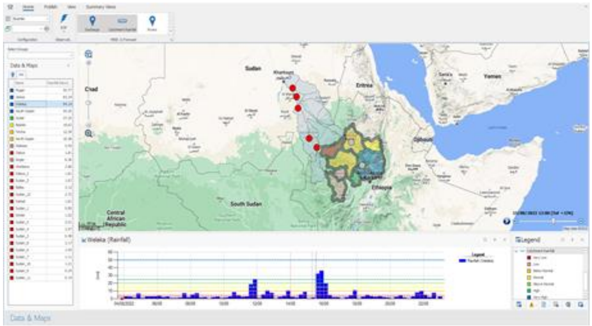


Figure 5. Three Month 2022 Lake Tana Flood Forecast

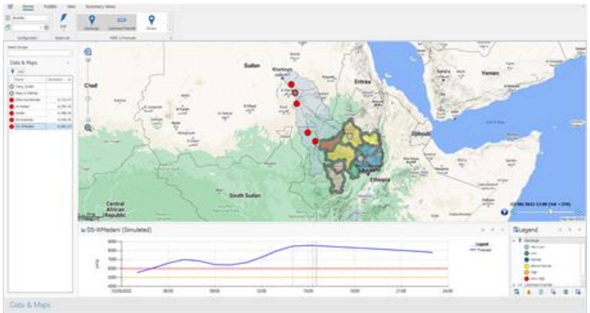
2.3.2 Blue Nile Forecast, Sudan

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 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 2022 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 Rosaries 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 infrastructures over flood susceptible areas.



a/ Rainfall forecast for Weleka



b/ Runoff forecast for Wd-Medani

Figure 6: Estimated mean rainfall (left) and river flows (right) for Blue Nile

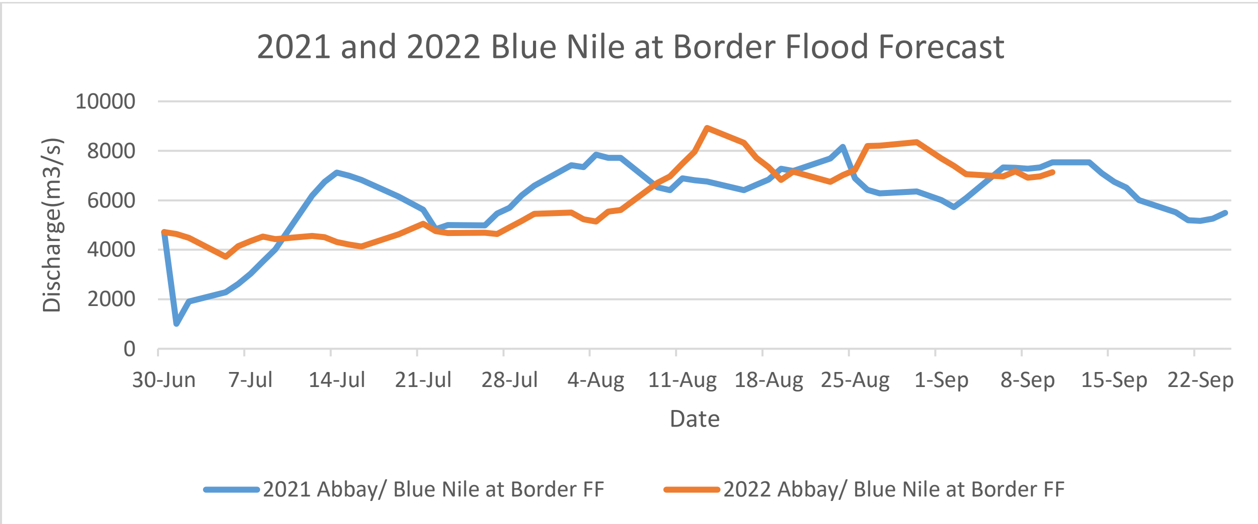


Figure 7. Three Month 2021 and 2022 Blue Nile Flood Forecast

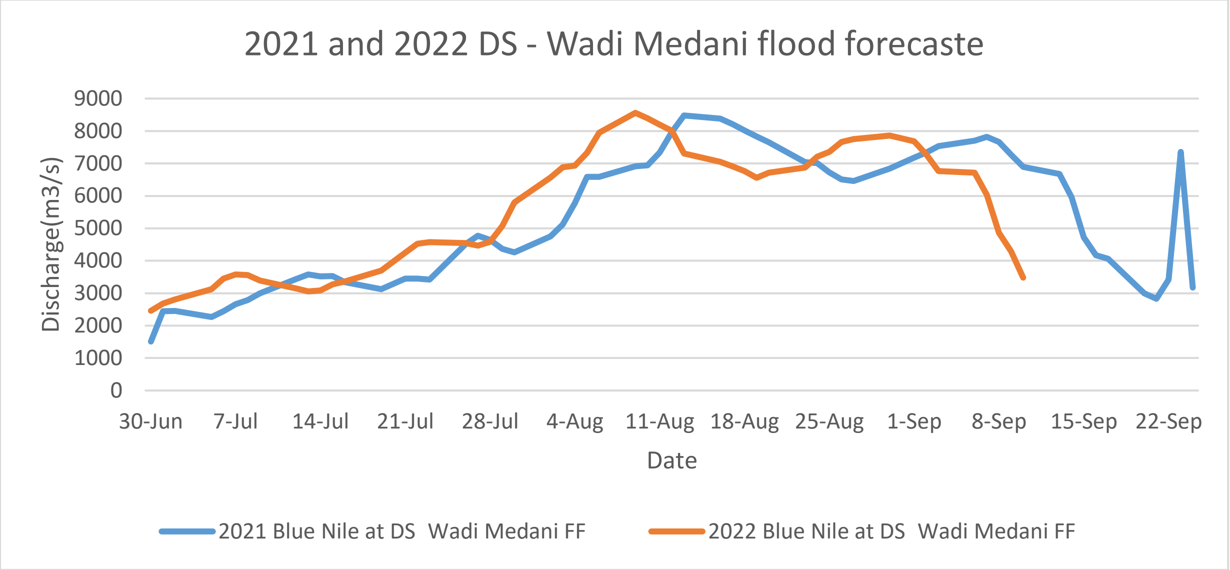
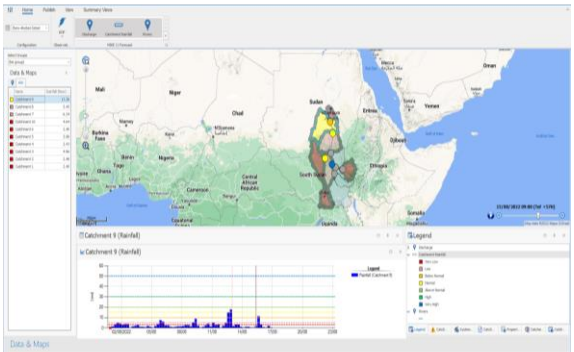


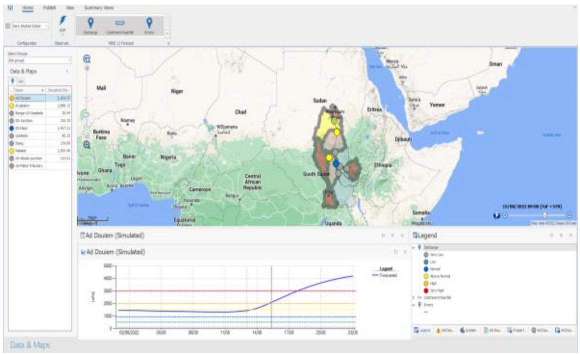
Figure 8. Three Month 2021 and 2022 DS-Wadi Medani Flood Forecast

2.3.3 BAS Forecast, Ethiopia and South Sudan

In the BAS forecasting system, the sub-catchments from upstream of the Baro River at Gambela gauging station, to Sobat areas 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 to get moderate runoff in the Baro river at Gambela 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 TSA and may affect people in the area.



a/ Rainfall forecast for Catchment 9



b/ Runoff forecast at Ad Douiem station

Figure 9: Estimated mean rainfall (left) and river flows (right) for BAS

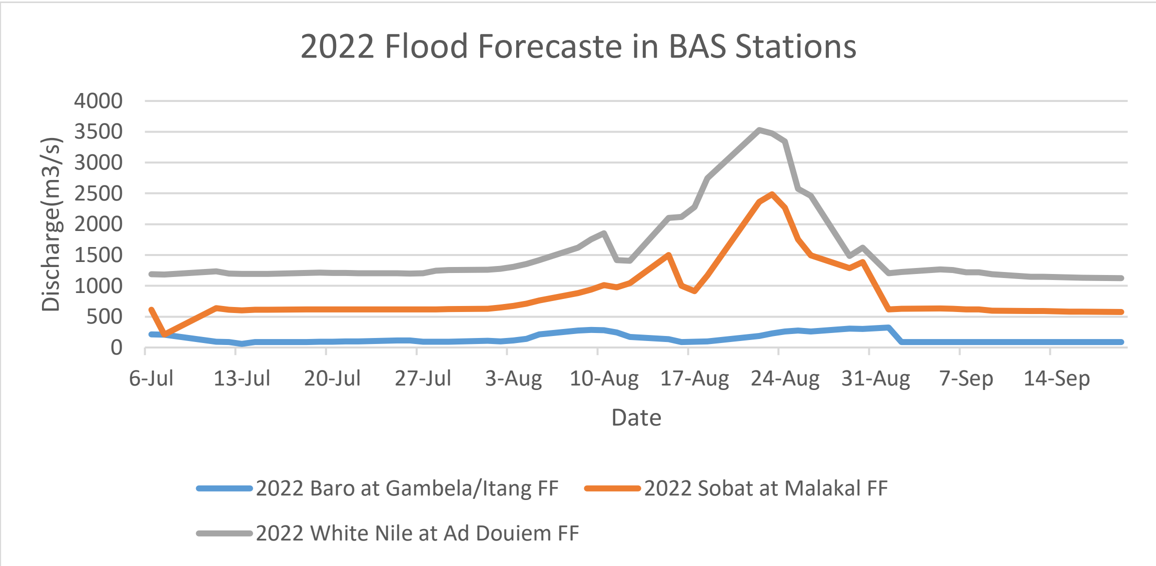
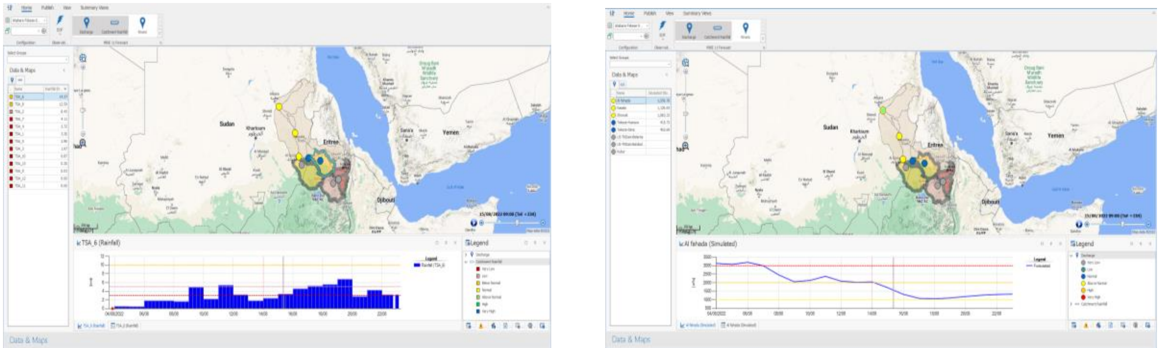


Figure 10. Three Month 2021 and 2022 BAS Stations Flood Forecast

2.3.4 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.



a/ Rainfall forecast for TSA_6 b/ Runoff forecast at Al Fahada station

Figure 11: Estimated mean rainfall (left) and river flows (right) for TSA

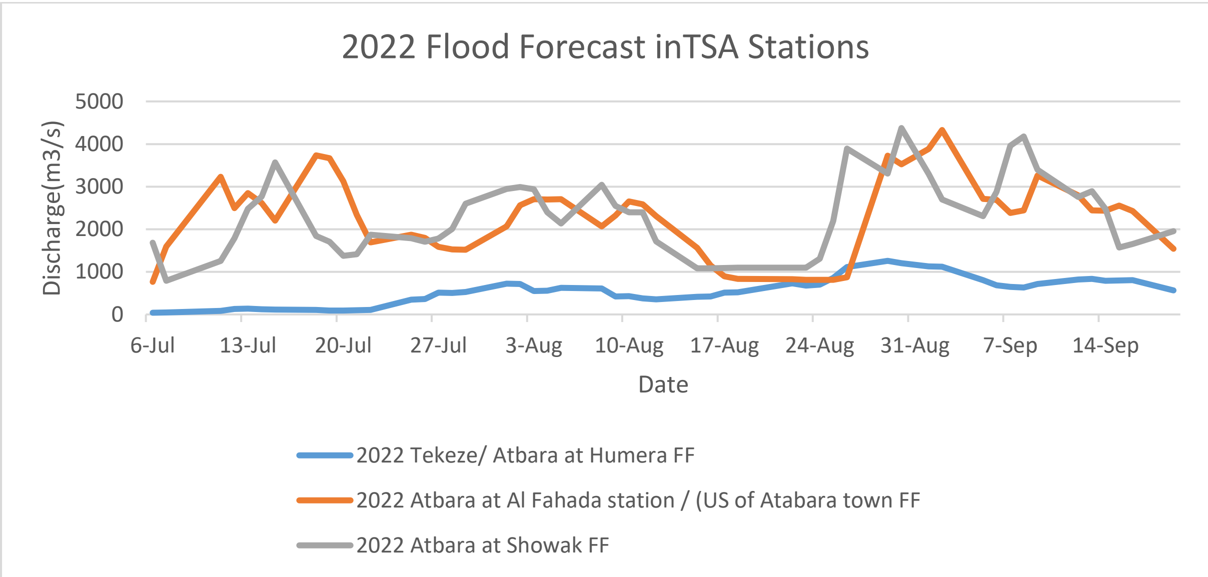


Figure 12. Three Month 2021 and 2022 TSA Stations Flood Forecast

3. MODELS SKILL ASSESSMENTS

3.1 WRF Model

The WRF model forecast skill was tested, using simply bias error, against CMORPH, because the CMORPH raw data is generated in near real-time and is available at several different spatial and temporal resolutions. Both the Flood and IPHEx CMORPH datasets include the one-hour estimates at approximately 0.25 lat/ lon spatial resolution (or 27 kilometers at the equator). The data provides global coverage (60 degrees south-60 degrees north). Detailed information is found on the CMORPH methodology in the following publication (https://doi.org/10.1175/1525-7541(2004)005%3C0487:CAMTPG%3E2.0.CO;2).

The 27 kilometers, CMORPH data is resampled into 6 kilometers to having it the same resolution with the WRF model output. And the forecast bias error is calculated, to determine the forecast deviation.

3.2 Spatial analysis

Putting every spatial analysis map will be difficult on this report that is why preferred to plot for the selected events which had heavy rainfall, more spatial coverage as well as flooding only. As we see from (Figure 8) *the* daily area average of the eastern Nile for 2022-JJAS season, its spatial distribution, as well as the amount, is relevant, and it's convenient to use it for hydrological impact models, such as MIKE. The spatial area average, daily rainfall variability is varied from -1.9 to 2 mm, through the basin.

Therefore, the daily spatial area average rainfall for the Eastern Nile (20E-50E and -1S to 24N) for JJAS-2022 season and the CMORPH (obs) observed satellite rainfall estimation, and WRF(Sim) which is WRF simulated rainfall output and Bias is (Obs-WRF) is presented in Table 2 below.

Table 2: Spatial area average EN rainfall for JJAS-2021 [CMORPH (obs), WRF(Sim) and Bias (Obs-WRF)]

No	Date	CM(obs)	WRF(sim)	Bias(obs - sim)
1	2021-06-15	1.07	0.5	0.57
2	2021-06-16	1.39	1.5	-0.11
3	2021-06-17	1.48	1.49	-0.01
4	2021-06-18	1.02	1.06	-0.04
5	2021-06-19	1.49	1.53	-0.04
6	2021-06-20	1.2	1.38	-0.18
7	2021-06-21	1.05	1.09	-0.04
8	2021-06-22	1.1	1.05	0.05
9	2021-06-23	1.36	1.56	-0.2
10	2021-06-24	0.79	0.59	0.2
11	2021-06-25	0.64	0.76	-0.12
12	2021-06-26	0.69	0.56	0.13
13	2021-06-27	1.26	1.45	-0.19
14	2021-06-28	1.51	1.12	0.39
15	2021-06-29	2.53	3.25	-0.72
16	2021-06-30	1.23	2.59	-1.36

No	Date	CM	WRF	Bias(obs - sim)
1	2021-07-01	0.99	0.68	0.31
2	2021-07-02	2.1	1.33	0.77
3	2021-07-03	1.62	1.5	0.12
4	2021-07-04	1.87	1.63	0.24
5	2021-07-05	2	1.15	0.85
6	2021-07-06	2.87	3.31	-0.44
7	2021-07-07	2.46	3.31	-0.85
8	2021-07-08	1.96	1.25	0.71
9	2021-07-09	1.39	1.52	-0.13
10	2021-07-10	2.46	2.68	-0.22
11	2021-07-11	2.23	1.43	0.8
12	2021-07-12	1.45	1.66	-0.21
13	2021-07-13	2.87	2.64	0.23
14	2021-07-14	2.5	1.65	0.85
15	2021-07-15	1.99	2.16	-0.17
16	2021-07-16	2.37	2.46	-0.09
17	2021-07-17	2.6	1.48	1.12
18	2021-07-18	1.5	2.67	-1.17
19	2021-07-19	1.05	2.9	-1.85
20	2021-07-20	1.95	2.35	-0.4
21	2021-07-21	1.79	2.93	-1.14
22	2021-07-22	1.41	2.16	-0.75
23	2021-07-23	1.91	1.8	0.11
24	2021-07-24	2.25	5.3	-3.05
25	2021-07-25	1.94	5.2	-3.26
26	2021-07-26	1.73	2.53	-0.8
27	2021-07-27	1.5	2.14	-0.64
28	2021-07-28	0.88	1.68	-0.8
29	2021-07-29	0.93	1.61	-0.68
30	2021-07-30	2.47	3.32	-0.85
31	2021-07-31	2.8	4.66	-1.86

No	date	CM	WRF	Bias(obs - sim)
1	2021-08-01	1.85	1.69	0.16
2	2021-08-02	1.41	1.39	0.02
3	2021-08-03	1.58	1.69	-0.11
4	2021-08-04	2.21	1.78	0.43
5	2021-08-05	1.81	1.4	0.41
6	2021-08-06	1.98	2.36	-0.38
7	2021-08-07	2.63	3.32	-0.69
8	2021-08-08	1.81	1.5	0.31
9	2021-08-09	1.89	2.56	-0.67
10	2021-08-10	2.3	4.95	-2.65
11	2021-08-11	1.94	2.09	-0.15
12	2021-08-12	2.13	2.56	-0.43
13	2021-08-13	2.42	3.18	-0.76
14	2021-08-14	2.28	2.06	0.22
15	2021-08-15	1.98	2.56	-0.58
16	2021-08-16	1.25	1.69	-0.44
17	2021-08-17	1.56	1.43	0.13
18	2021-08-18	1.41	1.99	-0.58
19	2021-08-19	2.06	3.02	-0.96
20	2021-08-20	1.82	2.47	-0.65
21	2021-08-21	1.13	2.58	-1.45
22	2021-08-22	1.83	1.47	0.36
23	2021-08-23	2.14	1.21	0.93
24	2021-08-24	1.66	1.51	0.15
25	2021-08-25	1.14	1.72	-0.58
26	2021-08-26	1.17	1.41	-0.24
27	2021-08-27	1.22	1.24	-0.02
28	2021-08-28	0.77	1.14	-0.37
29	2021-08-29	1.93	2.37	-0.44
30	2021-08-30	0.77	1.48	-0.71
31	2021-08-31	0.78	1.16	-0.38

No	date	CM	WRF	Bias(obs - sim)
1	2021-09-01	2.36	2.19	0.17
2	2021-09-02	2.31	1.62	0.69
3	2021-09-03	1.38	3.26	-1.88
4	2021-09-04	1.64	2.15	-0.51
5	2021-09-05	1.61	1.92	-0.31
6	2021-09-06	1.32	2.19	-0.87
7	2021-09-07	1.72	2.04	-0.32
8	2021-09-08	1.91	1.55	0.36
9	2021-09-09	1.6	2.25	-0.65
10	2021-09-10	1.23	2.14	-0.91
11	2021-09-11	1.35	1.19	0.16
12	2021-09-12	1.97	2.01	-0.04
13	2021-09-13	2.04	2.69	-0.65

The daily spatial average, for the Eastern Nile, is calculated for the Simulated WRF model, observed CMORPH, and bias error precipitation, at daily interval time steps. From the table days which has greater than 2.50 mm is taken for the spatial analysis due to its magnitude.

3.2.1 Time series analysis

Time series analysis comprises methods for analyzing time-series data to extract meaningful statistics and other characteristics of the data on the given time and places. The total WRF simulated precipitation and CMORPH observed precipitation inside the ENB are averaged. The average time series is analysis for three months (Figure 8), as we see it the bias error is -2 to 2 mm per day.

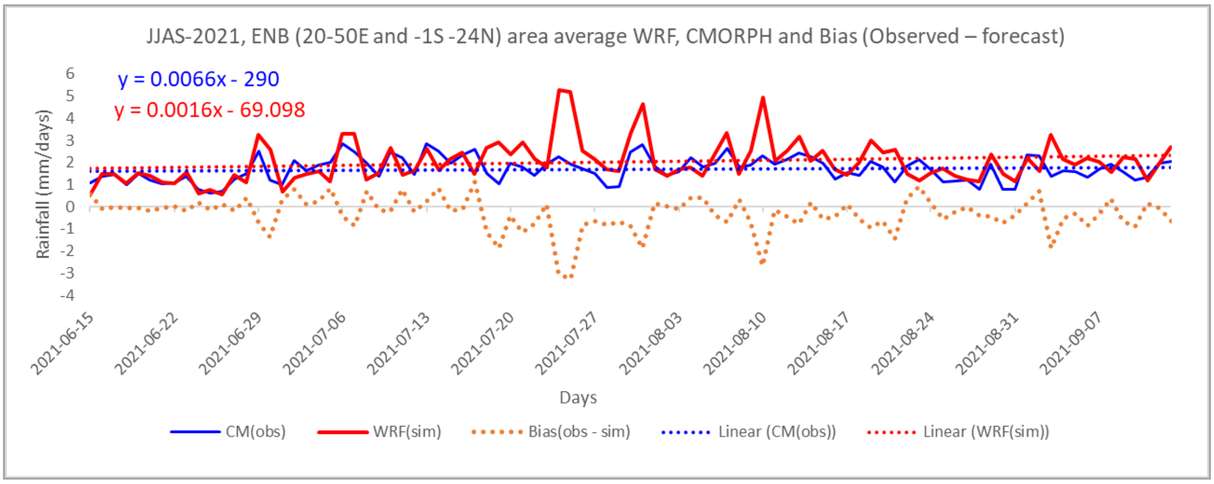


Figure 8: Area average WRF simulated, CMORPH and bias rainfall for JJA-2021

3.2.2 Comparative analysis of flood forecasts

In the 2022 EN flood forecast, a comparative assessment was got 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 model for some river gauging station as presented in the Table 3 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 3: Thresholds for some and accessible river flows

	TANA				BN								MN	BAS			TAS				
	Drima	Megech	Ribb	Gumara	Bahir Dar	Kesie	Border	Eldiem	DS-Roseries	US-Sennar	Medani	Khartoum	Donogla	Gambela	Itang	Melakal	Embamadre	Humara	Kibur	Griba MC	Atbara
Extreme	126	355.3	218.7	307.9	697	589.7	12684.4							1702.1	1338.1		3390.1	2184.6			
Very high	94.5	266.5	164	231	522.8	4422.8	9513.3							1276.6	1003.6		2542.6	1638.4			
High	31.5	88.8	54.7	77	174.3	1474.3	3171.1							425.5	334.5		847.5	546.1			
Above Normal	16	28.9	43.8	102.2	230.6	1702.6	4128.6							737.7	780.2		679.3	472.2			
Normal	3.7	9.1	15.2	39.1	135.5	715.1	1987.4							365.2	407.6		322.7	172.7			
Low	2.8	6.9	11.4	29.3	101.6	536.3	1490.6							273.9	305.7		242	129.5			
Very low	0.9	2.3	3.8	9.8	33.9	178.8	469.9							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 observed data limitation. On the other hand, it was tried to test the model performance indirectly using rainfall-runoff correlation approach but still it demands statistical modelling approach and it was needs to be addressed in the future similar activities instead.

4. FLOOD IMPACTS ASSESSMENTS FOR 2022

In **Ethiopia**, the 2022 flood season flood affects many local people in Gambela flood prone areas although no sufficient data was obtained from these areas. However, more than 75, 000 people in Gambela were displaced during the last month of 24 August 2022.A heavy rainfall resulted in flooding and impacts along the Baro and Gilo rivers (source;https://afro.news/2022/08/26/ethiopia-asdailyscoop-floods-displace-more-than-75000-people-in-gambella-state/

In **Sudan**, flooding has been affected many people across the country since the beginning of the rainy season since May. This is a significant increase is about 136,000 people. Torrential rains and floods destroyed about 8,900 houses and damaged another 20,600 in 12 states, the affected states are Central Darfur (38,390 people), South Darfur (28,730), River Nile (15,720), West Darfur (15,500), White Nile (13,920), West Kordofan (5,860), South Kordofan (5,770), North Kordofan (4,410), East Darfur (3,650), Sennar (3,160), Kassala (750) and North Darfur (210). More recently, Sudanese Red Crescent Society reported flooding in southern parts of Gezira (also Al Jazirah) state. The numbers affected by floods across the country have significantly increased from 161,730 in mid-August to over 204,000 as of 25 August. The worst hit states by population affected are Kassala (55,880 affected), South Darfur (38,575), and Al Gezira (23,280). In Khartoum State on 6 Auguast 2022, a flash flood affected State due to heavy rainfall. However, in comparison with the 2021 flood impacts (in Sudan), there are 303,330 people in Sudan have been affected by floods across the country since the beginning of the rainy season in the second half of July. This is a significant increase form the 60,000 affected as of 22 August. Furthermore 14,820 homes have been destroyed and 45,390 damaged (https://floodlist.com/africa/sudan-floods-update-august-2022).

In **South Sudan**, during July to September 2022, many localities were affected by heavy rains, especially the areas along the main rivers (Nile and Sobat) and tributaries since the beginning of the rainy season (early May), resulting in casualties and damage. For instance, 52,000 people have been affected and 3 people reported die across (upper state especially Maban county), (http://floodlist.com/tag/south-sudan.

5. CHALLENGES AND LESSONS LEARNED

5.1 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 limited number of automatic stations in all modeling areas become challenges for the verification and calibration of numerical WRF model to enhance the accuracy of the forecasts. On the other hand, limitations related to the computational resources, the forecast models (WRF and Mike) at ENTRO shall be implemented at member countries for nation level forecasts.

5.2 EN Flood forecasts

Receiving feedback from forecast user's 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 system for the EN region. 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 user (individual) 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 to improve and utilize 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, limitations on 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.

6. FORECAST ENHANCEMENT AND WAY FORWARD

6.1 Model Enhancement

Currently, the flood forecasting and early warning (FFEW) systems have been enhanced to produce more reliable forecast products. The enhancement of flood forecasting model will improve the capabilities of modeling skills 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 in addition to expand/incorporate Main Nile and White Nile FFEW system.

6.2 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 show 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 2022 flood season, the forecast products produced on a daily basis in the house of ENTRO and disseminated as daily forecast reports and presented online for users at ENTRO web page and on the Cloud (IKP) soon when the web page completed.

7. RECOMMENDATIONS

In EN forecast system, combined forecast models (WRF and MIKE) are used to produce reliable flood forecast products each flood season for the EN region. However, regular validation and verification of forecast results with the ground data, both for rainfall and runoff data are important and highly recommended to access (and share) observation data (real-time data if applicable from telemetry system) to improve the EN forecast products.

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. In addition, it is highly advised to implement additional hydro-meteorological stations within the flood prone areas and obey data sharing between member's countries through ENTRO.

Since the WRF numerical weather forecast model has more than 1000 physics options, additional schemes test 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 (e.g., telemetry system) and upper air data to improve the WRF forecasting system instead of using the GFS and GCMs data sources alone. Similarly, automatic river stations (river telemetry system) are important to comprise and use them for the verification of the flood forecast information as ground truthing.

It will be good if WRF and MIKE will be installed to the member EN countries as capacity building and enable countries to produce localized flood forecasts for the national and local uses.

Expanding the FFEW to both the Main Nile and White Nile systems is recommended and of course the enhancement of the FFEW forecast model considering the existing and up-coming infrastructures to support the flood related risks in the future.

It highly recommended the Integrated Knowledge-Base Portal (IKP) web page of ENTRO should be completed accordingly to integrate the web page of Mike Operation visualization tool which helps in facilitating and accessing the flood forecast information and other forecast products by users in the EN region and beyond.

WRF-Hydro forecasting model can be used as alternative forecast system for EN, if technical advancement is required (free version of global models) which can be customized to the region considering additional physical parameters and variables, might be considered as alternative future forecast modeling tool.

In the internship program, it is strongly recommended that selection of internship candidates from countries for the EN flood forecasting and early warning (FFEW) activities should be based on expertise skills, knowledge and modeling familiarities, capabilities and extensive experiences. This relies the FFEW demands advanced and skillful modelers that enable to run couple of climate and flood modeling, reporting and analysis of punch of model results. In general, ENTRO should select a highly motivated candidate with extensive experience and interdisciplinary skills in flood forecasting models and tools.

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

EN Flood Management Team:

Nasreen Ibrahim Elzen: Water Resource Engineer, Sudan Etayehu
Tuahir Issa Abdrie: Water Resource Engineer, Ethiopia
Augustino Changjwok Otin: Hydrologist, South Sudan

Yilma Seleshi (Prof.): (Flood and Drought Project Coordinator)
Surafel Mamo: Hydrologist/ Water Resource Modeler (Team lead)

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Appendix

Appendix Table 1. EN Basins Daily WRF Rainfall forecasts

	EN RFF			Lake Tana RFF		BN RFF		BAS RFF		TSA RFF	
Date	2022 RFFD1	2022 RFFD2	2022 FRFD3	2022 RFFD1	2022 RFFD2	2022 RFFD1	2022 RFFD2	2022 RFFD1	2022 RFFD2	2022 RFFD1	2022 RFFD2
04-Jul	55			15		55		10		55	
05-Jul	30	35		5	10	30	35	15	10	25	15
06-Jul	40	115		35	15	40	115	10	35	40	20
07-Jul	80	40	120	5	15	80	115	30	60	50	15
11-Jul	80	90	50	5	5	80	90	5	50	50	20
12-Jul	75	50	100	5	5	60	50	10	5	75	50
13-Jul	30	60	115	10	15	30	60	10	15	25	20
14-Jul	45	100	40	5	100	45	100	10	100	30	100
15-Jul	120	95	20	10	30	120	95	10	55	40	10
18-Jul	75	55	110	5	10	55	55	75	15	25	20
19-Jul	55	120	65	15	5	15	120	5	15	55	10
20-Jul	80	95	85	80	40	80	95	20	25	30	10
21-Jul	30	95	80	30	98	30	95	30	15	10	50
22-Jul	110	90	40	10	90	110	90	5	10	25	10
25-Jul	55	60	110	5	10	30	60	5	10	55	5
26-Jul	95	105	120	25	10	75	105	10	65	95	105
27-Jul	120	120	115	5	75	60	75	120	120	120	120
28-Jul	115	120	120	10	5	55	120	10	50	115	55
29-Jul	115	120	115	55	120	55	120	5	25	115	120
01-Aug	110	120	120	55	120	55	120	110	90	105	15
02-Aug	95	120	120	10	40	95	40	15	65	20	120
03-Aug	80	90	70	10	90	80	90	5	5	20	35
04-Aug	120	120	120	15	110	45	110	10	15	120	120
05-Aug	120	120	120	25	20	25	120	70	60	120	120
08-Aug	95	85	120	40	10	55	50	45	45	95	85
09-Aug	90	120	115	10	110	90	95	20	120	50	100
10-Aug	90	110	120	10	20	90	110	10	30	25	40
11-Aug	120	100	120	80	15	120	100	120	95	25	20
12-Aug	100	120	90	50	70	70	120	15	115	100	20
15-Aug	100	105	110	10	105	100	105	55	105	10	65
16-Aug	115	120	110	20	45	65	120	35	85	115	15
17-Aug	115	120	120	110	65	110	120	115	120	15	25
18-Aug	95	110	120	40	35	95	105	10	15	55	110
22-Aug	35	120	105	10	85	35	120	5	85	15	110
23-Aug	25	80	110	10	10	25	80	10	35	10	15
24-Aug	30	110	65	15	20	30	110	20	65	15	20
25-Aug	50	70	40	5	25	50	70	25	15	15	15
26-Aug	80	120	90	15	10	35	120	15	5	80	10
29-Aug	70	120	115	10	20	70	120	5	35	15	40
30-Aug	95	120	95	15	15	95	120	15	50	15	15

31-Aug	0	105	105	15	10	95	105	15	95	15	10
01-Sep	75	105	95	75	10	75	120	15	95	15	10
02-Sep	45	90	105	10	70	45	90	15	25	10	15
05-Sep	20	120	110	10	25	20	110	15	120	10	55
06-Sep	10	90	105	10	10	10	90	5	10	10	10
07-Sep	65	120	120	10	15	65	120	10	25	10	10
08-Sep	80	105	120	10	30	80	105	10	35	15	10
09-Sep	80	120	30	10	15	80	120	35	10	80	10
12-Sep	50	120	70	10	10	10	120	20	75	50	15
13-Sep	80	95	90	5	95	75	95	80	65	10	50
14-Sep	65	30	55	10	10	65	30	5	10	10	10
15-Sep	40	95	120	10	25	40	95	10	65	15	15
16-Sep	65	110	55	20	10	65	110	15	110	15	15
19-Sep	95	95	120	5	15	95	95	10	15	10	10
		90	20		10		90		25		10
			120								

Appendix Table 2. Around Lake tana and BN River Stations Daily Mike 11 flood forecasts

Date	For Dembia Flood Plain		For Fogera Flood Plain		BN Daily Flood forecast	
	2022 Dirma at Koladiba FF	2022 Megech Near Azezo FF	2022 Ribb near Addis Zemen FF	2022 Gumara near Woreta FF	2022 Abbay/ Blue Nile at Border FF	2022 Blue Nile at DS Wadi Medani FF
06-Jul	4.3	0.7	7.9	48	4716	2459
07-Jul	3	1	11	98	4632	2678
11-Jul	6	1	25	60	4477	2807
12-Jul	4	1	95	36	3718	3127
13-Jul	7	2	13	53	4144	3450
14-Jul	10	1	49	196	4357	3580
15-Jul	5	1	26	106	4530	3556
18-Jul	3	1	13	68	4430	3391
19-Jul	3	1	12	37	4565	3142
20-Jul	2	1	12	29	4502	3060
21-Jul	7	1	100	75	4311	3081
22-Jul	8	1	26	82	4206	3269
25-Jul	9	2	44	94	4137	3359
26-Jul	10	2	53	88	4619	3698
27-Jul	11	2	24	68	5045	4254
28-Jul	8	1	24	54	4760	4523
29-Jul	9	1	17	39	4672	4579
01-Aug	9	1	52	98	4694	4548
02-Aug	8	1	25	72	4643	4464
03-Aug	9	1	34	73	4910	4584
04-Aug	6	1	30	72	5171	5067
05-Aug	2	1	15	37	5449	5799
08-Aug	1	1	21	12	5501	6565

09-Aug	1	1	23	18	5229	6880
10-Aug	1	1	19	19	5138	6931
11-Aug	5	1	12	16	5539	7331
12-Aug	4	1	18	16	5606	7949
15-Aug	3	1	22	82	6710	8560
16-Aug	5	1	72	250	6964	8391
17-Aug	3	1	32	146	7484	8197
18-Aug	3	1	31	107	7961	8010
22-Aug	9	1	40	151	8923	7305
23-Aug	12	2	41	154	8322	7055
24-Aug	30	3	49	171	7713	6909
25-Aug	9	1	28	118	7344	6768
26-Aug	15	3	32	120	6824	6558
29-Aug	4	1	21	52	7160	6717
30-Aug	3	1	15	60	6744	6871
01-Sep	6	1	13	33	7023	7204
02-Sep	5	1	11	27	7230	7357
05-Sep	1	1	4	20	8200	7664
06-Sep	1	1	3	25	8204	7747
07-Sep	1	1	2	25	8346	7859
08-Sep	1	1	2	17	7695	7680
09-Sep	1	1	2	16	7392	7276
12-Sep	1	1	4	20	7055	6762
13-Sep	1	1	3	13	6971	6713
14-Sep	1	1	5	29	7175	6034
15-Sep	1	1	23	81	6911	4859
16-Sep	1	1	15	65	6961	4293
19-Sep	1	1	2	9	7133	3481

Appendix Table 3. BAS and TSA River Stations Daily Mike 11 flood forecasts

Date	BAS Daily Flood forecast			TSA Daily Flood forcast		
	2022 Baro at Gambela/Itang FF	2022 Sobat at Malakal FF	2022 White Nile at Ad Douiem FF	2022 Tekeze/ Atbara at Humera FF	2022 Atbara at Al Fahada station / (US of Atabara town FF	2022 Atbara at Showak FF
06-Jul	213	611	1189	40	765	1680
07-Jul	208	210	1186	47	1597	790
11-Jul	94	641	1237	83	3228	1254
12-Jul	89	612	1197	127	2497	1788
13-Jul	59	601	1192	140	2848	2480
14-Jul	90	613	1196	118	2618	2767
15-Jul	89	613	1194	112	2201	3571
18-Jul	90	617	1208	105	3736	1842
19-Jul	92	619	1214	94	3663	1709
20-Jul	94	618	1212	93	3124	1379
21-Jul	98	617	1208	99	2337	1411
22-Jul	99	616	1207	105	1690	1872
25-Jul	113	617	1205	343	1873	1789
26-Jul	112	617	1200	360	1793	1709
27-Jul	91	619	1207	509	1585	1784
28-Jul	94	620	1247	505	1529	2008
29-Jul	93	623	1259	526	1521	2598
01-Aug	108	630	1261	725	2069	2945
02-Aug	101	648	1279	713	2564	2993
03-Aug	116	674	1311	550	2706	2940
04-Aug	141	712	1354	558	2701	2396
05-Aug	213	762	1417	627	2705	2137
08-Aug	277	881	1619	607	2064	3042
09-Aug	285	941	1756	425	2321	2547
10-Aug	281	1010	1856	432	2655	2399
11-Aug	245	976	1418	379	2586	2396
12-Aug	170	1046	1409	354	2308	1710
15-Aug	135	1500	2105	416	1560	1083
16-Aug	90	1001	2119	421	1151	1084
17-Aug	92	912	2280	509	896	1088
18-Aug	97	1170	2747	523	832	1097
22-Aug	189	2364	3528	729	826	1099
23-Aug	229	2486	3474	677	812	1094
24-Aug	258	2267	3343	696	811	1306
25-Aug	276	1755	2575	856	816	2192
26-Aug	260	1493	2462	1114	869	3894
29-Aug	305	1288	1485	1258	3727	3308
30-Aug	300	1387	1621	1202	3521	4375
01-Sep	324	617	1203	1126	3881	3297
02-Sep	89	627	1226	1119	4329	2699
05-Sep	87	631	1265	806	2713	2308
06-Sep	87	628	1259	685	2688	2878
07-Sep	87	619	1220	644	2384	3957
08-Sep	87	617	1219	635	2441	4177
09-Sep	86	596	1188	714	3259	3394
12-Sep	87	593	1149	817	2793	2760
13-Sep	89	590	1146	835	2442	2896
14-Sep	87	586	1142	788	2438	2478
15-Sep	87	584	1137	801	2558	1573
16-Sep	87	581	1132	804	2430	1650
19-Sep	87	578	1125	564	1539	1952