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Executive Summary

One of the objectives of the FANFAR project is to set up an Operational Hydrological Forecasting and Alert system in West Africa. For this, it is necessary to derive information from different sources (hydrological models outputs, satellite altimetry-based water level, water bodies and in-situ observations) to produce flood alert information to assist decision-making. This document presents the service called "Post-processing". The post-processing is a separate Hydrology-TEP service to derive useful information (e.g. alert/risk/awareness maps & graphs) based on the forecast data. The service prepares the content for the distribution channels. The service provides different output to different target audiences (e.g. the Forecaster, the Stakeholders, different for different countries etc.) and corresponding distribution channels. The service can be applied on different variables (streamflow, water level, precipitation, etc.) and using different methods do define alert thresholds (return periods, percent of historic years, or based on local knowledge).

1. Introduction

The FANFAR system provides data from different sources (forecasted river flows, satellite-based water level, water bodies and in-situ observations). A common approach to produce hydrological alerts is to compare forecasted river flow with predefined alert thresholds. Through our previous collaboration, the FANFAR team have already developed some post-processing scripts that derive return-period magnitudes and use these as thresholds to compare current forecasts against, and produce mapped output displaying the current alert levels. However, to meet the needs of end-users, it is necessary to explore other ways of deriving flood alert information in order to make it more useful. Information provided by the post-processing service are derived at several levels of detail (e.g. text alerts, static maps, online visualization, and model data).This document describes how the post-processing service is developed. It presents the sources of the data used for information derivation, the methods for defining alerts thresholds and the outputs produced by the system. Figure 1 is a flow diagram showing inputs, processing steps and outputs.

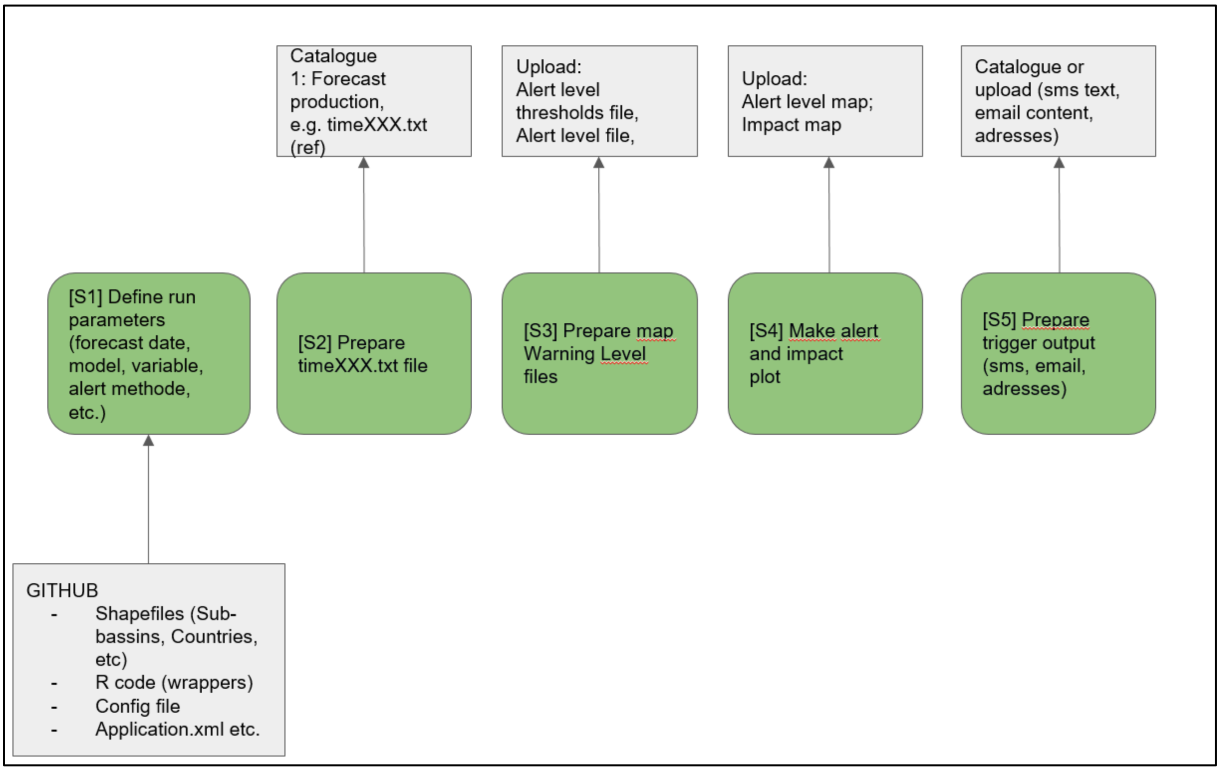

Figure 1: Flow diagram showing inputs, processing steps and outputs

2. Brief description of the hydrological models used

2.1. Niger-HYPE model version

HYPE model is a simplified representation of dominant hydrological processes in the modelled region (rainfall→ streamflow). It allows quantifying water fluxes and water stores. The different flows that the HYPE model can simulate are, for example, precipitation, evaporation, infiltration, surface runoff. In Hydrology-TEP, there is a service called "Niger-HYPE historical simulation" and “Niger-HYPE forecast” (Figure 2), which allows obtaining the HYPE models outputs. The Figure 3 shows the number of sub-basins defined in the Niger-HYPE model.

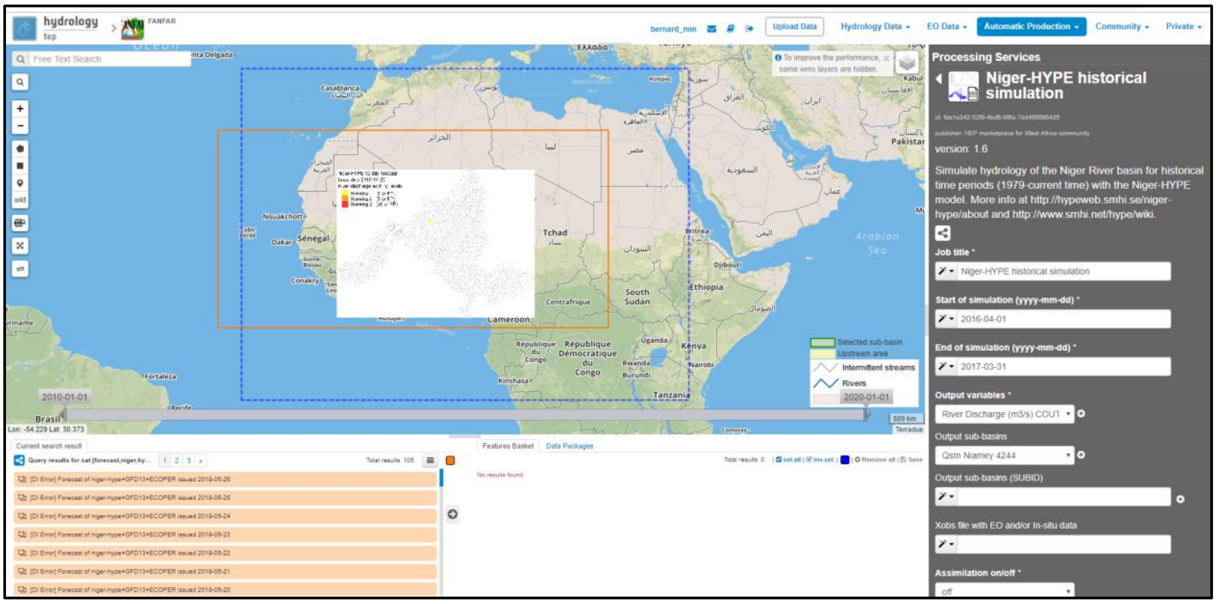

Figure 2: Niger-HYPE historical simulation service in hydrology-TEP

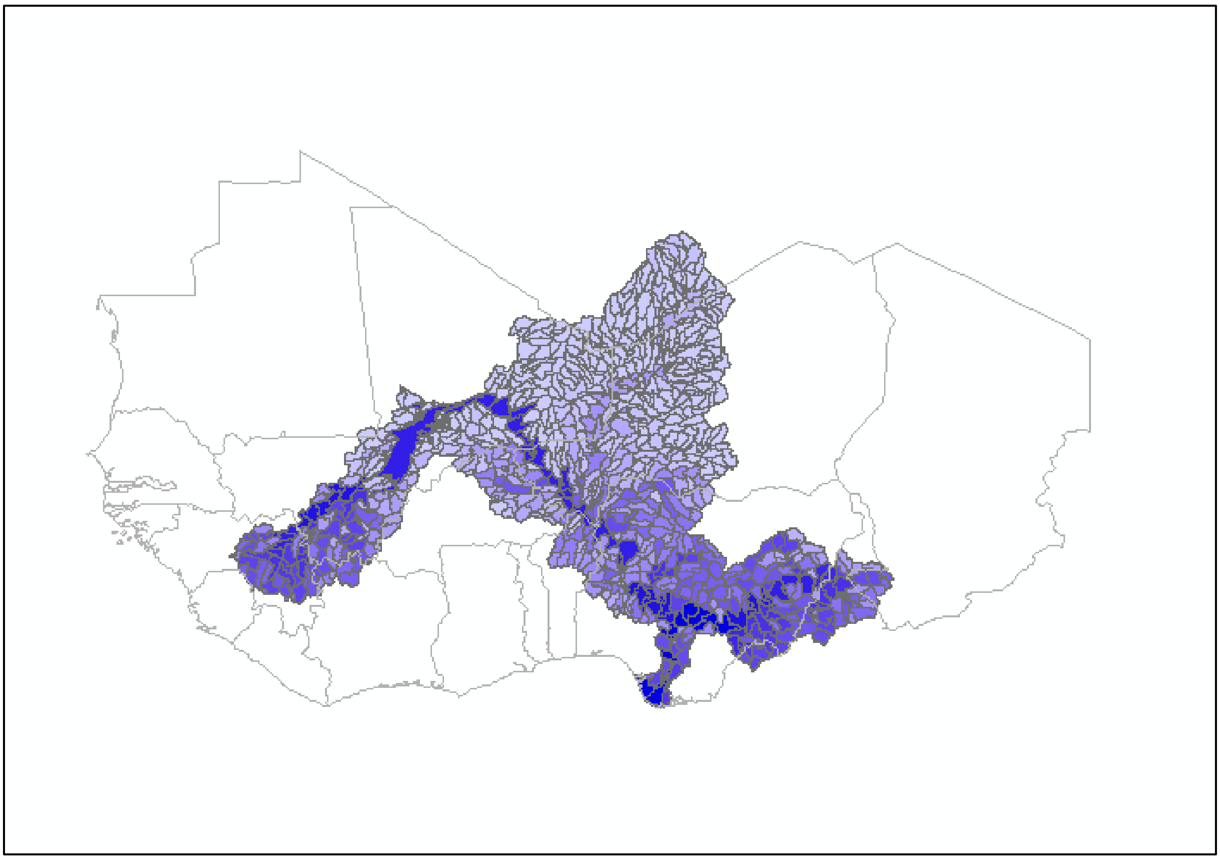

Figure 3: Intern annual (1981-2010) water flow (m^3/s) with Niger- HYPE

2.2. World-Wide HYPE model version

The World-Wide HYPE model is similar to the HYPE model but covers the entire globe. This World-Wide HYPE model covers an area of 135 million km^2, divided into some 131 300 catchments following the river networks. The average size of catchments is 1020 km^2. Catchments of deserts and flood plains have larger areas (~4500 km^2, and ~3500 km^2, respectively), while catchments in step areas at high altitudes have in general smaller areas. The model uses a large number of Open databases and is calibrated against time-series of various sources of observations (both from in situ monitoring and Earth observations). In FANFAR, we currently use the World-Wide HYPE version 1.3.6 extracted for West Africa. Figure 4 shows the configuration of the sub-basins on the countries covered by the FANFAR project.

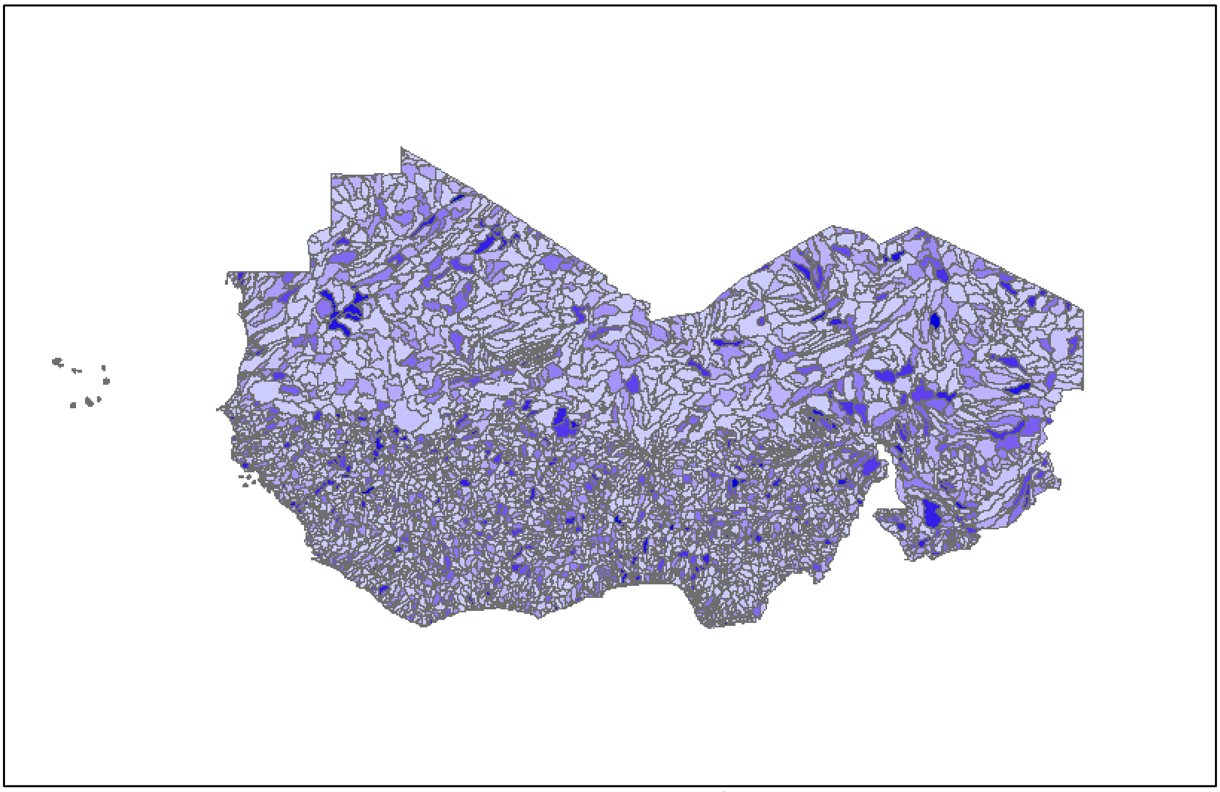

Figure 4: Intern annual (1981-2010) water flow (m^3/s) with World-Wide HYPE

2.3. Mosaic-HYPE model version 1

Mosaic-HYPE is a combined version of Niger-HYPE and World-Wide HYPE. To do this, the area covered by the model is West Africa. The combination consists of using the outputs of the Niger-HYPE model in the surfaces covered by this model and the outputs of World-Wide HYPE in the other parts of West Africa. Figure 5 shows the configuration of the sub-basins on the countries covered by the FANFAR project.

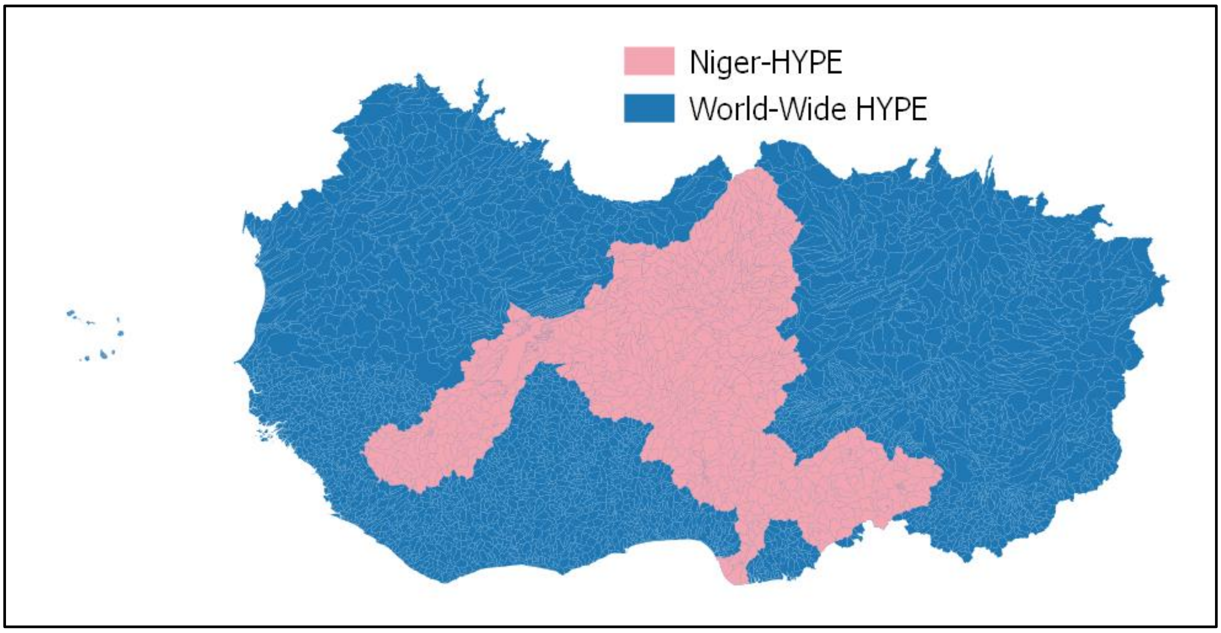

Figure 5: Mosaic-HYPE version 1, combining outputs from Niger-HYPE and World-Wide HYPE.

3. Data and variables used for post-processing

Several types of data were used, depending on the method of defining the alert levels considered:

- Precipitation hindcast and forecast;
- Historical observed discharge;
- Satellite altimetry-based water level;
- HYPE forecast and hindcast outputs;

3.1. Observed historical discharge

At present, in-situ observations are provided by local hydrological services. Data from hydrometric stations contains river flows, water discharge and rating curves. The data currently considered are those used for the calibration of Niger-HYPE and World-Wide HYPE. In Figure 6, the red polygons indicate the gauged sub-basins (that is, with hydrometric stations). The time step of the data is daily.

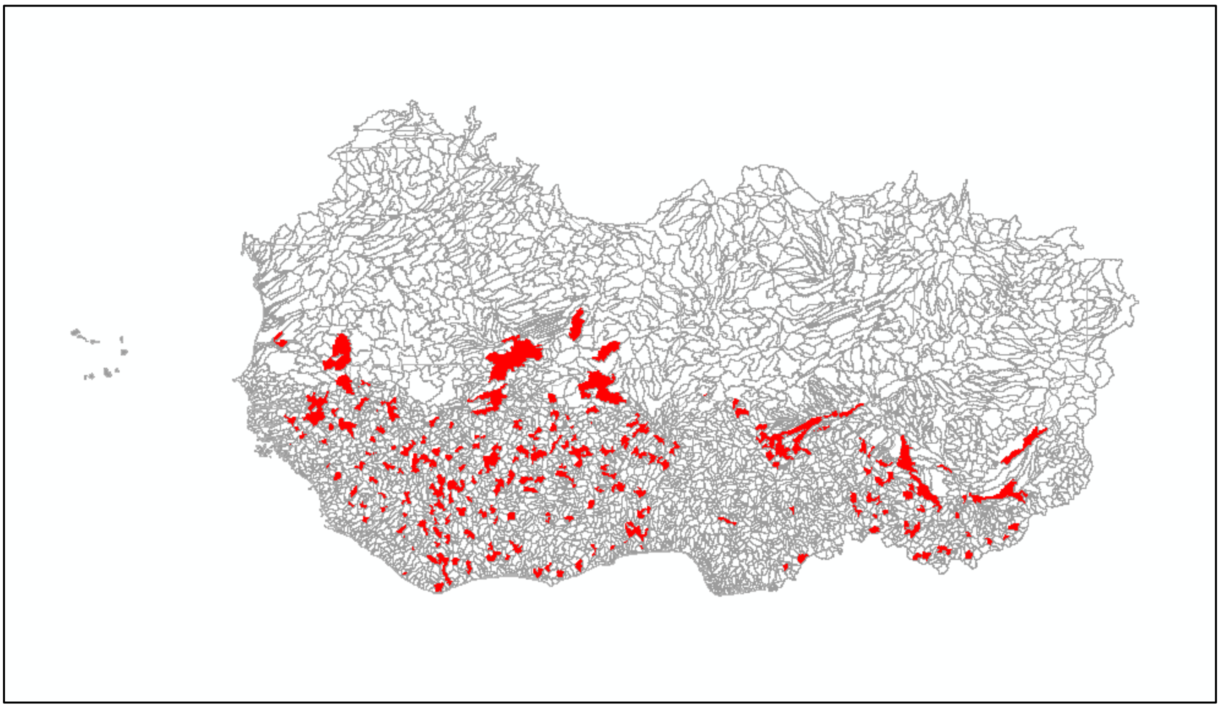

Figure 6: Catchments with hydrometric gauging stations in West Africa

3.2. Satellite altimetry-based water level

The Water Level Service developed by isardSAT provides the water level time series of a number of lakes and rivers. The service is based on altimetry data from Sentinel 3, Jason-2 and SARAL-Altika. isardSAT's satellite-based water level products of the Niger River basin floodplain are sequentially assimilated into a hydrological model from SMHI to generate river discharge return periods in FANFAR and complements in-situ sensor networks. It can also be used as a proxy of streamflow, for model calibration and validation as well as for hydrologic data assimilation making possible for the FANFAR community to access to data where there was none before. An input from the water level service is included in the figure below.

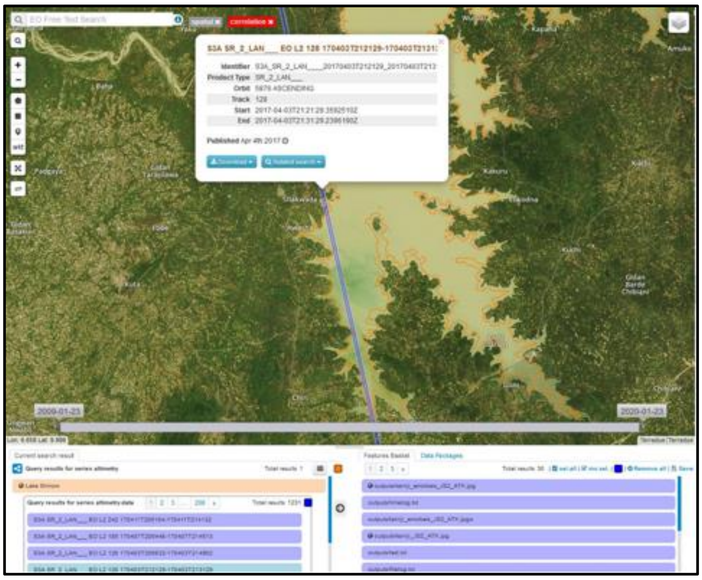

Figure 7: Track over Kainji lake, Western Nigeria, input to the water level service

3.3. HYPE forecast and hindcast outputs

The HYPE outputs include time series of simulations (for each time step or averaged/summed over a longer period). These outputs can be obtained by doing hindcasts or forecasts. HYPE time output files are one of the standard result files for time series output from HYPE. Time output files each contains results for a single HYPE variable for all modelled sub-basins or if it is an output regional variable for all modelled output regions. The variables considered in this service are: Precipitation, Discharge and Surface Runoff. Table 1 gives a brief description of the variables considered.

Table 1: HYPE output used

N°	Variable	Unit	Description	Aggregation formula	Reference area
1	cros	mm/day	simulated surface runoff (infiltration excess and saturation excess).	Sum	subbasin land area
2	cprc	mm/day	corrected precipitation (HYDROGFD2.0 + the precip. adjustments done within HYPE)	Sum	subbasin area
3	cout	m^3/s	simulated streamflow flowing out of a subbasin	Average	subbasin upstream area

3.4. Flood impacts on population and risk for disaster

The impact of streamflow peaks on society varies depending on how many people and valuable assets are exposed to the water, and how vulnerable these are to the exposure. The same amount of water can cause much more damage in a highly populated place than in a location with few people.

In other words, the disaster risk is higher in the former than the latter. Based on the feedback received from workshop participants, we are working on a method to combine the streamflow magnitude information (characterized e.g. by different return periods, see below) with information on population (Figure 8) to derive a disaster risk index (essentially combining the factors Flood Hazard, Flood Exposure and Flood Vulnerability). The visualisation and quantification will be based on the basic disaster risk index, but adapted to fit local conditions in the FANFAR countries.

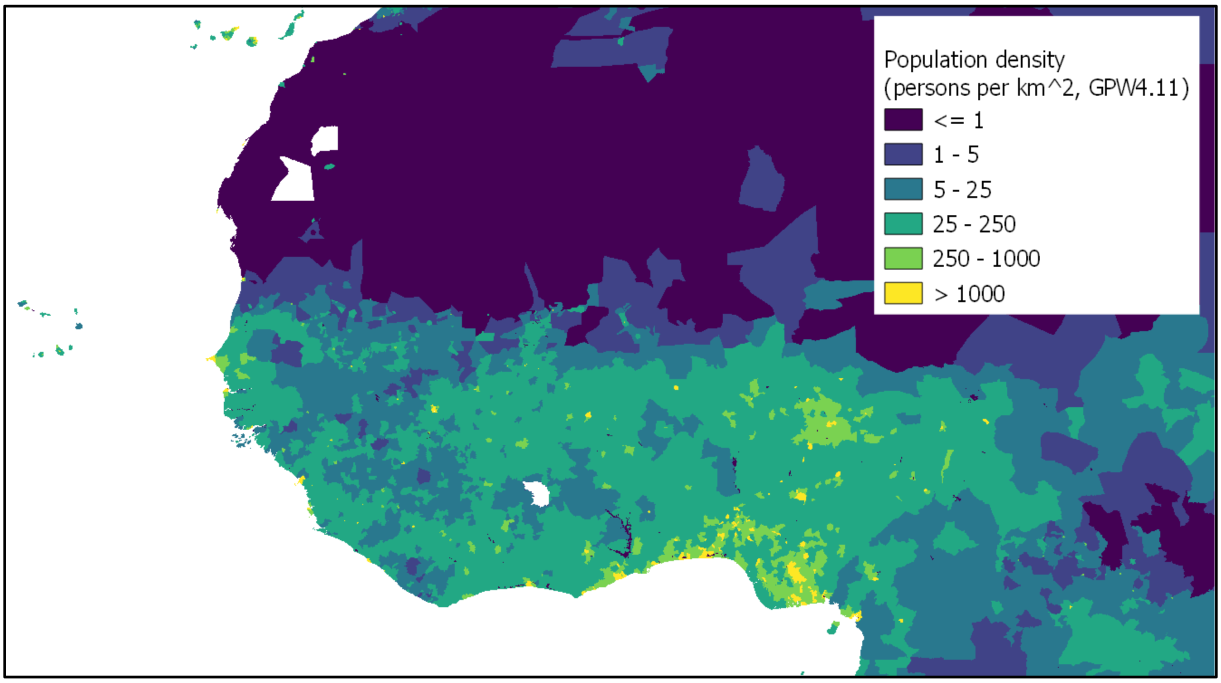

Figure 8: Population density in West Africa

4. Alert level methods

4.1. Alert level based on return period

A common approach to produce hydrological alerts is to compare forecasted river flow with predefined alert thresholds (Figure 9). The thresholds can be defined as flow magnitudes with varying statistical return periods (RP), based on long historical observations or simulations of extreme events. The quantification of floods gives a reference to judge the severity of a particular situation (e.g. a reference to trigger forecasts alerts). The magnitude of extreme events is related to their frequency of occurrence. The theoretical definition of return period is the inverse of the probability that an event will be exceeded in a given year.

To better understand peak flows in the basin, we here employed an extreme value analysis based on the Generalized Extreme Value distribution (GEV; Coles, 2001). In each sub-basin, the GEV was fitted to time-series of annual maximum discharge (AMAX, derived from daily discharge) by maximum-likelihood optimization of the three GEV parameters. The resulting statistical models of the annual maxima were subsequently used to derive potential peak flow magnitudes with a 10, 30, 50, and 100-year return period (statistical recurrence interval).

The service has been developed with the possibility for each user to define the return periods corresponding to alert level 1, 2 and 3 (for example 2 years, 5 years and 30 years). Thus for each

watershed, the discharge corresponding to each return period are calculated. The level of alert corresponding to each sub-basin for a given forecast will be 0, 1, 2 or 3 depending on whether the forecast is lower than the flow corresponding to the first return period, between the first return period and the second return period, or between the second and third return period or greater than the third return period (Figure 9).
For the definition of this alert threshold, two types of time series were used: the simulations of the HYPE models and the historical data observed.

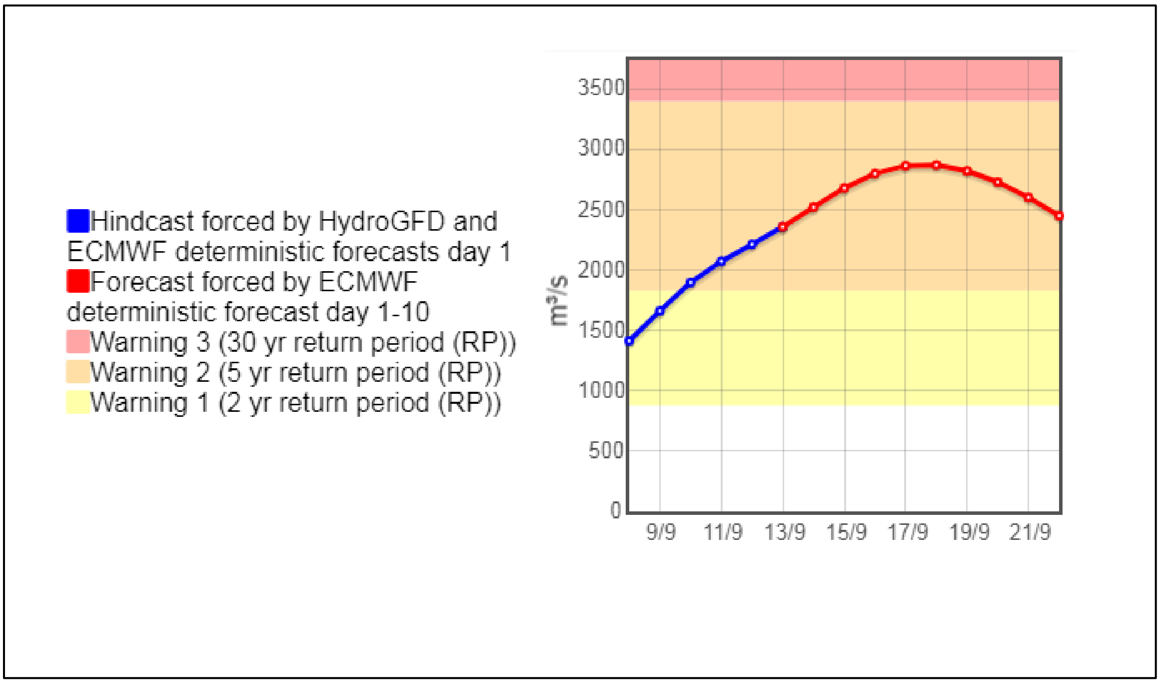

Figure 9: Definition of alert levels according to return periods

4.2. Alert levels based on percentage of selected historic years

National hydrological services have monitoring networks for water resources. At some stations, water levels during flood events are known. For example, the floods that occurred in Niamey in 2012, 2013 and 2016 correspond to flows observed at the Niamey station above 2130 m^3/s (Figure 10). On this basis, it is possible to define flood alert thresholds based on the percentage (80, 90 and 100 % for example) of a selected historic years (e.g. 2012 or the highest on record). These analyzes can be done by considering the (a) historical data resulting from the observations or (b) those resulting from the simulations of HYPE. The first option suffers from systematic bias of the model. Here we use the quantile-mapping bias adjustment method to minimize this bias.

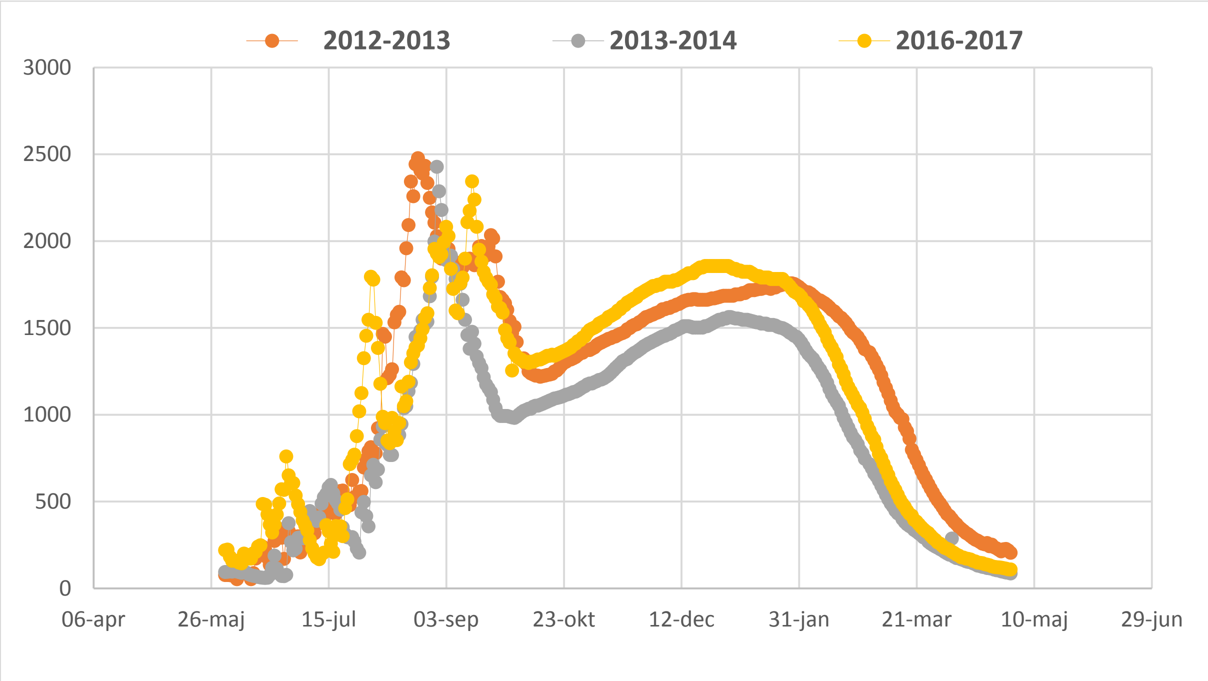

Figure 10: Hydrographs of flood years at Niamey station

The quantile mapping method (Teutschbein and Seibert, 2013) is used to bias adjust data. The bias adjustment consists to quantify the bias of the simulated discharge, assuming the model data to be accurate. The idea of quantile-mapping is to adjust the distribution function of the simulated discharge to agree better with the station data distribution function. If F_{SIM} is the Cumulative Distribution Function (CDF) of simulated discharge X_{SIM} at a given station during the historical time period, and F_{OBS} for the CDF of the same variable X_{OBS} from the hydrological model, for the same time period, the quantile mapping method aimed to match the distribution function of the simulated data with the station data.

$$F_{SIM}(X_{SIM}) = F_{OBS}(X_{OBS})$$

The adjusted value X_{bc} can be obtained empirically from:

$$X_{bc} = F_{OBS}^{-1}\left(F_{SIM}(X_{SIM})\right)$$

Where F_{OBS}^{-1}, defined from [0, 1], is the inverse function (quantile function) of F_{OBS}.

The Figure 11 represents the quantile-quantile plot between the outputs of the observed discharge and the simulated discharge before and after adjustment at Niamey hydrometric station.
The Figure 12 compares the observed discharge, simulated-adjusted discharge and simulated non-adjusted discharge at Niamey over the historical period.
Once the historical data has been adjusted, based on the date of the forecasts, the historical year chosen and the percentages defined by the user, the service defines the alert thresholds as follows:

- Choice of the historical period to be considered for comparison: if DD is forecast day, MM is forecast month and YYYY is the selected historical year, the historical time series is YYYMMDD-15 days to YYYMMDD + 15 days;

- The maximum discharge for this period is retained as the reference discharge. If the user-defined percentage is 80, 90, and 100%, the discharge values corresponding to the alert threshold will be 80, 90, and 100% of the maximum flows;
- Alert levels 0, 1, 2 and 3 are thus defined according to these calculated discharge thresholds.

For example, if the forecast issue date is 1st September 2012, the value to be considered for calculating the discharge corresponding to the thresholds is observed between 17th August and 16th September 2012. Taking the example on the Niamey station, this value maximum is 2477 m^3/s as shown in the Figure 13. It was observed on 22nd August 2012.

The discharge values corresponding to the alert threshold will be 80, 90, and 100% are then respectively 1982, 2229 and 2477 m^3/s. The daily forecasted discharged for the next 10 days are thus compared to these values to define the alert thresholds.

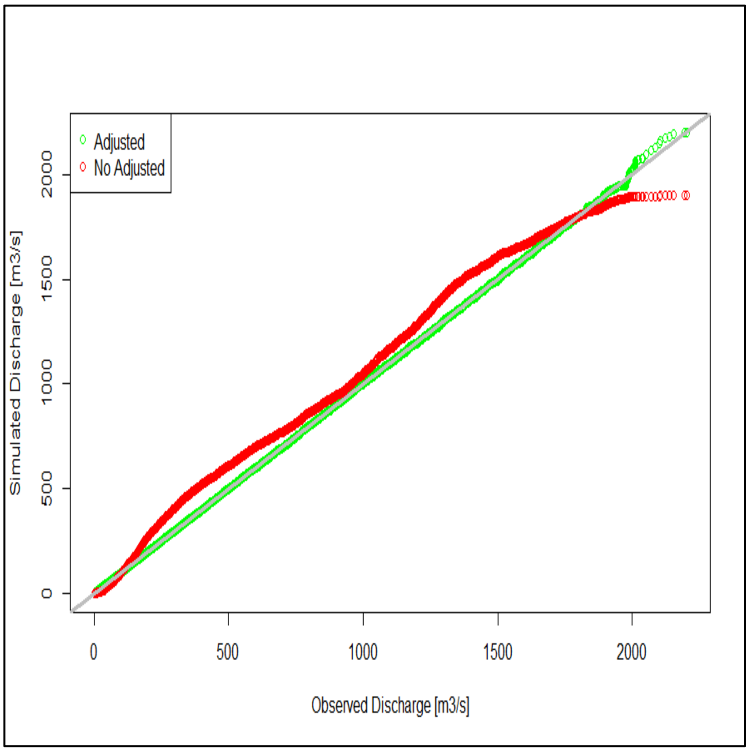

Figure 11: Q-Q Plot between observed discharge and simulated (with Niger-HYPE) discharge at Niamey, Niger.

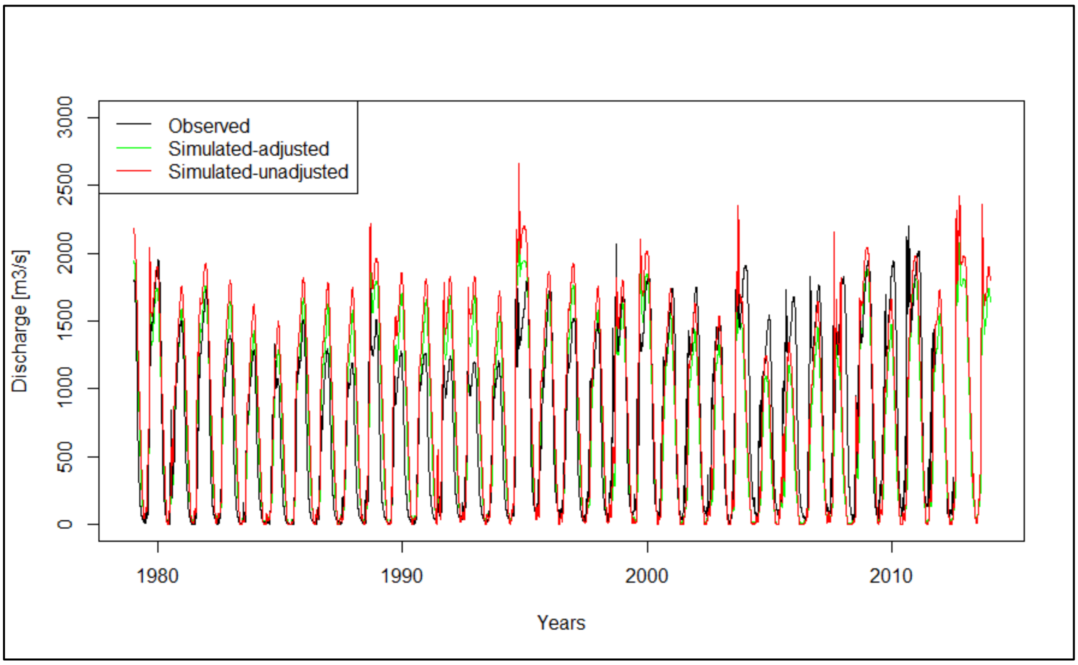

Figure 12: Observed, adjusted and unadjusted discharge in Niamey

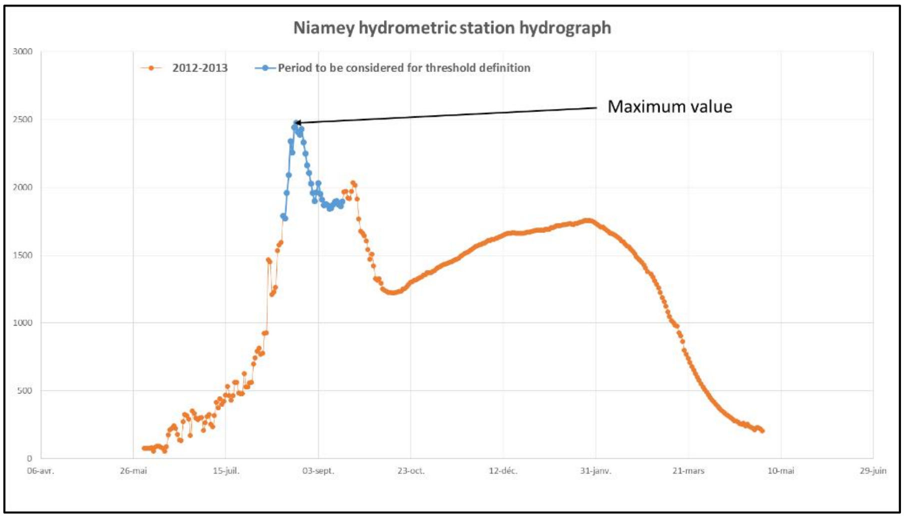

Figure 13: Choice of the maximum discharge for the calculation of the threshold discharge

4.3. Alert levels based on local threshold

The post-processing service has been designed to also offer the user the possibility of integrating his or her own alert threshold on the basis of which the alert maps could be generated. To do this the forecasts are first adjusted using the quantile-quantile method to fit the observed data. This adjusted data is then compared to the user-defined threshold for setting alert levels. If, for example, the user defined warning threshold is 1200m^3/s, the daily forecasted discharged for the next 10 days are first adjusted by the quantile-quantile method described above and thus compared with this value of 1200m^3/s. The Figure 14 illustrates how the alert levels are defined according to the threshold defined by the user.

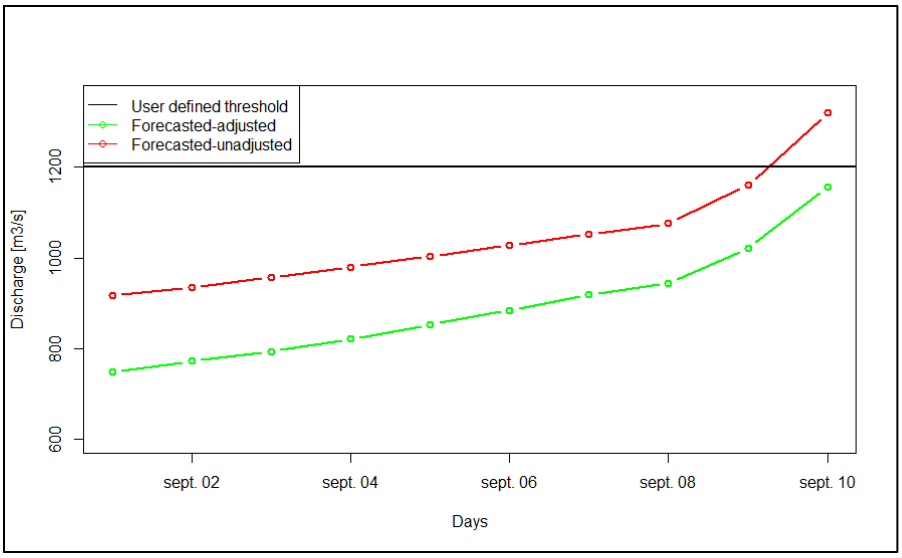

Figure 14: Determination of alert levels.

4.4. Water Levels

The FANFAR system takes into account water level data (in situ and satellite). The hydrological models (Niger-HYPE and World-Wide HYPE) used in the FANFAR system provide data related to rivers flows. A rating curve would then translate these flows into water levels into used to produce flood maps based on predefined thresholds (Figure 15). A rating curve is a graph of discharge versus stage for a given point on a stream, usually at gauging stations, where the stream discharge is measured across the stream channel with a flow meter. This involves an inventory to identify for each hydrometric station that has a rating curve, the water levels corresponding to different levels of alert.

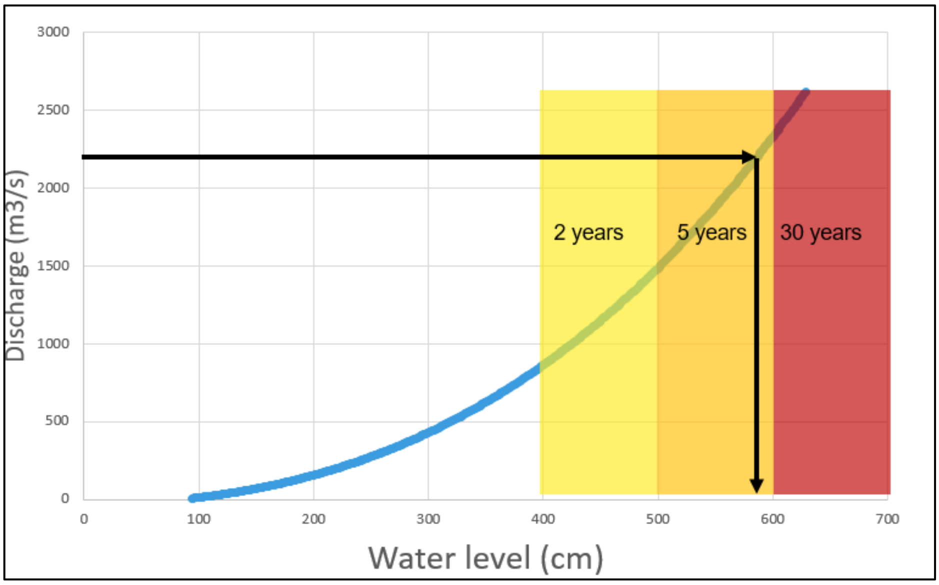

Figure 15: Relationship between streamflow and water level curve illustration

4.5. Alert levels based on the West African Flash Flood Index (WAFFI)

The definition of alert thresholds by this method only concerns the "precipitation" variable. The comparison of rainfall amounts, with thresholds could be used in detecting flash floods. A modified version of the European Precipitation Climatology Index (EPIC) proposed by (Alfieri and Thielen, 2015) for extreme rain storm and flash flood early warning is used. Modification to the EPIC included the monthly calculation instead of yearly values in EPIC. Thus, the West African Flash Flood Index (WAFFI) can be given by the following equation:

$$WAFFI = \frac{P_i}{\frac{\sum_{j=1}^{N} Max(P_i)}{N}}$$

P_i indicates the daily rain rate using the corrected precipitation data for the current forecast day, and N is the number of years with available historic precipitation data (1979-2018). The denominator is the monthly average of the maximum daily rainfall found in historic precipitation data. Monthly values of the denominator are based on daily time step for 40-year historic data sub-basin by sub-basin inside West Africa HYPE.

5. Information produced by the service

5.1. Alert information for each variable

For the considered variables (precipitation, discharge, runoff, water level), the following information is produced. The illustrations are given by the tables and figures below.

- List of the alert level thresholds for each sub-basin. The Table 2 below gives an example of the alert thresholds defined for flows, based on the return period method.

Table 2: Alert level thresholds based on return periods.

SUBID	RP2	RP5	RP30
200012	181.62	279.31	400.63
200023	16.67	25.09	36.78
200031	46.18	63.42	84.51
200034	33.73	45.97	62.82
205784	37.66	57.55	100.65
211592	118.23	177.80	305.98
200035	225.88	336.72	576.80
200040	8.69	16.34	39.53
200056	41.80	61.11	94.02
200058	75.63	112.11	175.83
200441	0.00	0.02	0.17
201773	0.00	0.01	0.11
201771	0.00	0.01	0.10
201766	0.00	0.01	0.09
200066	21.56	29.48	40.15

210484	38.14	59.43	93.18
210266	34.64	61.09	112.59
210919	59.80	105.71	197.92
208260	111.98	199.49	375.51
205851	186.54	319.72	577.99
210066	22.81	35.70	56.22
200068	352.88	580.45	990.32
200073	25.41	45.36	89.51
200077	36.03	46.81	57.34
200079	9.70	13.15	18.30

- Current alert level for each sub-basin. The example is illustrated by the Table 3.

Table 3: Current alert level for each subbasin

SUBID	AlertLevel_day1	AlertLevel_day2	…	AlertLevel_day10	AlertLevel_max10
200004	0	0		2	2
200012	0	0		2	2
214517	0	0		2	2
215451	0	0		2	2
200019	0	0		2	2
200023	0	0		2	2
200031	0	0		2	2
200034	0	0		2	2
205784	0	0		2	2
205467	1	1		2	2
205468	1	1		2	2
208780	1	1		1	1
213671	1	1		1	1
214846	1	1		1	1
200036	1	1		1	1
200072	1	1		0	1
205057	2	2		0	2
213566	2	2		1	2
214974	2	2		2	2
212621	2	2		3	3
203280	2	2		3	3
203065	2	2		3	3
215400	2	2		2	2
213115	2	2		1	2
210562	2	2		0	2
201931	3	3		1	3

204990	3	3		1	3
201836	3	3		1	3
202207	3	3		1	3
201519	3	3		1	3
206211	3	3		1	3
204465	3	3		1	3
213172	3	3		0	3
217015	3	3		0	3
216699	3	3		0	3
213508	3	3		0	3

- Map (PNG) showing the maximum alert level in each sub-basin for the coming 5 days. These maps take into account the spatial entity considered by the user. This can be the country, the flood prone area or the entire area covered by the model (Figure 16, Figure 17).

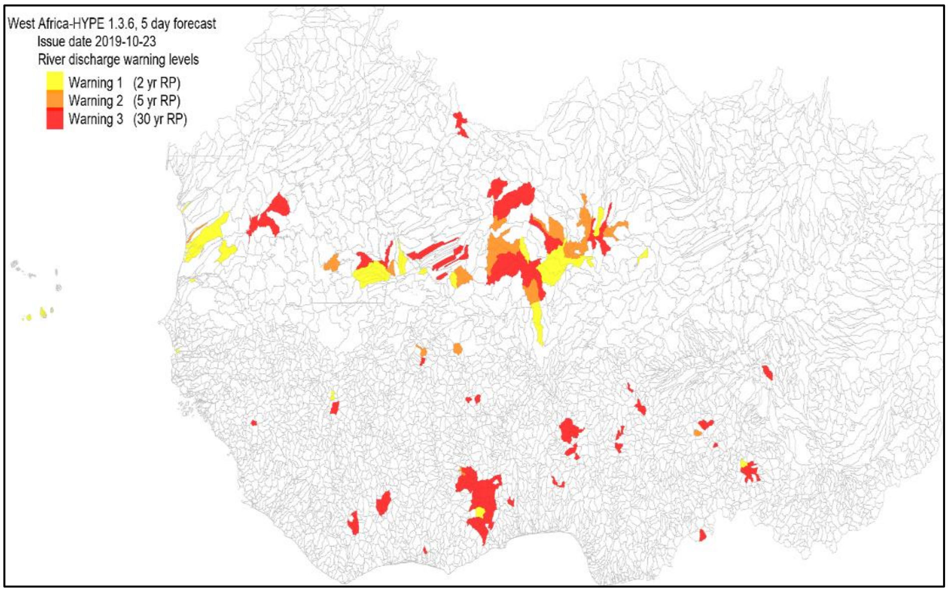

Figure 16: Flood hazard alert map for West Africa

Figure 17: Flood hazard alert map for selected flood-prone areas

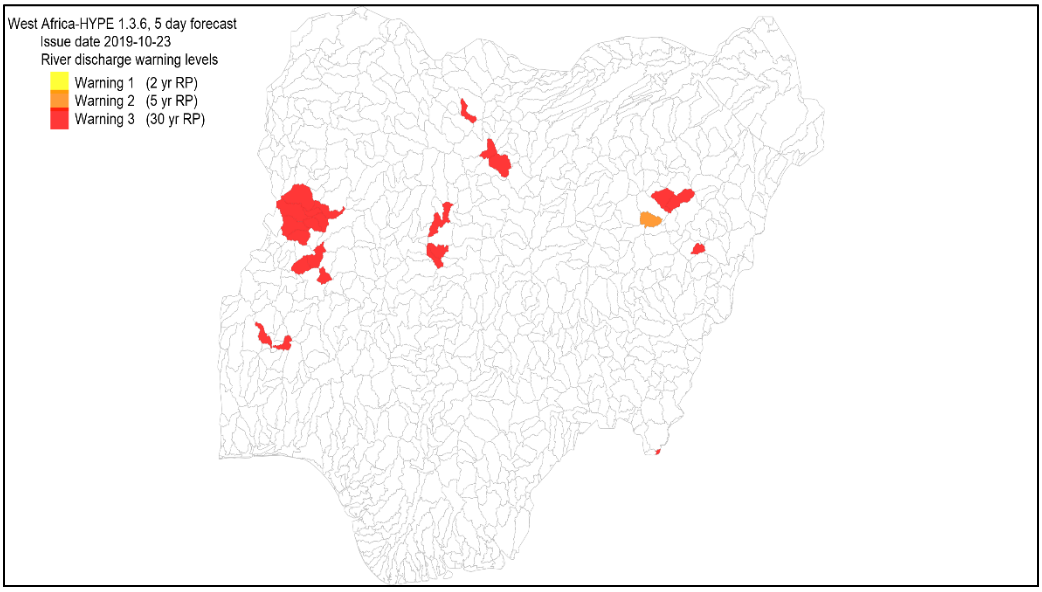

Figure 18: Flood hazard alert map for Nigeria

5.2. Trigger for SMS and email

The post-processing service calculates trigger for SMS and email notifications. For the moment, the n otifications are triggered if more than 10% of subbasins are at or above Alert level 2 or if any sub-basi ns are at or above Alert level 3.

On this basis, the service prepares the files necessary for the alert. It is:

- a file named "_send_messages.txt", indicating that the alert messages must be sent;
- a file called "_adresse_email&message.txt", containing the addresses (phone and email) of th e persons to whom the messages must be sent;
- a file called "_sms_message.txt" containing the messages to be sent by SMS;
- a file called "_email_message.txt "containing the messages to be sent by email.

The template of the email and SMS messages are show by Figures 19 to 22. The languages of the mes sages take into account the recipient.

_send_messages.txt _email_message.txt _sms_message.txt _adresse_email&message.txt

```
This is an automated message triggered by the FANFAR forecasting service.
The forecast issued YYYYMMDD for the model NigerHYPE_2.23 has triggered a risk notification:
XX subbasins=>risk 2 for streamflow
YY subbasins=risk 3 for streamflow
Link:
Kind regards, the FANFAR forecasting team.
```

Figure 19: Forecast and alert email template in English

```
Ceci est un message automatisé déclenché par le service de prévisions FANFAR.
La prévision publiée YYYYMMDD pour le modèle ZZZ a déclenché une notification de risque:
XX sous-bassins => risque 2 pour le débit
YY sous-bassins = risque 3 pour le débit
Lien:
Cordialement, l'équipe de prévision de FANFAR.
```

Figure 20: Forecast and alert email template in French

```
Model:NigerHYPE_2.23
XX subbasins=>risk 2.
YY subbasins=risk 3.
Link:
```

Figure 21: Forecast and alert SMS template in English

```
Modèle: NigerHYPE_2.23
XX sous-bassins => risque 2.
YY sous-bassins = risque 3.
Lien:
```

Figure 22: Forecast and alert SMS template in French

Conclusion

The post-processing service has been designed and the main prioritized functionalities have been developed. It is currently at the stage of being executed in local mode. The next step will be to deploy it on the Hydrology-TEP platform for interactive and automated application.

References

Alfieri, L. and Thielen, J. (2015) ‘A European precipitation index for extreme rain-storm and flash flood early warning’, 13(June 2012), pp. 3–13. doi: 10.1002/met.1328.

Teutschbein, C. and Seibert, J. (2013) ‘Is bias correction of regional climate model (RCM) simulations possible for non-stationary conditions ?’, pp. 5061–5077. doi: 10.5194/hess-17-5061-2013.