REPUBLIC OF GHANA

MINISTRY OF WORKS AND HOUSING

GREATER ACCRA RESILIENT AND INTEGRATED DEVELOPMENT PROJECT

Terms of Reference

Development and Installation of Flood Forecasting Models and the implementation of a Flood Early Warning System for Greater Accra (FEWS-Accra)

PROJECT COORDINATION UNIT

July 2022

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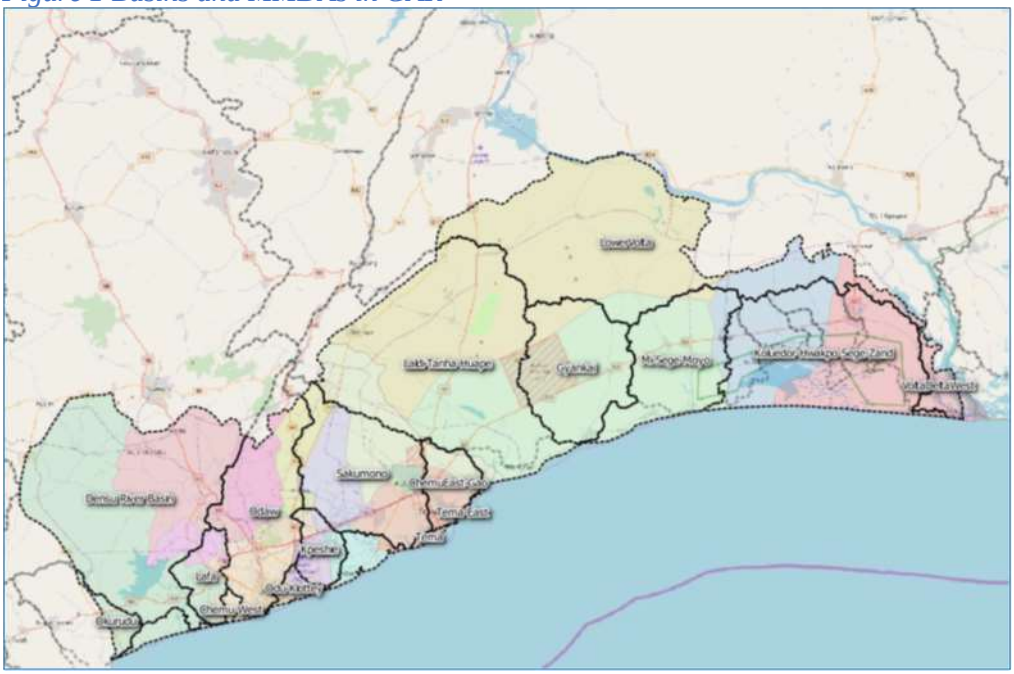
1 Background

Severe floods frequently affect the Greater Accra Region (GAR), including (and most prominently) the floods of June 3, 2015, which affected 52,622 people according to reports from the National Disaster Management Organization (NADMO). Floods have become a frequent phenomenon in the Greater Accra Region, compelling multiple responsible entities at national, regional, and municipal level to investigate the structural and institutional causes of floods, as well as ways to structurally address their underlying causes.

The Greater Accra Region (GAR) is one of Ghana's 16 Regions. It is subdivided into 29 Metropolitan, Municipal and District Assemblies (MMDAs). The hydrological basins[1] of the GAR are presented in Figure 1.

Figure 1 Basins and MMDAs in GAR



The infiltration capacities of the basin surfaces have changed drastically in recent decades. This is due to rapid expansion of the city, creating nearly impervious conditions with high runoff coefficients and continuously reducing retention capacity. Planned city developments will likely further reduce this infiltration capacity in the future. Furthermore, the drains are commonly used as garbage dumps/ collectors and, together with siltation, choke the channels, further reducing the discharge capacities as maintenance is generally lacking. Finally, most of the lagoon outlets to the sea are silted. The actual storage and drainage capacity is therefore insufficient to adequately drain stormwater and flooding has become a perennial phenomenon in large parts of the GAR.

The Government of Ghana is committed to addressing the flooding challenge in GAR, and that requires an integrated approach, including drainage improvements, flood forecasting, solid waste management, improved urban planning and support to informal settlements. The Government of Ghana has therefore received funds from the World Bank through IDA financing of US$ 200 million to support resilient, clean, and inclusive development in GAR through the Greater Accra Resilient and Integrated Development Project (GARID).

[1] Odaw, Densu-Delta, Kpeshie, Osu-Klottey, Sakumono, Okurudu, Lafa, Chemu-East-Gao, Tema, Chemu-West, Laldi-Tanha-Huape, Songo-Mokwe, Tema-East, Mi-Sege-Moyo, Lower Volta, Gyankai, Volta-Delta-West, Densu River Basin, Koluedor-Hwakpo-Sege-Zand.

2 Introduction to GARID

The proposed Project Development Objective (PDO) of the Greater Accra Resilient and Integrated Development Project (GARID) is to improve flood risk management and solid waste management in the Odaw River Basin of the Greater Accra Region and improve access to basic infrastructure and services in the targeted communities within the Basin.

2.1 Components of GARID

The project is designed around five components:

- Component 1: Climate Resilient Drainage and Flood Mitigation Measures
- Component 2: Solid Waste Management Capacity Improvements
- Component 3: Participatory Upgrading of Targeted Flood Prone Low-income Communities, and Local Government Support
- Component 4: Project Management and Planning for Next Phase
- Component 5: Contingent Emergency Response Component (CERC)

Under Component 1, two sub-components are foreseen (i) Structural interventions on drainage improvements and flood management within the Odaw basin and (ii) Improvement of flood warning and response capacity. This tender is part of the flood early warning system for greater Accra under sub-component 1.2, herewith referred to as "FEWS Accra".

In recent years Ghana has made some progress with the forecasting of floods and extreme weather events. The Hydrological Services Department (HSD) with the support of Ghana Meteorological Agency (GMet), Water Resources Commission (WRC) and National Disaster Management Organisation (NADMO) is currently conducting forecasts of water levels in the Volta basin (FEWS Volta and FEWS Oti) using Delft-FEWS applications. NADMO has established an Emergency Operations Centre at its headquarters and has early warning applications for ten districts in Ghana. The current setup of the Emergency Operations Center (EOC) of NADMO integrates the different forecast information for NADMO's actions and operations.

The government of Ghana is committed to further enhance the protection against floods in GAR by implementing a Flood Early Warning System (FEWS).

2.2 Outline of sub-component 1.2: "FEWS ACCRA"

The overall development and implementation of FEWS Accra is divided into two different parts: Part A and Part B. Part A is the currently ongoing assignment for the design and supervision of FEWS Accra. Part B is the detailed design, development, implementation, operation and maintenance, specific training/capacity building of stakeholders, and hand-over of FEWS Accra, including the procurement and installation of equipment and training. Part B is subdivided into four topics:

1. Meteorological equipment, including a rainfall radar
2. Hydrological equipment
3. Model development and Early Warning System
4. Communication & Dissemination

This request for proposal presents the assignment for the third and fourth topic, model development and Early Warning Systems and Communication & Dissemination. It is planned that in 2022 the first two projects are implemented resulting in enhanced meteorological observation (with Automatic Weather Stations, X-Band radar and disdrometers) and enhanced hydrological observations (with about 24 updated hydrological stations in 2022).

2.3 Stakeholders and project organization

Under the overall project coordination mechanism of the Greater Accra Resilient and Integrated Development Project (GARID), a technical working group of MWH, HSD, WRC, GMET, NADMO, MMDAs and other nominated ministries, departments and agencies has been created to support the coordination of activities under component 1.2 Strengthening Flood Management. The provider of the services shall work in close collaboration with this technical working group and under the overall coordination of the Project Coordination Unit (PCU), currently hosted by MWH. A steering committee for FEWS Accra, dedicated to this assignment and comprising of the technical working group, delegates from the respective MMDAs, the PIU and other relevant invited stakeholders will support the coordination of the assignment. More specifically, the steering committee for FEWS Accra would meet during project implementation when deemed necessary to discuss and review the work plan, deliverables and technical reports of the Consultant to ensure the technical quality of the assignment. The steering committee will formally review all deliverables and may be supported by dedicated technical experts in this process.

For this assignment GMet, HSD, NAMDO, WRC and the Metropolitan, Municipal and District Assemblies (MMDAs) are key beneficiaries.

These institutions are involved in operational flood forecasting, early warning and flood disaster management. Table 1 shows their tasks and responsibilities with respect to flood forecasting, early warning and response. The table also shows the components of FEWS Accra (detection, forecast, warning and response) in which the institutions are involved. GMET and HSD are respectively responsible for meteorological and hydrological observations and forecasts. The warnings and alerts produced by FEWS Accra are made available to the NADMO offices at the relevant levels (national, regional, district and zonal level) for the relevant areas. The information is disseminated from the NADMO zonal office to local communities. Through the EOCs other agencies are informed (e.g. fire and police departments, etc.). This procedure is described in the National Standard Operational Procedures for Emergency Response (NSOP). The following chapter describes the current alert response system in more detail.

2.4 Establishment of the Accra-FEWS Centre

Currently, an MOU is being developed to commit all the participating institutions to establish a specialized unit to be known and called Accra-FEWS Centre (AFC). The team shall comprise the following:

- One Senior Staff with Managerial Responsibilities from each implementing institutions (HSD, GMET and NADMO), so 3 in total
- Two Junior Staff with good technical background from each implementing institutions (HSD, GMET and NADMO) and trainable in their area of expertise, so 6 in total
- WRC in conjunction with GARID PCU will continue to coordinate the implementation of FEWS-Accra, so 2 in total.

The AFC will consist of 11 staff members, those with managerial responsibility are assigned part time, the junior staff members full time.

The AFC will be stationed at the offices of HSD.

The consultant will work on a daily basis with the staff members of the AFC. AFC staff will support the consultant in the development of the models and related tools. The consultant will train the staff on the job in the development and maintenance of these models and tools. Final responsibility for the results is with the Consultant.

Table 1 stakeholders and their tasks

Institution	Component of FEWS	Tasks/responsibility
AFC	All components	Integrate all the tasks and responsibilities of GMET. HSD and NADMO
GMET	*Monitoring* *Forecast*	*provide meteorological observations;* *assess quality of meteorological observations;* *interpretation of meteorological observations;* *make meteorological forecasts;* *assess quality of meteorological forecasts;* *interpretation of meteorological forecasts;*
HSD	*Monitoring* *Forecast*	*provide hydrological observations;* *assess quality of hydrological observations;* *interpretation of hydrological observations;* *make hydrological forecasts;* *assess quality of hydrological forecasts;* *interpretation of hydrological forecasts;*
NADMO	*Dissemination* *Response*	*crisis information management;* *alert dissemination;* *response coordination;*
WRC	*No operational role in FEWS Accra*	*link with policy and legal embedding;* *manage cross-border information exchange;*
MMDAs	*Dissemination* *Response*	*issuance of early warning messages;* *preparedness, response, and recovery actions;*

2.5 Characteristics of flood risk in the basins in GAR

GAR is impacted by 19 basins (partly upstream and partly within GAR), with all different flood risk characteristics in terms of impact as well as hydrology. Basins with high flood risk require more detail in the models that are used for forecasting, and thus justify efforts (e.g. surveys) necessary for model development and accurate forecasts. This type of forecasting is also known as impact-based forecasting.

Lag times between heavy rainfall and floods also differ. For basins with long lag times (in the magnitude of a day or more), a detailed hydrologic and hydraulic model can be applied to forecast the flood levels and the exact timing of the flood. Less accuracy is necessary for the rainfall forecasting, since ample time is available and ground measurements of rainfall can serve as input for the models. For basins with small lag times (flash floods) in the magnitude of one to several hours, the focus must be on an accurate forecast and nowcast of the rainfall. In this situation, ground measurements of rainfall and hydraulic and hydrologic models are not useful for forecasting since the crisis management organisation will need to react immediately to a heavy rainfall threat even when the precipitation has not yet manifested on the ground. The available time to react to measured high rainfall or high-water levels on the ground is simply too short to make the response effective.

Table 2 shows the calculated flood risk and lag times. The values in this table follow from earlier analysis. From the table it appears that the lag times of the basins in the GAR are (in general) short, emphasizing the flash nature of the floods. Odaw basin shows the highest flood risk, followed by the other basins that are situated in the urban area of Accra.

Table 2 Lag times and flood risks of basins in GAR.

Basin	Area in GAR (km^2)	Area Total (km^2)	Lag time (hours)	Risk ($/yr)	Area Risk (1000$/yr-km2)
Odaw	246	273	5	47,236,863	192.0
Densu-Delta	56	56	2**	1,951,074	34.8
Kpeshie	55	55	2	1,307,908	23.8
Osu-Klottey	19	19	1	587,275	30.9
Sakumono	276	283	4	1,845,819	6.7
Okurudu*	27	137	12	576,261	21.3
Lafa	65	65	2	808,062	12.4
Chemu-East-Gao	69	69	2	821,239	11.9
Tema	6	6	1	111,583	18.6
Chemu-West	12	12	1	149,220	12.4
Laldi-Tanha-Huape	666	697	7	867,088	1.3
Songo-Mokwe	36	36	1	187,420	5.2
Tema-East	2	2	1	496	0.2
Mi-Sege-Moyo	233	233	4	20,598	0.1
LowerVolta*	624	5,256	7	43,164	0.1
Gyankai	240	240	5	14,608	0.1
VoltaDeltaWest	36	36	1	0	0.0
Densu River Basin*	614	2,567	x	3,055,034	5.0
Koluedor-Hwakpo-Sege-Zand	425	425	14	95,468	0.2

The basin highlighted in red shows the highest flood risk, followed by orange and yellow, as a combined ranking of the total risk and the relative risk.

Notes:

** The risks calculated for Densu river basin upstream of the Weija dam, Okurudu and Lower Volta are considered less accurate and therefore highlighted in grey.*

** The lag time in Densu basin is calculated as the travel time of a flood wave resulting from spilling of Weija dam to the outlet into the sea. The spilling itself is normally known a few days ahead.

2.6 This project: FEWS Accra

FEWS Accra will support and facilitate the process from detection (“Rainfall is measured or expected”) to response (“How to act on an expected flood”). This process is divided into four components.

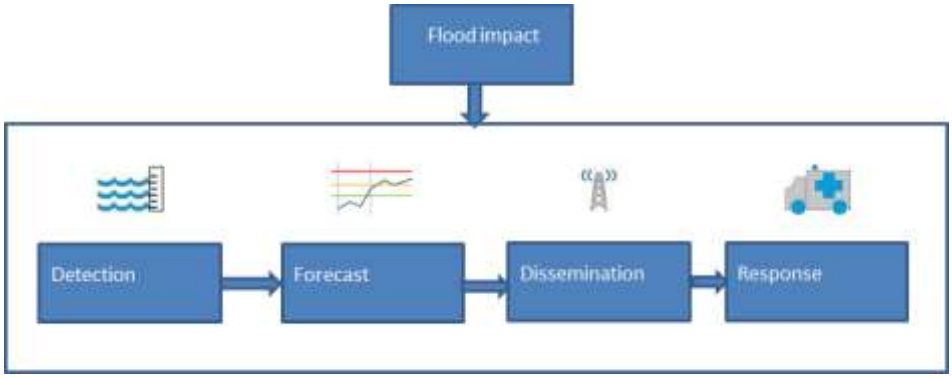


Figure 2: Components of flood early warning and response system.

FEWS Accra will run the collection of information and dissemination of warnings automatically. All the information (input and processed data, hydrological and meteorological, model results and warnings) shall be visualised on a workstation and/or web interface. The four components in this process are:

1. Detection

In general, meteorological data is essential to make forecasts. The following data aspects are important for a FEWS system 1) the data should be informative about flooding, 2) the data should be sufficiently accurate, and 3) the data should be available in near-real time. Detection data includes data from weather stations, gauges in GAR, satellite and radar data and nowcast for rainfall. Parallel to this project, two projects are implemented where the hydrological network as well as the meteorological network is updated. An outline of these updated systems is described in Annex B and C.

2. Forecasting

Relevant data collected in the detection component must be translated into information that provides flood indicators. This translation requires knowledge on local flood mechanisms and hydrological and/or hydraulic models. Flood indicators are translated to warnings by relating them to vulnerability to floods; this results in impact-based forecasts. Hydrological and hydraulic models shall be developed in the projects, and a system shall be developed that support the automation of this process.

3. Dissemination

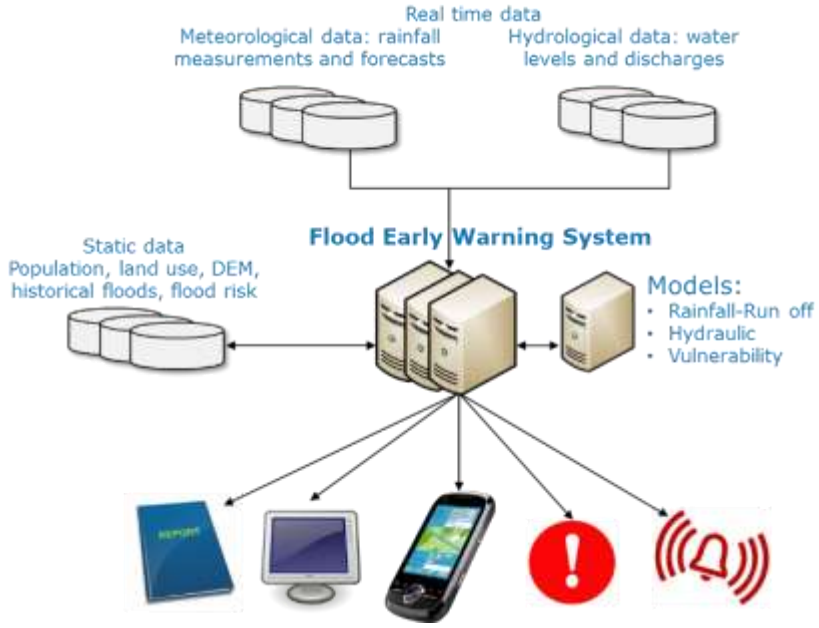
The FEWS Accra should not only forecast a flood threat, it should also provide a flood warning. Threshold values for flood indicators ensure that timely warning for different severity levels of floods can be generated. The warnings are visible in the user interface of the workstation and/or web interface. Warning messages should be disseminated to a selected group of stakeholders including public authorities, companies, and the public.

4. Response

The crisis team can decide how to act and who needs to be informed based on the measurements and observations, forecasts, warnings, and the static ‘background’ information (such as land use, population, historical floods, and flood risk), all of which should be available in the FEWS. The response can be considered the most important aspect of the early warning process as it concerns actions that lead to a reduction of casualties and damages resulting from a (forecasted) disaster. Stakeholders shall be warned by the operational communication networks using the information from the monitoring and warning system.

This project focusses on Component 2 and 3. *Figure 3* shows a general setup of elements that are part of a FEWS.

Figure 3: General overview of the real time monitoring and operation system for flood forecasting



3 FEWS Accra

3.1 Objectives of the assignment

The overall objective of this assignment is to setup FEWS-Accra Centre, operate and maintain, train and build the capacity of stakeholders, and hand-over of FEWS Accra.

FEWS-Accra is envisaged to be an end-to-end approach from improving weather and climate forecasting, to appropriate forecasting models, to strengthened responses and community actions for Greater Accra (see Figure 1), FEWS Accra will consist of the following four building blocks:

a. System development and implementation, including modelling, information dissemination and capacity building:
   i. Flood risk assessment and early warning system for basins in Greater Accra, including a dynamic hydrological-hydraulic model for basins in Greater Accra and its drainage network;
   ii. Conducting adequate topography and bathymetry surveys in all basins of greater Accra with the aim to support the development of the hydrological – hydraulic model;
b. Development and implementation of early warning dissemination systems;
   i. Dissemination of information and communication with affected communities, including communication and outreach campaign to communities at risk and clear and usable warning; ensuring that people understand warning.
   ii. Strengthening response and preparedness, including contingency plans updated at Metropolitan, Municipal and District Assemblies (MMDAs) and community levels, as well as strengthening the emergency response capacity of NADMO and central and MMDA level.

3.2 Activities

The project starts with a kick off work shop in the inception phase. During the inception phase, the consultant will familiarize himself further with the project, the stakeholders, verify the assumptions made in the proposal, assess the available data and, detail their workplan, set up a training schedule, prepare an overview of the available data, describe the selected software, and update the functional design and prepare a technical design of FEWS ACCRA. The consultant will assess the capacity of the staff members of the AFC and will prepare a training plan to enable them to actively participate in all the steps of the development.

Also, the consultant will share their first ideas on the information products that will be developed. The draft inception report will be available 2 months after the star of the project.

Following the inception report, the consultant will start with the modelling activities. The hydrologic models and the corresponding reports are expected in month 5 of the project, the hydraulic models in month 7.

In Month 8 the results of the precalculated relations are made available in draft.

In Month 10, the FEWS system is operational.

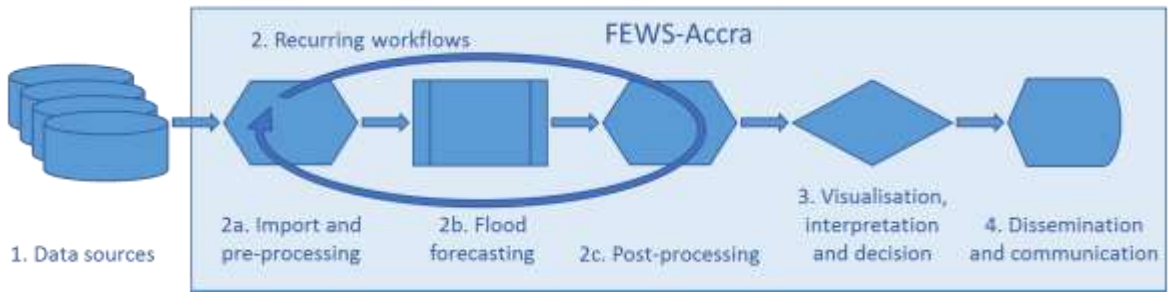
A year after the start of the project, the dissemination tools are available.

In Month 13, a training report is provided, and the project anticipated closing date is in Month 14.

3.3 Introduction

FEWS Accra should be modular, easily scalable, sustainable and impactful. FEWS Accra should be a complete end-to-end solution that facilitates the process from the collection of measurements and forecasts of rainfall and water levels until the dissemination and communication of flood forecasts, warnings and alerts. Figure 4 shows a schematic overview of how these steps shall be implemented in the structure of FEWS Accra.

Figure 4: Schematic overview of the steps from data collection until dissemination and communication.



The schematic steps in the generic process of FEWS Accra contain the following objects and features:

i. Data sources
FEWS Accra shall use static (background) data and dynamic data (grids and timeseries with measurement and forecasts). The static data shall be part of the configuration.

ii. Recurring workflows
The 'engine' of FEWS Accra shall be a workflow engine with recurring scheduled tasks. These tasks include:

a) Import and pre-processing
FEWS Accra shall import data from external data sources. The data shall be validated and corrected

(e.g. gap filling). The data shall be processed to the required spatial and temporal resolution. All data (raw and validated) shall be stored in the database.

b) Flood forecasting
FEWS Accra shall run calculations in four flood forecasting stages (see

c)

d)

e) *Figure 5*). The system shall prepare the input data, start the calculation, and import the model results.

f) Post-processing
The post-processing will transform the results of the calculation into the required format and spatial and temporal resolution: e.g. the water depth shall be calculated.

iii. Visualization, interpretation, and decision
The visualizations and information products shall show the source data, current and forecasted situation, for hydrological as well as meteorological data. To support the interpretation, the information shall be classified using configured thresholds. The visualization supports stakeholders to act on the visualized situation.

iv. Dissemination and communication
Information, forecasts and warnings can be communicated with internal and external stakeholders. FEWS Accra shall include the distribution of automatic and manually generated warnings and alerts.

The stakeholders for the detection and forecasting component are the professional users within primarily GMet, HSD and NADMO.

3.4 Outline of functional design of FEWS Accra

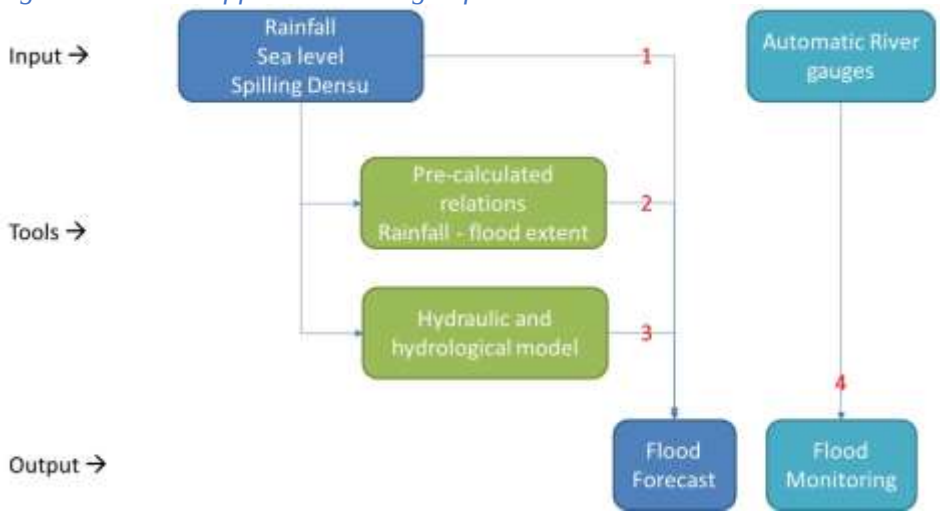
From the flood characteristics of the basins in the GAR as presented in Section 2.5 the following points are of importance for FEWS Accra:

1. For all basins, rainfall radar and satellite observations are necessary for a reliable forecast and nowcast of heavy rainfall to enable effective response. This is in combination with daily rainfall forecasts and automatic weather stations on the ground.
2. Automatic river gauges are very useful for flood monitoring and offline model calibration, but due to short lag times, not always for forecasting.
3. The basins with high flood risk (in the order of 1000$/yr-km2, see *Table 2* in Section 2.5) all have extremely short lag times, except for the Odaw and Sakumuno basins. For these two basins (and for Kpeshie and Lafa) FEWS Accra shall be set up using hydrological and hydraulic models.
4. For all the other basins, short lag times limit the time for hydraulic and hydrologic models to forecast the magnitude of the flood in an operational setting.
5. For all basins (including Odaw, Sakumuno, Kpeshie and Lafa), pre-calculated rainfall - flood extent relations shall be developed as a baseline solution.
6. Those pre-calculated relations shall be derived from calculations with state-of-the-art hydraulic and hydrologic models that need to be developed for all basins of the GAR.

The resulting preliminary outline of the functional design is shown in

Figure 5.

Figure 5: Outline of functional design of FEWS Accra.



FEWS Accra includes four stages of flood monitoring:

1. The rainfall forecast and nowcast, and sea level and Densu spilling forecast.
2. The area at risk determined by the pre-calculated relationships between heavy rainfall and flood extents.
3. Detailing the forecast by applying hydrologic and hydraulic models for the basins with the highest risk and largest lag times (Odaw, and Sakumuno, Kpeshie and Lafa) in the first year and subsequently all other basins within the FEWS-Accra Project Area.
4. Monitoring of the actual flood with automatic river gauges in the basins with the highest risk.

Stage 1 and Stage 2 also serve as a fallback option in case the hydraulic and hydrologic models fail.

3.5 Forecasting stage 1: Detection of Rainfall & Nowcast

See Annex B for a description of the meteorological data that shall be the input for the FEWS Accra.

The detection and nowcast of rainfall for FEWS Accra consists of the following components, which all need to be available in the FEWS:

A. Real-time rainfall observations of the new X-band radar. Latency of the data after processing should not exceed 15 minutes.
B. Real-time rainfall observations of precipitation from telemetric ground stations (disdrometers, rain gauges). Latency of the data after processing should not exceed 15 minutes.
C. Integration of A and B, including correction or continuous calibration of the radar-images with available ground observations using a processing algorithm that includes spatial integration of the identified errors. The processing algorithm needs to adapt to varying availability of ground station data. The integrated data should be available with a latency of at most 30 minutes after observation.
D. Quantitative estimates of precipitation based on Meteosat Second Generation received through the receiver at GMet. These data are available every 15 minutes at approximately 3x3 km resolution with a latency of 45 minutes.
E. Nowcasting. A nowcasting model uses the merged product of C with a latency of maximum 30 minutes to generate a nowcast up to 2 to 4 hours ahead. The nowcasting model needs be suitable for high rainfall amounts and the convective rainfall events. For example, AI based models such as Shi et al. (2017)[2] or equivalent alternatives.

3.6 Forecasting stage 1: Detection of spilling Weija dam and sea levels

Introduction

For flood forecasting, the FEWS system needs (besides rainfall data) the following inputs:

1 forecast and nowcast of spilling of the Weija dam;
2 forecast and nowcast of sea level.

Spilling Weija reservoir

Current situation - monitoring

The water level in the Weija reservoir is monitored by water level gauges; some manual and one electronic. The gauges are visited by an operator of the Ghana Water Company Limited (GWCL) every hour, day- and night-time, during the wet season. In the dry season the water level gauges are visited three times during the day. There is also a water level gauge at the riverbank upstream, close to the Nsawam water treatment plant. This gauge is also visited hourly by an operator of the Ghana Water Company, but only during daytime.

Current situation - forecasting

If water levels are rising in the river at the Nwasam water treatment plant, the GWCL operator communicates this to the head office. The lag time between water levels rising at the Nsawam water treatment plant and the Weija dam is about three to four days. Water levels at the Weija dam usually rise slowly over the course of a week. If water levels are rising and GWCL expects spilling, a warning is disseminated by GWCL to a number of stakeholders including NADMO. This usually happens one or two weeks in advance. The warning is provided to the communities living in flood prone areas downstream of the dam (by letter, TV and radio), NADMO, the assembly member responsible for that area, the Metropolitan, Municipal and District Assemblies (MMDAs), the

[2] Shi, X., Gao, Z., Lausen, L., Wang, H., Yeung, D.-Y., Wong, W.-k., & Woo, W.-c. (2017). Deep Learning for Precipitation Nowcasting - A Benchmark and A New Model. 31st Conference on Neural Information Processing Systems.

police and all other organizations providing flood response. In some cases, the spilling occurs when GWCL does not expect it. In that case, warnings are spread locally as soon as it is noticed.

Functional design FEWS Accra

The forecast and dissemination of the spilling of Weija dam is already functional and effective and requires no enhancement. The Densu basin shall be included in FEWS Accra, which requires the following functionality:

a. Precalculated relations expressing the flood extent downstream of Weija dam as a function of the maximum spilling discharge and sea levels.
b. Transfer of the forecasted spilling discharges into the FEWS Accra. Considering the lag times, the expected spilling discharges can be entered manually and tabularly (time label as hh:dd:mm:yyyy and expected spilling discharge as m^3/s).

Sea level

Current situation - monitoring

GMET has installed a tide gauge at Tema. Data from this gauge shall be made available for the FEWS system.

Current situation - forecasting

In the current situation, the sea levels are not forecasted by HSD or GMET. The following global forecasts of sea levels are available:

1. Tide forecast: https://www.tide-forecast.com/locations/Accra/tides/latest
2. Open data products from NOAA (https://polar.ncep.noaa.gov/waves/ensemble/) and ECMWF (https://www.ecmwf.int/en/forecasts/datasets/set-ii.
3. Open data from the EU Copernicus program (daily forecast of hourly and daily mean data, SSH variable, +10 days forecast), to be found at https://resources.marine.copernicus.eu/products
4. Other open data products.

Functional design

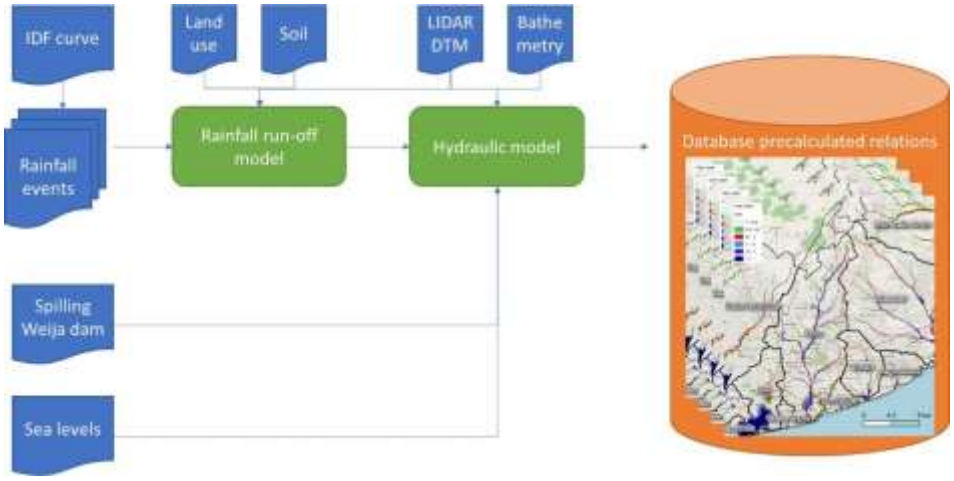
It is recommended that a forecast of the sea levels along the coast of Greater Accra Region be obtained from one of the open data products that is freely available. The forecast horizon should be at least one day ahead. Data needs to be transferred to the FEWS system using a (public domain) API.

3.7 Forecasting stage 2: Modelled precalculated rainfall flood extent relations

Introduction

The precalculated relations consist of a database of calculated flood extents (flood hazard maps) for various design rainfall events and sea level events for all basins except Densu. For Densu basin the rainfall is replaced by the spilling discharge of Weija dam. Reference is made to *Figure 6*.

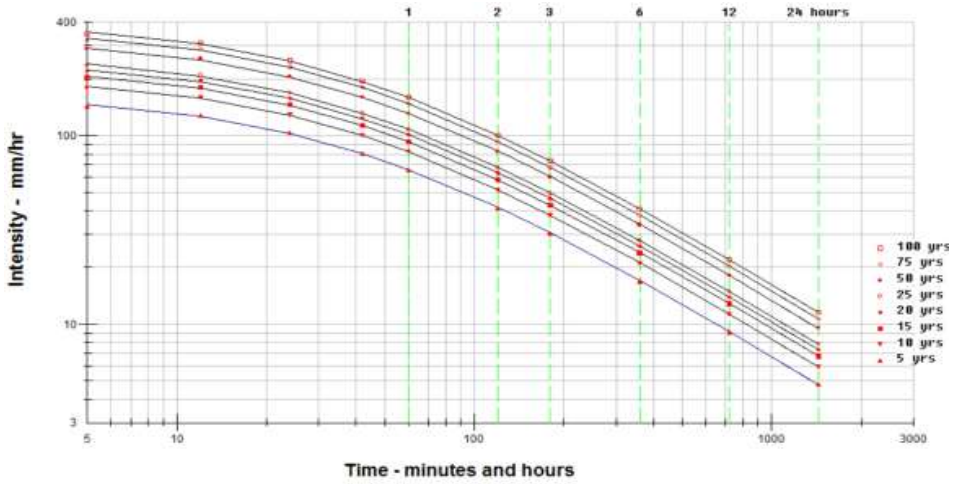
Figure 6: Workflow development of precalculated relations



IDF curves

The most recent official Rainfall Intensity Duration Frequency (IDF) diagrams need to be collected at GMET. The IDF curves that were used to develop the Greater Accra flood Risk Mitigation Strategy in 2019 for derivation of rainfall design events is shown in *Figure 7*.

Figure 7: Intensity Duration Frequency (IDF) curves for rainfall at Accra airport provided by GMET



Defining rainfall events

It is proposed to derive about 14 rainfall events from the IDF curves ranging from 5 minutes to 24 hours (e.g. 1, 2, 4, 6, 12 and 24) hours and with rainfall totals ranging from 5 to 400 mm/hr. A practical approach for this is the alternating block method. The rainfall events need to be scaled to the size of the river basins, applying an appropriate areal reduction factor on top of the rainfall totals from the IDF curves.

Collection of data for model development

The following data needs to be collected:

1. Rainfall data of GAR (especially Odaw Basin) to enable model calibration on the observed flood of June 3rd, 2015 in Odaw basin. This data is to be collected from GMET.
2. Hydrological data in the Greater Accra Region for calibration and validation of the flood models. It is noted that this data is not available at HSD. Some data may be available at the University of Ghana and Water Research Institute (WRI). The Client will assist the consultant to obtain this data, however its availability and accuracy is not guaranteed by the Client.
3. Other hydrological data for calibration or validation:
    - Field assessment report from HKV (2017/2018), that will be made available to the consultant.
    - Satellite data (if available, could be challenging due to the flash flood characteristics), to be decided by the consultant.
    - Data collected by consultants that developed Odaw HECRAS model
    - Data collected by consultants (HKV) that developed Sakumono model
4. Land use data from open data sources, especially to determine the surfaced and non-surfaced areas.
5. LIDAR data to be collected from GARID. At the time of drafting this ToR the LIDAR DTM is going through QA&QC and will be made available to the consultant.
6. Bathymetry data, typology of main drains and data of structures that obstruct the flow (bridges, interceptor weir in Odaw basin, etc.). This data is not available at HSD. The client will support the consultant to obtain the data, such as survey data of primary drains of Sakumo, Lafa and Kpeshie basins (IUESMP Project, GAMA Master Plan) from MSWR GAMA SWP PCU. The client cannot guarantee making all the available data freely available. Also, existing hydraulic models of Odaw and Sakamonu may serve as a data source, as well as open-source satellite images and the Lidar DTM. The consultant however must be prepared to work around critical data gaps by means of e.g. interviews with current and past HSD staff on design criteria and collection of design maps to obtain the probable and logical dimensions of drains and structures where data is missing. For critical stretches it is foreseen that the consultant together with staff of HSD will need to go into the field themselves for a (rudimentary) field survey to overcome data gaps.

The availability of data and its usage shall be described in the inception report.

Schematization

The basins of Odaw, Sakumono, Lafa and Kpeshie need to be schematized in a coupled 1D and 2D hydraulic model. The other basins shall be schematized in a 2D model only, allowing for a less detailed schematization of the riverbed itself (drains) in view of the less economical value of those basins, with less inhabitants and in view of the availability of data. Proper arrangements need to be made to incorporate the bathymetry (layout and estimated cross sections) of the main drains into these models as stated above. The 2D part of the model can be restricted to the flood prone areas or should cover the entire basin if the run-off calculated by the hydrological model is distributed over the entire basin.

The hydrological model should be able to calculate the run-off resulting from heavy rainfall events with durations of 1 to 24 hours resulting in flash floods, considering the spatial variation in land use, soil types and altitudes.

Calibration and validation

No data of water levels is available for calibration and validation of the models. Instead, the coupled rainfall-runoff and hydraulic model need to be calibrated on the observed flood extent of the June 3rd, 2015 flood event in Odaw basin and other basins as described in HKV reports that will be made available to the consultant. In those reports the observed flood extent is obtained based on expert judgement of Ghanaian representatives of various institutes and MMDA's, testimonials, photographs, social media, etc. No hard data (water levels, discharges) is available. If during the implementation of this project a flood event in the project area occurs, and the relevant authorities can make the data available to the Consultant, this event should be used for validation purposes as well.

Calibration mainly concerns the infiltration and storage of rainfall in ponds, roofs, etc. (transforming the rainfall into run-off) and the hydraulic roughness of overland flow and the drains. The suitability of the models needs to be proven for the flood prone areas alongside the main (primary and secondary) drains. Local small inundations (e.g. excess rainfall inundating roads without causing substantial damage) do not need to be covered by the models since the flood risks concentrate in the low lying areas along the main drains (in many cases in the downstream low lying areas where also the economic activities are concentrated and the highest population densities and informal settlements can be found). Model parameters will be varied by the consultant in a sensitivity / uncertainty analysis within physically realistic limits that follow from literature, to determine its impact on the uncertainty of predicted water levels and flooded areas.

Precalculated relations

Once the model is ready, the pre-calculated relations can be developed. As stated, those precalculated relations link scenarios for rainfall and sea levels to precalculated flood maps. For all basins, calculations need to be made for various rainfall events (ranging from 1-24 hours with recurrence intervals of 5-100 years) combined with sea levels ranging from low tide, average tide, high tide to extreme high tide. The following precalculated relations need to be derived (to be decided in the Inception phase):

Intensity (mm/hr)	Duration
5	24 h
10	12 h
10	24 h
20	5 h
20	12 h
50	1 h
50	6 h
100	25 min
100	2 h
200	5 min
200	40 min
300	5 min
300	15 min
400	5 min

These 14 relations, combined with four different sea level scenarios, result in 56 possible combinations to be included in the precalculated rainfall flood extent relations. The consultant should also indicate, based on the IDF curves, what the recurrence period is for each flood hazard map.

Note that:

- These relations need to be confirmed during the inception phase of the project (in case new IDF curves are available);
- The system should be flexible and scalable, so in case additional relations are to be added the beneficiary should be able to do that as well. A manual shall be prepared for guidance, and it shall be part of the training activities.
- The flood hazard maps shall be included in the FEWS system, but also shall be delivered in a georeferenced file and on 1: 25.000 pdf maps. The lay out of the maps is to be discussed in the inception report.

The statistics of sea levels for the coast of Accra can be found in open (reanalysis) data sources, to be validated in discussions with the HSD. Values for extremely high tide (coastal swells) also need to be determined together with HSD. For the Densu basin, the rainfall input is replaced by discharge scenarios for spilling of Weija dam. The timestep applied in the calculations needs to agree with that of the rapid rainfall-runoff process, probably in the order of 10 minutes.

The result is a database with flood extent (flood hazard) maps for all calculated events, as well as the meta data (applied rainfall and sea level and spilling discharge Weija dam for Densu basin).

The consultant will, based on the results of the calculated events, propose triggers for warnings and alerts. These will be discussed and agreed upon with the Client, and will be used in the FEWS system.

Functional design

FEWS Accra needs to translate the rainfall forecast and nowcast into expected floods and flood extents, applying the precalculated relations for all basins.

3.8 Forecasting stage 3: Hydraulic and hydrological models

Alternatives

As described, it is proposed to implement the stage 3 forecasting (applying the developed 1D2D hydraulic and hydrological models) for Odaw, Sakumono, Kpeshie and Lafa basin in the first year and the 2D models of the other basins in the year after. Applying the hydrological and hydraulic models will result in a refined forecast of the floods in those basins on top of the forecasts based on the precalculated relations (stage 2). Basins other than Odaw, Sakamono, Kpehie and Lafa show extremely short lag times and/or less flood risk, and/or will have no gauging stations flood monitoring. Note that the models shall be available offline for all basins as well, since they are already developed to derive the precalculated relations for flood forecasting (stage 2).

- The input for the hydrological model is the forecast and nowcast of the rainfall in (e.g.) mm/10 minutes.
- The output of the hydrological model is the distributed run-off for the grid size that has been chosen for the model development.
- The output of the hydrological model is the input for the hydraulic model.
- Other inputs for the hydraulic models are the expected sea levels and the spilling of Weija dam (Densu basin).

- For the basins for which the hydraulic models are implemented and data of gauging stations is available, the observed discharges also serve as input for the hydraulic model. As a fall-back option in case of missing observed discharge data, the discharges shall be taken from the results of the hydrological models.
- The output of the hydraulic models are the water levels of the main (primary and secondary) drains for areas that are prone to floods.
- Those calculated water levels need to be combined with the DTM derived from the LIDAR data, resulting in inundation depths and flood extents.
- All data flows should be handled by FEWS Accra automatically.

3.9 Forecasting stage 4: Monitoring network

The hydrological network shall be extended in 2022 (see Annex C). The data from this network should be made available for monitoring in the FEWS system. The Client will ensure access to these data sources.

In case additional stations are to be added the beneficiary should be able to do that as well. A manual shall be prepared for guidance, and it shall be part of the training activities.

3.10 Scenarios

FEWS Accra can use current measured and forecasted rainfall and water levels. The visualisations and information products show the results of the data processing and model calculations.

In order to determine and visualize the impact of temporally and spatially deviating rainfall, FEWS Accra will have a mode for making scenario calculations. An authorised user can overrule the measured and forecasted rainfall, start model calculations, and visualise the results and impact.

The scenario mode shall offer the following features:

- The rainfall can be overruled by:
  1. A percentage of the measured and forecasted rainfall (e.g. 0 - 50%);
  2. A fixed number of millimeters of rainfall.
- The scenario settings are for the full geographical area of FEWS Accra.
- The scenario settings are for an indicated period.
- Definition of more than one scenario is possible, but scenarios cannot overlap in time.
- The results of scenario calculations can be visualised using the regular available visualisations and information products.
- An authorised user can replace the current (measured and forecasted) situation by scenario settings. All regular visualisations, information products, alerts and warnings in the indicated period shall be based on the scenario settings.
- An authorised user can switch back to the current (measured and forecasted) situation by switching off the activated scenario settings.

3.11 Results and information products

The information of FEWS Accra should be available for stakeholders in a web-based user interface in regular web browsers on pc's, tables and smart phones. The visualisation must have a responsive web design. All visualisations and information products should be accessible by a clear menu structure. Additionally, locations can be selected in a map. See appendix A for a detailed specification of the visualisation and information products. The perspective of the user is key in the development of these results and information products. The

Consultant will outline their ideas for this in the inception report already. During the development of these products, the consultant will organize at least 2 workshops with the relevant end users (max 20, to be appointed by the Client) to discuss how the results are visualized and to get their early feedback in the development process.

FEWS Accra shall contain the following visualisations and information products:

Tables and graphs

It shall be possible to combine in one table or graph the visualisation of more than one parameter or for more than one location. The reference levels/thresholds are visualised as a horizontal line in the graphs. All visualisations and information products are available for the current situation and for scenario runs.
The table and graph visualisations shall be:

a. Measured and forecasted (including the nowcast) rainfall for one or more locations, including validation flag.
b. Measured and forecasted water levels for one or more locations, including validation flag.
c. Combination of measured and forecasted rainfall and water levels on one or more locations.

Maps and animations/simulations

Spatial data be visualised in a map. The map component offers regular GIS-features such as zooming and scrolling. The dynamic spatial data can be combined with static maps, e.g. location of measurement stations, river catchments, roads, important objects, administrative areas and the Digital Elevation model (DEM).
The spatial data visualisations in maps and animations/simulations are:

a. Geographical area of FEWS Accra with all available map layers with static data.
b. Measured and forecasted rainfall.
c. Measured and forecasted water levels.
d. Measured and forecasted water depth.
e. Calculated flood risk.

Alerts and warnings

FEWS Accra can visualize alerts and warnings. The functionality and specifications are described in Chapter 5.

3.12 Software

Hydraulic and hydrologic models are necessary for:

- Calculating the flood levels and flood extent (flood hazard maps) for several rainfall events (reference is made to the rainfall scenarios for the precalculated relations as described in section 3.5) for each basin in the GAR. The flood extent has already been calculated before for all basins in the GAR before (see Appendix A) but needs to be recalculated applying the models that are to be developed by the consultant and the LIDAR DTM of GAR that will be available.
- Determination of the pre-calculated rainfall- flood extent relations that are used by the FEWS in Stage 2 of the flood forecast (see Figure 6 and Figure 7). The results of the hydraulic and hydrological models are necessary for the determination of those relations.
- Detailed flood forecasting.

The Consultant will use and apply the HEC modelling platform in compliance with the following demands of the Client:

- The ability to calculate 1D flow, 2D inundation patterns and rainfall-runoff
- Connectivity with FEWS operating systems
- Numerical stability
- Suitability for urban flash floods
- Knowledge and experience at HSD, which is related to training needs
- User friendliness
- License free and no recurring license costs after the completion of the project
- Availability of a (online) help desk.

4 FEWS specifications

4.1 Specification

The Consultant will use and apply the Delf-FEWS system of Deltares, in compliance with the demands and selection criteria that were applied by the Client:

1. Initial license fee limited and included in the proposal of the consultant for the development and implementation
2. No recurring annual license fee
3. Preferably open source
4. Large International Installed base
5. Configurable (ability to e.g. add measurement stations, parameters and/or background maps)
6. Expandable: (ability to e.g. add, change or delete data sources, including additional data processing features, adding new hydrological models, generating additional standard visualisations and the export of data)
7. Maintenance: ability to maintain the FEWS by the functional and technical maintainers of FEWS Accra, e.g. by providing access to authorised users, installing updates and patches and database management
8. 'Open' model connection: ability to connect various (hydrometeorological) models, including exchange of input data and results
9. 'Open' workflows: ability to schedule tasks (e.g. import of external data, model runs and dissemination of data) in workflows by a task schedular
10. API-access: accessibility of the database by an Application Program Interface (API).

Detailed technical specifications for the FEWS system are presented in Annex A.
During the inception phase, the consultant – with the support of the AFC staff - will prepare an update to the functional design if needed and provide technical design for the development of FEWS Accra as well.

4.2 Hosting and hardware

NADMO will host the back end of the FEWS, the front end will be installed at AFC office. the Consultant should include the installation and configuration of a server in their proposal. NADMO will ensure accessibility and support to the Consultant to allow a s smooth installation process.
The required hardware for FEWS Accra (monitoring, forecasting, dissemination, communication and evaluation) is expected to be:
• Three Windows servers 2022 (or any recent OS) including Windows licenses. (one application server, one backend server and one database server)
• 16 GB RAM on each server.
• 6 cores on each server.
• 60 GB C-partition on each machine.

• 60 GB D-partition on the application server and the backend server.
• 300 GB D-partition on the database server.
• Backup facilities for at least 500 GB.
• Maximum bandwidth available at the site.
• Domain name registration.
This should be further elaborated in the inception phase.

The National Information Technology Agency (NITA) will host a backup system. The Client will ensure accessibility and support to the Consultant to allow a s smooth installation process. No additional server capacity is needed at NITA.

5 Dissemination and communication

5.1 Introduction

The forecasting system provides information on floods with alerts and warnings that need to be disseminated and communicated to the different stakeholders at the right location and at the right moment. This section gives an overview of the functional features to support this dissemination and communication. The detailed specifications are listed in appendix A.

5.2 From detection to dissemination

FEWS Accra shall contain various options for the dissemination and communication of information on floods:

- Situation reports.
- Making data, maps and information products accessible in a public interface.
- Making information available on public websites (e.g. NADMO).
- Dissemination of alerts and warning to (local) stakeholders.
- App 'My Flood Risk Accra'.
- Messages to social media.

5.3 Situation reports

Functional design

FEWS Accra shall support the user to create situation reports based on information in the system. The system contains features for:

1. Composing a template for a situation report.
2. Automatic and manual generation of situation reports.
3. Completion, approval, presentation, and dissemination of situation reports.

Information products

The information products are dedicated situation reports that can be presented in FEWS Accra and disseminated to external stakeholders by email or fax.

ICT-environment

The situation reports are generated on the ICT-infrastructure of FEWS Accra. The dissemination with external stakeholders shall use email facilities on one of the servers of FEWS Accra.

5.4 Public interface

Functional design

FEWS Accra should be accessible by a web-based user interface. For access to the system, a distinction is made between professional users and public users. The distinction shall be made in the url-name or through an authentication. The professional users need a user-id/password authentication, the access for the public should be open.

All information selected for public information shall be directly available and accessible. The selection of the information shall be made in the configuration of the user profile for public users. The consultant should ensure that vulnerable population and persons with disability also can assess warning information.

Information products

The visualisation and information products in the public interface shall be clickable maps with measured and expected rainfall, flood risk and water depth in time steps of one hour.

ICT-environment

The (public) interface shall be available in commonly used web browsers on pc's, tablets and smart phones (in an app).

5.5 Public websites

Functional and technical design

Information of FEWS Accra shall be available for presentation on other (public) websites. The information can be provided by:

1. An Application Program Interface (API) which will make it possible for external integration using bulk SMS, Interactive Voice Response Systems (IVRS) for feature phone users to allow dissemination through short voice recordings.
2. Data exchange on a secured SFTP-location.
3. Export of graphs and maps in a standardized format, e.g. HTML or GeoTIFF.

FEWS Accra offers the system administrator features to select the information that shall be available on a public website.

Information products

All public data and information products of FEWS Accra shall be available for presentation on public websites.

ICT-environment

The public websites are available in their own ICT-environment. For the data exchange with these websites the ICT-environment of FEWS Accra shall contain:

1. For direct data access an API, accessible by an external application and protected with a user-id/password authentication and/or,
2. A secured SFTP-location for file exchange.

5.6 Dissemination of alerts and warnings

Functional design

All measurements and forecasts in FEWS Accra can be classified using thresholds. These thresholds can be added to presentations and information products to indicate the importance of the measurements and forecasts. When a reference level is exceeded, FEWS can send alerts and warnings. These messages shall contain:

- Explanation of the critical situation.
- Expected water depth (using RAG code), including expected moment (as a time series).
- How to act.

- Shelter location in case of evacuation.

The messages can be sent automatically or after approval of an authorised user. The messages can be sent to local stakeholders using:

- SMS, WhatsApp, email, and cell broadcasting (SMS message to people in a restricted area).
- The app ‘My Flood Risk Accra’ (see Section 5.7).
- Posted on social media (see Section 5.8).

Information products

The information product is a message to local stakeholders with clear information regarding the critical situation and instructions on how to act.

ICT-environment

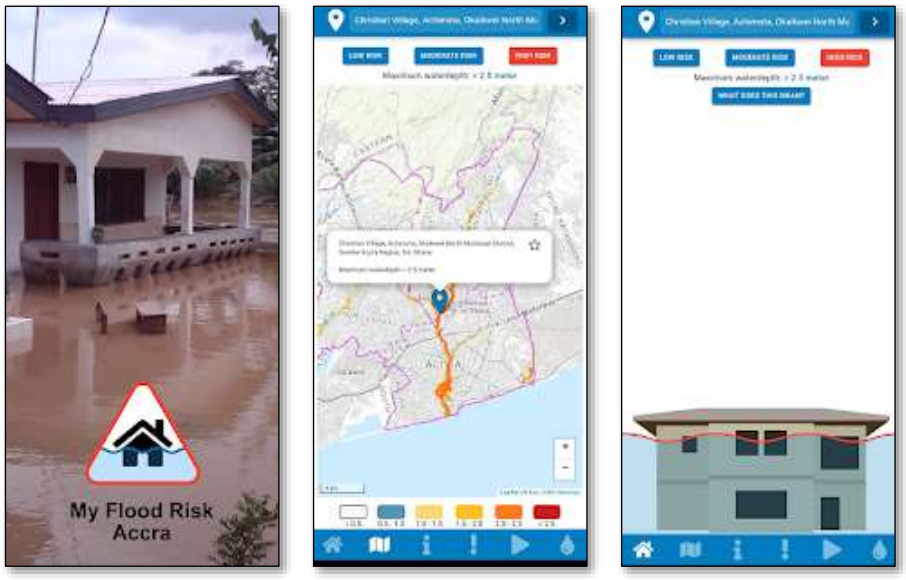
The warnings and alerts shall be generated by FEWS Accra. For the dissemination of the messages the ICT-infrastructure of FEWS Accra shall be connected to internet with adapters to the devices to be used for the communication.

5.7 App ‘My Food Risk Accra’

Introduction

NADMO and GMET developed and implemented the app ‘My Flood Risk Accra’.

Figure 8: Screenshots of the app ‘My Flood Risk Accra’



The app informs citizens about their exposure to flood risks. It answers the question: “how high can the water rise in my neighbourhood?” The app contains multiple flood maps, for different statistical return periods. The water depth is presented in meters above mean street level and is to be regarded as an indication. The Consultant will decide together with the Client about this app as a basis for dissemination of flood alerts.

Functional design

The functional improvements and extensions for the app ‘My Flood Risk Accra’ are:

- The flood maps for the app shall be replaced by updated flood maps for FEWS Accra.
- The app shall present the current and forecasted water depth in maps;
- The app shall receive and present alerts and warnings.

Information products

The information products in the app ‘My Flood Risk Accra’ related to FEWS Accra are:

- Updated flood maps.
- Current and forecasted water depth.
- Alerts and warnings.

ICT-environment

The ICT-infrastructure for the app ‘My Flood Risk Accra’ is available and shall be shared with the Consultant. These facilities shall be integrated in the ICT-infrastructure of FEWS Accra.

5.8 Social media

Functional design

FEWS Accra supports scheduled and manual posting of information to social media (Facebook, Twitter, Instagram and TikTok). The message can be prepared in advance and selected from a list or entered by an authorised user.

Information products

Post on social media

ICT-environment

The messages shall be generated with FEWS Accra. For the dissemination of the messages the ICT-infrastructure of FEWS Accra shall be connected to internet with adapters to be used for social media networks.

5.9 Digital support system for NADMO

A digital system additional to the FEWS Accra system, that supports NADMO in its response activities. This system is best to be developed separately from the FEWS Accra system, as it will support NADMOs internal activities only.

Functional design

- allow the submission of situational reports by district EOCs, according to a fixed format, such that they shall be automatically archived and shared with relevant people within NADMO,
- share instructions and protocols in response situations, to coordinate actions,
- keep the inventory of response equipment up to date digitally, such that all relevant persons within NADMO can easily assess where the nearest available equipment is located.

ICT-environment

A smartphone application, because this is easier to distribute and maintain at local and zonal NADMO levels.

6 Training

The Consultant will provide a 3-month training program to a variety of experts during the assignment. Trainings will include:

- Hydrological modelling (5 days total, for 10 experts)
    - Data collection and verification
    - Setting up of models
    - Analysis of results
    - Calibration & verification

- Hydraulic modelling (5 days total, for 10 experts)
    - Data collection
    - 1D modelling, 2 D modelling
    - Flood hazard modelling
    - Calibration & Verification

- Updating and maintaining the FEWS
    - Training for users (5 days total, for 10 experts)
    - Training for IT professionals on maintenance (3 days, for 5 experts)
    - Adding additional stations, or relations in the FEWS (2 days, for 5 experts)

- Updating and maintaining the dissemination tools
    - Linking to new FEWS results (3 days, for 5 experts)
    - Training for IT professionals (3 days, for 5 experts)

- On-the-job training during rainy season, during the rainy seasons of 2023, 2024 and 2025
    - Training for users (3 days total, for 10 experts)
    - Training on maintenance (2 days total, for 5 experts)
    - Assess need for updating models (2 days total for 10 experts)

During the inception phase, the Consultant will prepare a more detailed training program for approval, based on a brief gap analysis. The Consultant will include all costs (for facilities, lunches, transport) for the training session in his financial offer.

In addition to these training activities, the Consultant will outline the anticipated involvement of the AFC staff members, how they will be involved in the development of the deliverables, how day-to-day on-the-job support will happen to ensure that capacity building is an integral part of the project.

7 Delivery schedule

Deliverables	Draft available (Month after signing of contract)
1 Inception report including a detailed workplan, training schedule, overview of available data, selected software, update function design and technical design of FEWS Accra.	2
2 Hydrologic models and reports	5
3 Hydraulic models and reports	7
4 Results of precalculated relations	8
5 FEWS system, with test report and a user manual	10
6 Dissemination tools and user manuals	12
7 Training report, with an overview of all trainings, materials and participants	13
8 Final report	14
Review and finalization of reports	16
Training rainy season 2023	Tbd in 2023
Training rainy season 2023	Tbd in 2024
Training rainy season 2023	Tbd in 2025

All reports shall be sent in draft, the Client will provide feedback within a month. The consultant should make the report final within a month after receiving the feedback.

The consultant will provide monthly progress report to the Client on the implementation progress of FEWS Accra.

8 Experience of Consultants

The Consultants should provide information demonstrating that they have the required qualifications and relevant experience to undertake this assignment. The minimum experience required to undertake this assignment include;

a. The firm must be a legally registered as an engineering consulting firm;
b. The Core business must be in undertaking
    i. hydrologicy and hydraulic modeling,
    ii. drainage,development of flood early warning systems,
    iii. development of water related integrated risk management,
    iv. developing of water related emergency and disaster management and operations;
c. The firm must be, at least, 10 years in business;
d. The firm must have experience in the development of hydrologic and hydraulic models for an urban environment;
e. Must have experience in undertaking flood warning systems over a period of not less than 10 years;
f. Should be registered with a relevant regulatory body;
g. Must have experience in preparing ??meteorological forecasting and nowcasting in tropical areas.;
h. Demonstrate experience in the development, implementation, and maintenance of at least 2 Flood Early Warning Systems in the last 5 years;
i. Experience in training and capacity development;
j. Must have past experience in the development, implementation, and maintenance of Flood Early Warning Systems; and
k. Evidence of Technical and Managerial Capability.

9 Key experts

Key experts for this assignment include:

Project manager shall be responsible for the overall coordination and supervision of the project with at least 15-year experience with managing projects related to flood risk management and early warning, at least 10 year experience in project management. Work experience in Ghana and / or West Africa is an advantage. The Project Manager must have a master's degree in hydrology or hydraulic engineering or similar, with knowledge and experience in national (flash) flood prevention projects, (flash) flood monitoring and flood risk assessment in an urban environment.

Meteorological expert with extensive (at least 10 years) experience in processing and combining rainfall data from various sources (rainfall radar, ground stations, satellite) and rainfall nowcasting in tropical areas.

Hydrological expert with extensive (at least 10 years) experience in hydro-meteorological data collection and processing, hydrologic modeling, rainfall/runoff analysis; master's degree in hydrology, hydraulic engineering or related field. Must have sound understanding an experience in applying and developing hydrological models and demonstrated flash flood management knowledge in developing countries and urban environments. Has provided training in similar projects.

Hydraulic modelling expert with extensive (at least 10 years) experience in hydraulic modeling and flood hazard mapping. Master's degree hydraulic engineering or related field. Must have sound understanding an experience in applying and developing hydraulic models in developing countries and urban environments. Has provided training in similar projects.

Flood Forecasting expert MSc Degree in Hydrology or Water Resources Engineering or relevant fields; with at least 10 years of flood warning and forecasting systems, hydrometric monitoring and data management. Has provided training in similar projects.

Disaster management specialist: ideally at least 10 years of experience in the implementation of disaster management protocols, such as Common Alerting Protocols (CAP), multi-channel mass notification and Standard Operating Procedures (SOP) and providing training including training for Community –based prevention and knowhow of flash flood emergency approaches, and good understanding of multi-channel mass notification systems. Must have a Masters degree in related field.

Community outreach, communication, and gender expert: At least 10 years experience in working with communities, specifically on gender issues and disaster preparedness. A masters degree in Social Work, communication or field related to disaster risk management with at least 5 years of relevant experience in community-based disaster prevention in developing countries. Work experience in Ghana and / or West Africa may be an advantage.

Non-key experts

IT specialist: at least 10-year experience in the installation and maintenance of IT systems hosting real-time systems (hardware, operating systems, IT system monitoring); at least BSc degree in computer science, software engineering or closely related fields; with a minimum of 10 years of experience in systems analysis, design and development of web-based modelling systems preferably related to hydrology/flood/drought forecasting and warning system. Has provided training in similar projects.

If the bidder finds it appropriate, the bidder can add additional experts. It is also allowed to combine two of the experts mentioned above, as long as they comply with the requirements.

10 Project organization

- Monthly progress meetings with the Client shall be organized. If the COVID-19 situation allows, these meetings shall be organized at the Client's office in Accra.
- Most experts should spend at least 50% of their time in Ghana, with following exceptions:
    - Project manager, disaster management specialist and community outreach, communication and gender expert should spend at least 75% of their time in Ghana
    - Non key experts can work from their home office and are only required in Ghana in case the service provider finds that appropriate
- All documents shall be written in English. All documents and presentations should be provided in electronic form (MS Office for Windows) and 10 printed copies to the Steering Committee at least 10 working days before the scheduled Steering Committee meeting. Specific guidance on the provision of maps and spatial data and information is presented below.
- The AFC at HSD office will provide working space for the consultant. The consultant will work from this office to support transfer of knowledge.
- The consultant will explain how Quality assurance is implemented, including review of products from the AFC staff members.
- Travel expenses: All travel expenses of the Consultant shall be covered by the Consultant. The Consultant shall make adequate budget allocations for travelling in the GAR during the entire duration of the assignment.

A Specifications FEWS

1. Non-functional

Table 3
Non-functional specifications.

No.	Priority	Description
		Easy to use, intuitive and to the point Some stakeholders will use FEWS Accra for their daily work, others will use the system only in disaster situations. Even when a user does not use the system frequently the user must find its way easy in the system. Information shall be easy to find (not more than three mouse clicks), and end user functionality should be available in a logical way.
		FEWS Accra shall be based on standard software, proven technology and an installed base for similar purpose (at least 10 implementations for large river basins, cities or on national level). A support and maintenance organisation shall be available for the software.
		FEWS Accra shall run 24/7.
		The configuration/setup of FEWS Accra shall be open, extendable and maintainable. The maintainer should have the possibility to extend the configuration with new developments, insights, locations and data sources.

2. Technical

Table 4: Technical specifications.

No.	Priority	Description
		The ICT platform for FEWS Accra shall be compatible with existing ICT infrastructure of the agencies of the Government of Ghana.
		FEWS Accra will use a standard database management system.
		The proper operating and availability of all components and data flows of FEWS Accra shall be monitored automatically. In case of failure the system administrator will be informed by email and/or text message.
		The user interface of FEWS Accra will be available on PC's (desktop and laptop), tablets and smart phones.
		The user interface will be available in commonly used web browsers.
		The web-based user interface should have a responsive design.
		The ICT-infrastructure shall be protected with adequate security protocols and anti-virus software, including encryption/protection from malicious attacks (DDOS, ransomware etc).
		FEWS Accra, including data, shall be frequently back upped or mirrored using a dedicated or existing off site backup solution.
		All versions of the software, scripts, configurations, models and documentation shall be stored in a version management system.
		The user interface will be available in commonly used web browsers.
		The web-based user interface should have a responsive design.
		The interface must meet at least the Level A standard of the Web Content Accessibility Guidelines (WCAG).
		The system should comply with the Common Alerting Protocol, CAP http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2-os.html

3. Conditions, institutional and finances

Table 5: Conditions. institutional and financial specifications.

No.	Priority	Description
		Open source: the software for FEWS Accra shall be preferably open-source software.
		License fee: the software for FEWS Accra shall be available without any recurring license costs (including database management system).
		The ownership all products (configuration, scripts and documentation) will be transferred to the Client after the implementation of FEWS Accra.
		The implementation of FEWS Accra shall not trigger any World Bank Social or Environmental Safeguards.

Support and maintenance

Table 6: Specifications for support and maintenance

No.	Priority	Description
		FEWS Accra will be easy to maintain with limited resources from the agencies of the Government of Ghana.
		Bugfixes and regular updates of the software for FEWS Accra including models will be available without additional costs.
		The supplier shall include a Service Level Agreement (SLA) with services and service levels (response time): First, second and third line support; Solving problems; Providing and installing bug fixes; Installation of regular updates.

Monitoring, flood forecasting and decision taking

4. Functional

Table 7
Functional specifications flood forecasting and decision taking.

No.	Priority	Description
		All processes will run automatically. The import, data processing, model calculations can be scheduled in workflows in a task manager.
		The workflows of the task manager are configurable.
		The workflows should contain functions for aggregation and disaggregation (spatial and in time)
		The user interface supports the manual start of all configured workflows.
		The workflows should contain functions for validation and correction of data:
		Validation of source data: spikes, shifted values, etc., Gap filling by interpolation or based on related time series; The metadata should contain information regarding validation; (Statistical) analysis; Calculations (using parameters from other timeseries).
		The results of analysis and calculations can be stored in the database of FEWS Accra.
		Export of datasets to files can be fully automated
		Data will be published in open, machine-readable, formats.
		All actions of FEWS Accra will be stored in a log file.

5. Flood modelling

Table 8: Specifications flood modelling.

No.	Priority	Description
		FEWS Accra supports the usage of (hydrological and hydraulic) forecasts models and tools.
		FEWS Accra shall automatically pre-process the input data, start the model calculation, import and post-process the results.
		FEWS Accra contains flood forecasting modules based on: Stage 1: Detection of Rainfall Stage 1: Detection of spilling Weija dam with: Import of the forecasted spilling discharges into the FEWS Accra. Use of precalculated relations expressing the flood extent downstream of Weija dam as a function of the maximum spilling discharge. Stage 1: Detection sea levels by: The import of sea level forecasts (tide-forecast.com, NOAA/ECMWF or Copernicus); Use of precalculated relations expressing the flood extent as a function of the maximum forecasted sea levels. Stage 2: Modelled precalculated rainfall flood extent relations by translation of the rainfall forecast and nowcast into expected floods and flood extents (water levels and water dept), applying the precalculated relations, for all basins. Stage 3: Hydraulic and hydrological models by the implementation of the hydrological and hydraulic models for at least the Odaw and Sakumono basins. Stage 4: Monitoring network with the import of measurements from gauging stations in at least the Odaw and Sakumono basins.
		The meta information of a forecast contains the type of forecast calculation.
		FEWS Accra supports scenario runs with deviating rainfall (mm or %).

6. Data handling and storage

Table 9: Specifications data handling and storage.

No.	Priority	Description
		The data standards should be based on WMO standards and WMO endorsed OGC standards.
		Geospatial coding will be compatible with OpenGIS standards.
		Codes for administrative bodies, locations and parameters will be standardised using Ghanaian or international standards.
		The database shall contain grids and timeseries, both scalar and forecasts.
		FEWS Accra can contain reference levels/thresholds (alert and alarm levels) for all grids and timeseries.
		Measurements, observations and forecasts are available in FEWS Accra for 30 days.
		Measurements, observations and forecasts older than 30 days are stored in an historical database (archive).
		FEWS Accra can import data in several formats: CSV NetCDF Griddata Map layers in common vector formats such as shapefiles, GeoJSON, geo-package, CSV etc for vector data and GeoTIFF.
		All data will be supplied with its associated metadata.
		Datasets are accessible by an API-call, also to download in bulk.
		APIs will be RESTful and accessible over HTTPS.
		API-access will be protected by an user/password authentication.

Table 10
Specifications user interface and information products.

No.	Priority	Description
		The access to FEWS Accra will be protected by an user/password authentication.
		FEWS Accra contains user profiles which give access to a selection of functional features of the user interface.
		Datasets are listed in categories and can be selected from configured categorised list.
		The listed datasets can be visualised individually in tables, graphs, maps and animations.
		The time window for the visualisation of datasets in graphs can be changed (smaller, larger and to another period).
		The visualisation can visualise the reference levels/thresholds for each data set as: Lines in graphs; Coloured values in tables; Colours in maps.
		Map layers are available and can be selected as background map (e.g., Open Street View or satellite images).
		Multi geographical data layers can be visualised in one map using one or more background maps
		The map display contains features for zoom in, zoom out and panning the map.
		The map display contains a time slider to facilitate temporal navigation of the presented data.
		The map display supports the selection or filtering of objects.
		The map display presents selected metadata in a tooltip.
		Datasets can be copied using 'Copy' and 'Paste' into text- and Excel-files.
		Datasets can be exported in CSV-format.
		FEWS Accra will provide information products with: Tables and graphs with measured and forecasted rainfall for one or more locations, including validation flag. Tables and graphs with measured and forecasted water levels for one or more locations, including validation flag. Tables and graphs with combination of measured and forecasted rainfall and water levels on one or more locations.

No.	Priority	Description
		Maps and animations/simulations with the geographical area of FEWS Accra with all available map layers with static data; Maps and animations/simulations with measured and forecasted rain fall Maps and animations/simulations with measured and forecasted water levels Maps and animations/simulations with measured and forecasted water dept Maps and animations/simulations with calculated flood risk
		All visualisations and information product are available for the regular current situation and for results of scenario runs.

Dissemination and communication

8. Functional

Table 11
Functional specifications dissemination and communication.

No.	Priority	Description
		FEWS Accra supports information providing for external websites by: API-access to the database; Export of timeseries and grids; Provision of picture.
		FEWS Accra supports the generation and distribution of alerts and warnings (CAP compliant).
		Alerts and warnings can be distributed automatically and after confirmation by an authorised user.
		The alerts and warnings are categorised in: Low Level Emergency Medium Level Emergency High Level Emergency
		The alerts and warnings can be send to specified group of stakeholders. The selection of stakeholders can be based on: Role and responsibility Warning and alarm level Effected geographical area

No.	Priority	Description
		The alerts and warning contain: Effected area Height, duration and period for expected water level Additional threats Instruction how to reaction
		The warnings and alerts can be send by email, fax, SMS, WhatsApp and cell broadcasting.
		Situation reports: An authorised user can compose templates for situation reports by: Selecting information : time series measurements and forecasts; maps with grid data and static background maps; other information products. Adding blocks with free text with basic layout features; Adding other pictures and logo's; Adding hyperlinks. A situation report can be generated be generated by: A scheduled workflow; A manual started workflow; By exceeding an alert or warning level. FEWS Accra shall contain two mechanisms for making available the automatic generated situation reports on the selected communication and dissemination devices: Direct available without intervention of an authorised user; Available after an authorised user completed and approved the situation report. • Manual created situation reports shall always be approved and disseminated by an authorised user; FEWS Accra shall offer features for the presentation, communication and dissemination of situation reports: Presentation in the users interface of FEWS Accra; Presentation in the public interface (see paragraph 5.4); Presentation on public websites (see paragraph 5.5); Dissemination by email or fax.
		Alert and warning: An authorised user can compose templates for alert and warnings by selecting information from FEWS Accra, a link to a geographical area and adding free text.

No.	Priority	Description
		The content of the alert and warnings can be customised on the current and forecasted situation on the location of the local stakeholder (receiver of the message). The message can contain: Explanation of the critical situation; Expected water dept, including expected moment (as a time series); How to act; Shelter location in case of evacuation. A alert and warning can be generated be generated by: By exceeding an alert or warning level; Manual by an authorised user.
		App 'My Flood Risk Accra': The flood maps for the app shall be replaced by updated flood maps for FEWS Accra. The app shall present the current and forecasted water dept in maps; The app shall receive and present alerts and warnings.
		FEWS Accra support scheduled and manual posting of information to social media (Facebook, Twitter, Instagram and TikTok). The massage can be prepaid in advanced or be entered by an authorised user.

9. User interface and information products

Table 12: Specifications user interface and information products.

No.	Priority	Description
		Clickable maps with measured and expected rainfall, flood risk and water dept in time steps of one hour.
		Data exchange by an Application Program Interface (API).
		Data exchange on an secured FTP-location.
		Export of graphs and maps in a standardised format, e.g. HTML or GeoTIF.
		Tailor made situation reports.
		Warning and alerts by SMS, WhatsApp, email and cell broadcasting to local stakeholders with clear information regarding the critical situation and instructions how to act.

No.	Priority	Description
		In the app 'My Flood Risk Accra': Updated flood maps; Current and forecasted water dept in maps; Alerts and warnings.
		Messages to social media (Facebook, Twitter, Instagram and TikTok).

Monitoring and Evaluation system

10. Functional

Table 13: Functional specifications of the M&E system.

No.	Priority	Description
		The availability of external data sets and the results of workflows, model runs and dissemination of and response time on alerts and warnings shall be stored in timeseries.
		The accuracy of rainfall and water levels shall be stored as an flag as result of the validation.
		Measurements, nowcast and forecast of rainfall and water levels shell be stored in ab archive for a period of at least one year.
		The statistics for the usage of the public website shall be monitored, analysed and visualised by a free available tool, e.g. Google Analytics.
		The availability of the components of FEWS Accra shall be checked every five minutes. The result of every check is stored in a logfile or database.

11. User interface and information products

Table 14: Specifications user interface and information products for the M&E system.

No.	Priority	Description
		Quality parameters of FEWS Accra can be presented and analysed in tables, graphs and maps within the user interface of FEWS Accra. The quality is visualised in different colours (from green to red).
		Statistics of the public website can be visualised by the used tool, e.g. Google Analytics.

No.	Priority	Description
		The logging with the availability of FEWS Accra can be accessed by an external tool, e.g. Microsoft Excel.

Static geographical (background) data

FEWS Accra shall be able to visualise at least geographical background data for:

Geometry of:

a. Location of hydrological and meteorological measurement stations, including sensor coordinates
    a. Rivers
    b. Roads
    c. Important and critical objects
    d. Shelters

1. LIDAR Digital Elevation model (DEM): resolution
2. Contours of geographical areas:

a. River catchments: resolution
b. Administrative areas resolution

B Meteorological Network

Line Item N°	Description of Goods	Quantity	Physical unit
1	***Compact Automatic Weather Stations (AWS)*** *-which will record weather parameters such as rainfall, wind speed, temperature, humidity, solar radiation, lightning etc. with telemetry using GSM/GPRS*	6	No
2	***Disdrometers*** *Laser precipitation Monitor (Type, Intensity and Spectrum)* ***These include 1 Spare***	6	No
3	***X-Band Weather Radar*** *With a service/maintenance agreement of 3 years*	1	No

C Hydrological measurements Network

SN	Basin	Location/ Coordinates	Picture	Equipment needed
1	Lower Densu	Weija Bridge on N1 5°33'13.00"N 0°18'47.00" W		• Staff Gauge • Radar Sensor
2	Lafa	Odorgono Bridge on Awoshie-Pokuase Road 5°35'16.00"N 0°16'52.00" W		• Staff Gauge • Radar Sensor
3	Chemu West	Mamprobi 5°32'11.00"N 0°15'20.00" W		• Staff Gauge • Ultrasonic WLS
4	Odaw 1	Onyasia on Atomic Road bridge 5°40'4.00"N 0°12'50.00" W		• Staff Gauge • Ultrasonic WLS

SN	Basin	Location/ Coordinates	Picture	Equipment needed
5	Odaw 2	Odaw bridge at Avenor 5°34'47.64"N 0°13'5.43"W		• Staff Gauge • Radar Sensor with integrated Camera
6	Odaw 3	Nima Drain bridge at Paloma 5°34'21.00"N 0°12'18.00" W		• Staff Gauge • Radar Sensor
7	Odaw 4	At Old Ashongman Culvert crossing 5°42'2.53"N 0°12'25.66" W		• Staff Gauge
8	Osu Klottey	Bridge on Osu beach road 5°33'12.00"N 0°10'32.00" W		• Staff Gauge • Ultrasonic WLS

SN	Basin	Location/ Coordinates	Picture	Equipment needed
9	Kpeshie	Kordjor bridge 5°35'46.00"N 0° 7'55.00"W		• Staff Gauge • Radar Sensor with integrated Camera
10	Sango	Bridge on Teshie Beach Road 5°35'32.00"N 0° 5'28.00"W		• Staff Gauge • Ultrasonic WLS
11	Mokwe	Bridge on Teshie Beach Road 5°36'29.00"N 0° 4'36.00"W		• Staff Gauge • IP Camera
12	Sakumo 1	Dzorwulu Drain on Tema Motorway 5°40'33.00"N 0° 2'30.00"W		• Staff Gauge • Radar Sensor fitted on a post
13	Sakumo 2	Mamahuman Drain on Tema Motorway 5°39'55.00"N 0° 3'53.00"W		• Staff Gauge • Radar Sensor fitted on a post

SN	Basin	Location/ Coordinates	Picture	Equipment needed
14	Sakumo 3	Onukpawahe Drain on Tema Motorway 5°39'24.70"N 0° 5'21.40"W		• Staff Gauge • Radar Sensor with integrated Camera
15	Chemu East	Bridge on Chemu River on the Tema New Town Road 5°38'46.00"N 0° 1'10.00"W		• Staff Gauge • Radar Sensor with integrated camera
16	Okurudu	Okurudu River -Bridge at Nyanyano 5°30'15.44"N 0°24'13.56" W		• Staff Gauge • Ultrasonic WLS
17	Tema-East (Gao)	Bridge on Kpone road 5°41'35.55"N 0° 3'1.59"E		• Staff Gauge • Ultrasonic WLS

SN	Basin	Location/ Coordinates	Picture	Equipment needed
18	Laldi-Tanha-Huape	Dawhe River Bridge on N1 5°45'55.55"N 0° 3'31.65"E		• Staff Gauge • Radar Sensor with integrated Camera
19	Nyibe 1	Old Ningo bridge on the Nyibe river 5°44'44"N 0°10'48"E		• Staff Gauge • IP Camera • Ultrasonic WLS
20	Nyibe 2	Bridge on N1 Highway on the Nyibe River 5°49'55.42"N 0°12'39.48"E		• Staff Gauge • Ultrasonic WLS
21	Gyankai	Ayetepa Bridge (down of Dawa) on the beach road 5°46'43"N 0°16'40"E		• Staff Gauge • Ultrasonic WLS

SN	Basin	Location/ Coordinates	Picture	Equipment needed
22	Koluedor	The bridge between Koluedor and Kasseh on N1 5°53'28.39"N 0°28'53.99"E		• Staff Gauge • Ultrasonic WLS
23	Alorgbos hie	Existing staff gauge Upgrade of station required 5°37'41.02"N 0° 13'43.23"W		• Staff Gauge • Ultrasonic WLS
24	Alajo	Existing station. The staff gauge plate at Alajo is missing 5°35'26.34"N 0° 13'03.90"W		• Staff Gauge • Ultrasonic WLS

SN	Basin	Location/ Coordinates	Picture	Equipment needed
25	Avenor	Existing Station at Avenor with a staff Gauge. Staff Gauge 15m from the Avenor bridge to the Right. 5°34'48.00"N 0° 13'05.00"W	 	• Staff Gauge • Ultrasonic WLS
26	Odawna	Odawna site had a staff gauge which is missing.		• Staff Gauge • Ultrasonic WLS
27	Berekusu	Berekusu has no gauge station.		• Staff Gauge