IBADAN FLOOD FORECAST AND WARNING SERVICE AND IMPLEMENTATION SUPPORT CONSULTANCY SERVICES

Inception Report (Revised)

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Prepared and Submitted by:
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Abbreviations Used

Abbreviations	Expanded form
3DVAR	Three dimensional Variational
ACL	Access Control List
ARW	Advanced Research WRF
CP	Cumulus parameterization
CRIN	Cocoa Research Institute of Nigeria
DEM	Digital Elevation Model
EOC	Emergency Operation Centers
EWS	Early Warning System
FNL	Final Analysis
GFS	Global Forecasting System
GIS	Geographic Information System
HEC-DSS	Hydrologic Engineering Center - Data Storage System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-MFP	Hydrologic Engineering Center – Meteorological Forecast Preprocessor
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HEC-RTS	Hydrologic Engineering Center – Real Time Simulation
IITA	International Institute of Tropical Agriculture
ISO	International Organization for Standardization
IUFMP	Ibadan Urban Flood Management Project
LAM	Limited Area Model
LSM	Land surface model
LULC	Land Use and Land Cover
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NEMA	National Emergency Management Agency
NIHSA	Nigeria Hydrological Services Agency
NIMET	Nigerian Meteorological Agency
NISHA	Nigeria Hydrological Services Agency
NOAA	National Oceanic and Atmospheric Administration
NSE	Nash–Sutcliffe Efficiency
OGC	Open Geospatial Consortium
OYSEMA	Oyo State Emergency Management Agency
PBL	Planetary Boundary Layer
RRTM	Rapid Radiative Transfer Model
SL	Surface layer
SOP	Standard Operating Procedure
SOP	Standard Operating Procedure
SSL	Secure Sockets Layer
TRMM	Tropical Rainfall Measuring Mission
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WMO	World Meteorological Organization
WMS	Web Map Service
WPS	WRF Pre-processing System
WRF	Weather Research and Forecasting model
YSU	Yonsei University

1 Introduction

1.1 Background

Ibadan is a major city in Nigeria's (one of the developing countries in sub-Saharan Africa) southwest region. Surrounded by seven hills, it is the largest indigenous city in West Africa and is located in the South Western part of Oyo State of Nigeria. It is the capital city of Oyo State and is centered about latitude 7° 23' 47" North and longitude 3° 55' East and it is located approximately 119 km North-East of Lagos. These include the banks of streams as well as isolated wetland areas that dot the city, which is enclosed by valleys and swamps. Eleven Local Government Areas are grouped together to what is called the Ibadan metropolitan area, Ibadan region or Ibadan land. The overall population density of Ibadan metropolitan area is 586 persons per km^2. It is situated close to the boundary between forest and grassland, which makes it a melting point for people and products of both the forests and grassland areas.

Ibadan's rainy season runs from March through October, though August sees somewhat of a lull in precipitation. This lull nearly divides the rainy season into two different rainy seasons. November to February forms the city's dry season. There are two peaks for rainfall, June and September. The rainfall pattern here has changed in recent times. In spite of the decrease in the amount of rainfall in recent years, the set time of occurrence of rainfall in the year is now between April and June in contrast to the past where rainfall started in early March. This has led to the reduction in the growing season of most crops as it is hard to get two to three planting seasons for maize, which is considered an important staple food crop for consumption here.

The capital city of Oyo State, Ibadan, is the third largest metropolitan area in Nigeria after Lagos and Kano and is highly prone to flooding. Flood has been an incessant problem in Oyo State. Ibadan is drained by three major rivers. These are River Ogunpa, River Ona, and River Ogbere, and each has numerous tributaries. Flooding problems in Ibadan have also been attributed to land use factors. Notable among others is the indiscriminate and relentless construction of buildings on flood plains. There were over 26,553 buildings found within the statutory set-back of various streams and rivers in Ibadan. Deforestation has also been identified as another contributory factor to the flooding problem in Ibadan. The destruction of natural forests, for example the depletion of the teak plantation buffering the River Ona on the Eleyele – Apete axis has aided flooding in Ibadan.

In recent years, the city has been affected by several extreme flood events, which have resulted in loss of lives and infrastructure. The Oyo state has experienced flood disasters during the years 1960, 1961, 1963, 1969, 1978, 1980, 2011, 2013, 2016, 2017, and 2018. Climate change, although uncertain in terms of the magnitude and location of impacts, is also likely to increase the frequency and magnitude of heavy rainfall events and exacerbate flooding in the coming decades of the 21st century.

To bring the problem in perspective, flood disasters in the city in the years 1980 and August 2011 still remain fresh in the consciousness of the residents and even outsiders as a result of the heavy human and material losses that were left behind. The Ogunpa disaster (1980) resulted in 500 deaths. The last major flood event took place on August 26, 2011. It led to overflowing of the Eleyele reservoir. Apart from the more than 120 people who lost their lives, the biggest impact was on the housing sector with partial/severe damage to about 2,100 homes causing losses close to Naira 2 billion (USD 12.5 million). Similarly, the agriculture sector experienced damages worth over Naira 300 million (USD 1.9 million) in terms of machinery, infrastructure, and fish and food stocks, and the transport sector was worst hit with damages running into more than Naira 4 billion (USD 25 million) mostly in

terms of damages to bridges culverts, and roads. Substantial damages occurred to the transport sector. The event also severely affected the water sector, including the Eleyele[1] dam. Again, a six-hour downpour (one of the worst in recent times) in Ibadan on Tuesday, June 20, 2017 between the hours of 3:00 am and 9:00 am led to submergence of several parts of the city and destroyed valuables worth millions of Naira.

With a population now estimated closer to 5 million and being the largest, most highly built up and densely populated metropolitan area in West Africa, the threat to the city of Ibadan from increased flooding cannot be taken lightly.

Even though the national disaster response capacity in Nigeria has improved in the recent years with the establishment of National Emergency Management Agency (NEMA) in 1999, flood risk reduction and mitigation capacity to effectively respond to flood risks still needs to be strengthened. A preliminary assessment by the World Bank and State Government team identified a number of interconnected factors mainly connected to increased runoff due to various factors, uncontrolled development in floodplains and natural drainages, improper debris management and poor drainage management, lack of formal emergency management, limited community awareness of flood risks, and finally the lack of modern flood forecasting, warning and dissemination tools that contribute to the growing challenge of flooding in Ibadan.

To address these issues, the World Bank is providing support through the Federal Government of Nigeria to the Oyo State Government to finance the Ibadan Urban Flood Management Project (IUFMP) with a clear objective to "improve the capacity of the Oyo State to effectively manage flood risk in the city of Ibadan".

As part of the risk identification, prevention and preparedness measures under the IUFMP, an integrated flood early warning and response system is needed to improve flood forecasting to communities and government for response (a sub-component). This is being developed in partnership with the National Emergency Management Agency (NEMA), the Nigeria Meteorological Agency (NIMET), the Oyo State Emergency Management Agency (OSEMA), and the Nigeria Hydrological Services Agency (NIHSA). The key objective of the proposed consultancy assignment is to develop a Flood Early Warning and Response System and to enhance community resilience to respond effectively to early warning, which is a critical element of the project design and implementation of this sub-component.

This warning system will be an integral part of the national system taking advantage of and providing inputs to the federal systems of NISHA, NIMET and NEMA.

1.2 Scope of the Study

The scope of work in this consultancy assignment consists of priority activities ensuring the development and integration of an effective early warning service that includes the following key components:

1. Design of meteorological and hydrological observational networks for Ibadan Metropolis. This includes various activities including flood modeling and forecasting, development of Standard Operating Procedures (SOPs), and developing a communication plan for warning dissemination
2. Supervise installation of meteorological and hydrological observational networks (in particular the river gauges) within the Eleyele Dam and Ona River Basin
3. Supervise installation of a Limited Area Model (LAM) for very short and short range rainfall forecasts (1 hr. to 24 hr.) which has the ability to assimilate quantitative precipitation estimates derived from satellites (Satellite derived rainfall estimates will be used alongside ground observation)

[1] ToR – Section -7 – Terms of reference page 50

4. Supervise installation of hydrological/ hydraulic models (with integrated 1-D / 2-D models where necessary) which can provide robust rainfall estimates based on those derived from observations and/or LAM and hydrological data from river gauges
5. Develop a web-based Early Warning System capable of providing detailed information on inundation and impacts coupled to and integrated with the flood forecasting system.
6. Design a warning service which will include an automated alarm system and which can be related to actual water levels and/or forecasts.
7. Carryout training and capacity building of various tasks including but not limited to design and installation of the systems, maintenance and processing of data
8. Prepare various documents as defined in the deliverable section of the ToR.

1.3 Study area

With reference to ToR, the study is broadly divided into two components:

1. Component 1 - Design of meteorological and hydrological network for Ibadan Metropolis
2. Component 2 - Support for procurement and installations along with design and development of EWS for Eleyele Dam and Ona River Basin

Figure and table below show the basin wise geographical coverage of component 1 and component 2.

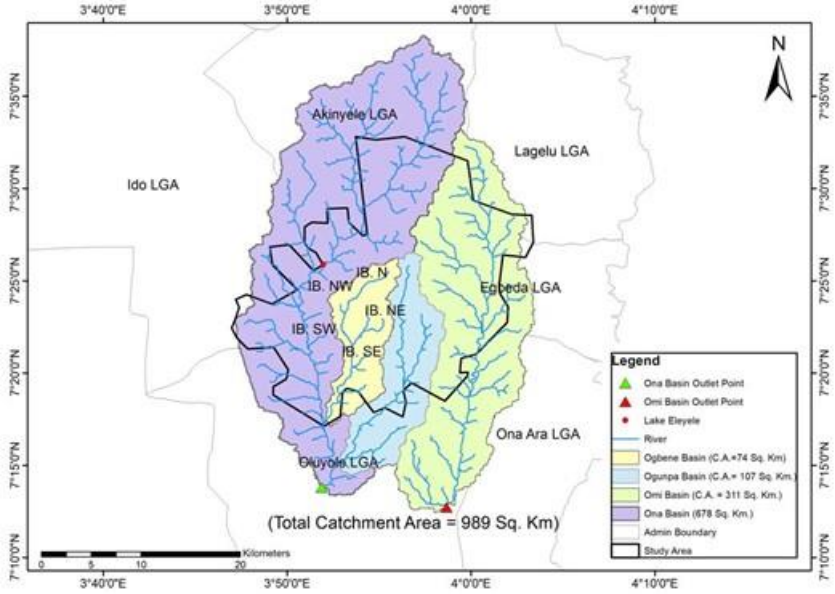


Figure 1: Study are – Component 1 – Ibadan Metropolis (shown in black) Component 2- Part of Ogbene, Ogunpa and Ona River basin

Table 1: Component wise study area details

S.No.	Sub basin	Catchment Area (Km2)	Details	Remarks
1	Ogbene	74	Tributary of Ona River - Part of Ona Basin	As per ToR Included in Component 1 &2
2	Ogunpa	107	Tributary of Ona River - Part of Ona Basin	As per ToR Included in Component 1 &2
3	Ona	678	Outlet point defined in map	As per ToR Included in Component 1 &2
4	Omi	311	Outlet point defined in map	As per ToR Included in Component 1 only

2 Task 1: Inception, scoping and concept

For such a large and complex project, the inception phase is very critical as several sub tasks mentioned have to be jointly finalized in close consultation with the key stakeholders and client. Towards this, we have carried out a series of consultations in addition to reviewing the existing database, system and models available with the State. The details of activities carried out during the inception phase are provided below.

2.1 Project inception meeting

RMSI, with the help of IUFMP, conducted a project inception meeting at the IUFMP office on 25th Feb 2019. The main objective of this meeting was to introduce the project team, proposed methodology, and planned course of action to the client and key stakeholders.

This meeting was conducted in close coordination with Ibadan Urban Flood Management Project (IUFMP), the RMSI team undertook a project inception meeting for presenting and brainstorming its methodology for the development of the Flood Forecast and Warning System and for planning project management and communication activities. Since, this was the first and guiding meeting, the RMSI team requested IUFMP to invite representatives from all key stakeholders to this meeting. Some of the representatives from key stakeholder departments were:

- Nigerian Emergency Management Agency (NEMA)
- Oyo State Emergency Management Agency (OYSEMA)
- Nigeria Meteorological Agency (NIMET)
- Ministry of Environment and Water resources

Plate 1: RMSI's presentation during project inception meeting at IUFMP

This meeting not only helped in involving stakeholders from the project inception stage but helped in getting early feedbacks on the methodology and various features of the proposed Flood Forecast and Warning System.

The finalized methodology and other project related aspects are presented in the present Inception Report at the culmination of this activity.

2.2 Evaluation of existing meteorological and hydrological network

As part of the evaluation of the flooding in Ibadan, the team has collected all the available reports from the State as well as from other sources and carried out an in-depth review of the same. We have accessed international flood event databases including Dartmouth Observatory, etc.

2.2.1 REVIEW OF EXISTING METEOROLOGICAL WEATHER MONITORING STATIONS

The heterogeneous nature of urban environments means that atmospheric research ideally requires a dense network of sensors such as Automatic Weather Stations to adequately resolve the local climate. WMO Standards for location or siting of meteorological stations is 100 km of radius and must be sited in an area that represents all the regions or cities it covers. Densification of NIMET synoptic offices equipped with Automatic Weather Stations (AWS) within 100 km of radius will be of great importance to have, as weather parameters across a large area cannot be represented by very distant manual weather stations. Currently, NIMET operates about 54 Automatic Meteorological Weather Stations across the country (Figure 2)[2]. The existing meteorological stations within the Oyo state that are managed by NIMET are as given in the Table 2 below.

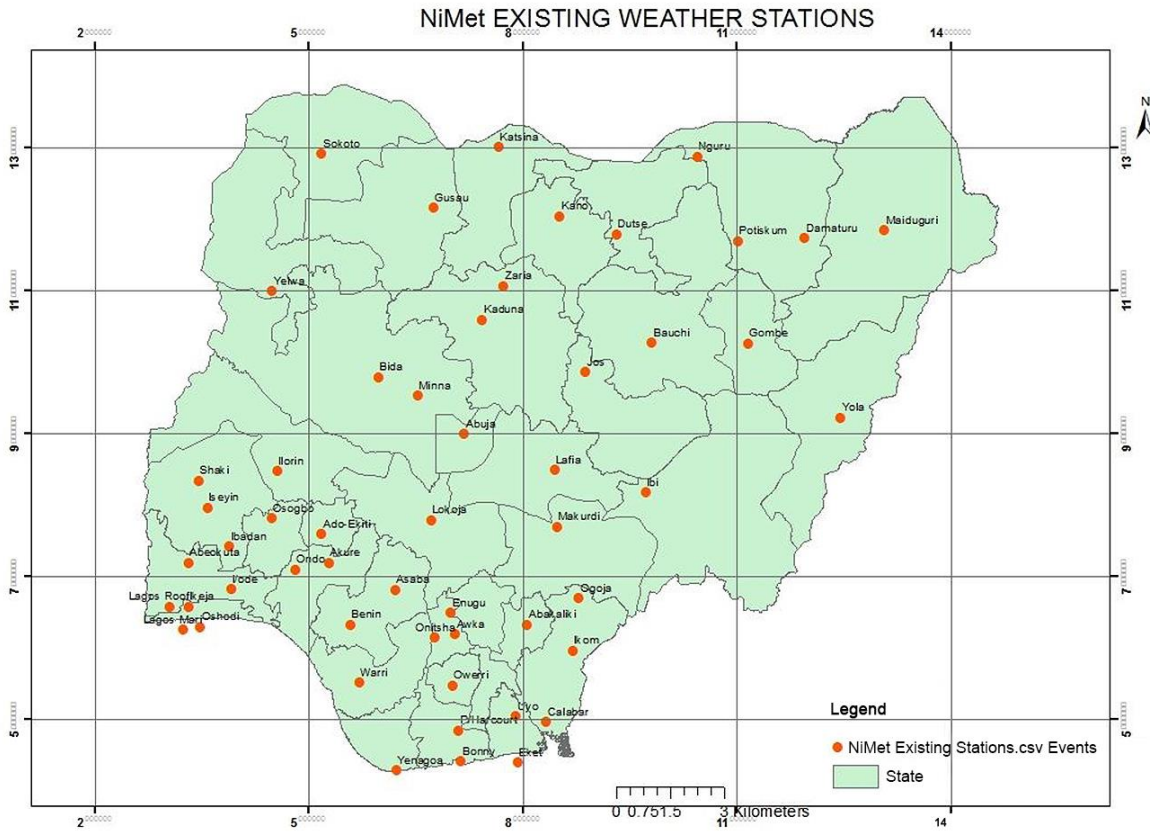


Figure 2: Existing NIMET weather stations

[2] Mohammed U. Abdullateef (NIMET): Densification of Nigerian Meteorological Agency Automatic Weather Stations (Draft Note - abdullateefmuhammed@yahoo.co.uk)

Table 2: List of existing meteorological stations in Oyo state managed by NIMET

Station Name	Latitude, N	Longitude, E
Ibadan	3.90	7.43
Iseyin	3.60	7.97
Shaki	3.47	8.35
Kishi (proposed)	3.86	9.05

The Ibadan Meteorological Observatory is located at the New Ibadan Airport. The conventional (manual monitoring) meteorological instruments installed here have been monitoring synoptic weather observations at two standard synoptic hours and transmitting them to NIMET's Ikeja Office for validation, keeping records, and transmitting to National NIMET Headquarters at Abuja. The AWS installed here a few years back is currently not fully functional due to break-down of some sensors and lack of regular maintenance (only a few of the sensors such as wind recorders are working). The observatory has 12 staff including engineers and observers at the new airport NIMET office. As informed by the station officer at Ibadan Airport, Saki and Iseyin Observatories also are currently manual operating stations (no existing/operational AWS).

NIMET has also proposed to install an additional AWS at the site Kishi in Oyo state in its expansion plan.

Plate 2: RMSI team of experts at NIMET New Airport Observatory site in Ibadan

Plate 3: Weekly auto recording device for temperature and pressure at New Airport Observatory

Plate 4: Automatic weather recording tower (in the background) at the New Ibadan Airport Observatory

Plate 5: Display device for AWS sensors at the New Ibadan Airport Observatory

Apart from NIMET observatories within Oyo state as identified in

Table 2 above, the old Ibadan airport site of NIMET continues to monitor rainfall observations at standard synoptic hours and submit the data to Central Observatory for record keeping. In addition, the Ibadan city has other weather monitoring observatories managed by other entities also. These include the observatory maintained by the Agronomy Department of the University of Ibadan, which has a compact electronic data monitoring and transmitting module that transmits the data directly to NIMET Abuja Headquarters (data not shared by NIMET to University of Ibadan). They also have a Stevenson screen with dry bulb and wet bulb thermometers, thermometers for measuring soil temperatures at varying depths and a Pan evaporimeter, which are currently non-functional due to non-availability of observers and lack of regular upkeep and maintenance. Other weather monitoring stations within Ibadan Metropolis area are located at the International Institute of Tropical Agriculture (IITA), Forestry Research Institute of Nigeria (FRIN), and Cocoa Research Institute Headquarters (CRIN). The location of all the five weather monitoring sites within Ibadan Metropolis area are depicted in Figure 3 below.

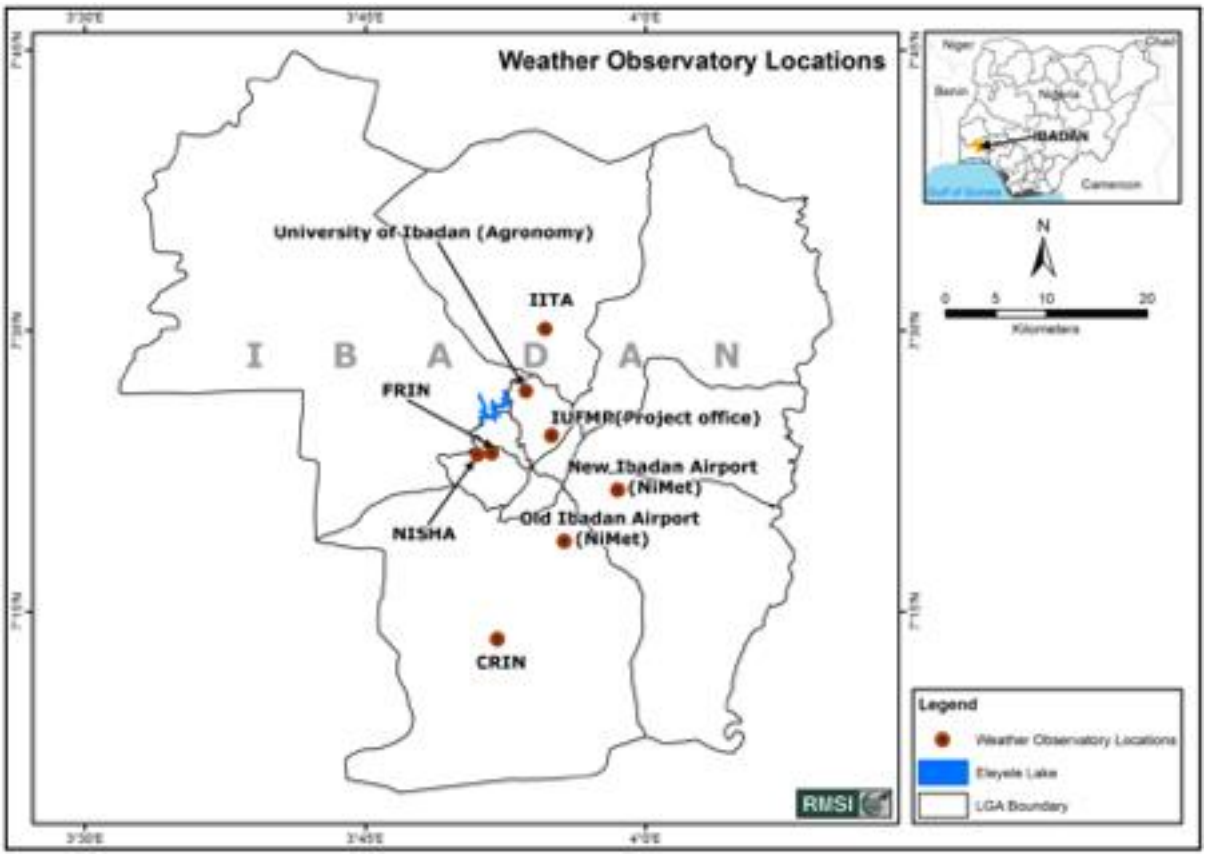


Figure 3: Weather observatory locations

IITA has a conventional meteorological monitoring observatory consisting of manual instruments and are monitoring daily weather data that cover rainfall, dry and wet bulb temperature, relative humidity, solar radiation, sunshine hour, pan evaporation, and soil temperatures at varying depth from 1973, when the station was established, till present. They also collect diurnal weather data (15 min or 30 min intervals) of the weather parameters as listed above for daily observation using automatic weather data loggers for some years. The details of the company supplying the instruments installed at their observing sites, the calibration frequency of the sensors with standard WMO/NIMET instruments at regular intervals are being ascertained.

The observatory site of Forestry Research Institute of Nigeria (FRIN) also has conventional meteorological / agro-meteorological instruments, which are monitoring weather parameters including rainfall; however, the length and frequency of data available, the details of sensors functioning at present and their calibration with standard WMO/NIMET instruments are not known.

CRIN Headquarters (has a mandate to focus on R&D for five cash crops, namely, Cocoa, Kola, Tea, Coffee and Cashew nuts to enhance productivity and provide guidance to stakeholders / farmers on sustainable livelihoods) in Ibadan (Oyo state). It also has an automatic weather monitoring tower along with conventional manual weather stations within its compound. However, while automatic weather observing system continues to monitor the hourly weather data, manual instruments for sunshine hour, soil temperature recording thermometers, rainfall measuring instrument are currently functional. The Stevenson screen installed here has been badly damaged and no dry / wet bulb thermometers are available. The details on the length of data records available with CRIN could not be ascertained.

Plate 6: Old Airport observatory site of NIMET in Ibadan

Plate 7: RMSI team at the Old Airport observatory site of NIMET in Ibadan

Plate 8: Department of Agronomy in College of Agriculture at University of Ibadan

Plate 9: Automatic weather monitoring device of NIMET installed at observatory site of University of Ibadan (top-open and bottom-closed view)

Plate 10: Observatory site at Forestry Research Institute of Nigeria (FRIN) in Ibadan

Plate 11: Cocoa Research Institute of Nigeria (CRIN) in Ibadan

Plate 12: Automatic weather monitoring device installed at Observatory site of CRIN in Ibadan

Plate 13: Sunshine hour device installed at Observatory site of CRIN in Ibadan

Plate 14: Status of Stevenson screen at Observatory site of CRIN in Ibadan

All the five sites located within Ibadan Metropolis area were visited by the RMSI team and the experts are of the opinion that a majority of instrumentations available at these sites need replacement with properly calibrated sensors and telemetry devices for collection of weather-related data and transmitting them in real time mode to a central location for improved flood forecasting, which would be used for early warning services. The observatory compound at the five sites is secure and has ample space for installation of appropriate monitoring sensors. These sites would be considered appropriately for designing of the observing network for flood forecasting.

It may be noted here that Ibadan is host to another premier institution namely the National Horticultural Research Institute (NIHORT), which was first established as the National Fruit and Vegetable Research and Development Centre (NFVRDC) with the assistance of UNDP/FAO Project NIR/72/007. Subsequently, by the Federal Government Agricultural Research Institutes Establishment Decree Order No. 35 of June 1975, the Centre metamorphosed into the National Horticultural Research Institute (NIHORT) along with other

Agricultural Research Institutes. The Institute's headquarters is situated on 350 ha of land at Ibadan under the coordination of the Agricultural Research Council of Nigeria (ARCN). The key mandate of the institute is to conduct research into genetic improvement, production, processing, storage, utilization and marketing of fruits, vegetables, spices and ornamentals plants of both nutritional and economic importance. It has its own weather monitoring site which is primarily meant to support crop research. The NIHORT has no mandate to provide routine operational weather forecasting for disaster management.

2.2.2 REVIEW OF EXISTING HYDROLOGICAL MONITORING STATIONS

The detailed discussions have been carried out with Engr. Joseph Akpan from the Nigeria Hydrological Services Agency (NISHA) to get information about existing networks and flood forecasting practices. According to him, there is only one station installed at Eleyele Dam and they collect this data and send it to the Abuja head office. The site does not seem to have any weather monitoring device installed at the Eleyele dam site or in the upper catchment area.

RMSI team visited the Eleyele dam site with Engr. Akpan and found that the discharge measuring instrument was not in working condition due construction work at the Eleyele dam. Engr. Akpan informed us that they have to relocate the instrument once construction work is finished.

Plate 15: RMSI Team with Engr. Joseph Akpan (NISHA) at Eleyele Dam

The RMSI team has also collected water marks of the 2011 flood at the pumping station of Eleyele dam, which can be used for calibration and validation of the Hydraulic model.

Plate 16: Flood water mark for 2011 flood at Eleyele dam

No discharge data is available at NISHA's Ibadan office. The RMSI team has therefore requested the Managing Director, Ogun - Oshun River Basin Development Authority, Alabata Rd. Abeokuta through IUFMP Project Coordinator to provide access to discharge data.

2.3 Develop and refine a preliminary concept of the flood forecast and warning service

RMSI team based, on its understanding of the requirement mentioned in the TOR, and international best practices has suggested an ideal solution suiting the requirements of the State.

During the inception phase of the assignment, based on the review of the flood issues, institutional issues, and information gathered through consultation with the key stakeholders, the project team has revisited various options to improve the methodology – in terms of the approach for flood modeling, technology for EWS, training activities, etc. We have prepared various options including impacts on cost and project schedule and are presenting these in the present Inception Report.

2.4 Inception workshop

The project inception workshop is the concluding key activity of the inception phase. By this time the team will have substantial information related to the ground situation and also have a better understanding of the client's requirements. In coordination with the IUFMP, the project team will host an inception workshop. The objective of the inception workshop is to present the project methodology to a wider audience, summary on information gathered including flood and institutional issues, suggested interventions, planned actions including any changes in the proposed methodology, etc.

The workshop will also help discuss and gather information on the following activities:

1. Identification of institutions to be involved in the training activities including point of contact and the potential staff profiles. Understanding this will help in assessing the training requirements and will help appropriately design the training plan for the stakeholders

2. Development of a rough outline of the training plan, which can be further worked upon to prepare the final training plan, which is one of the deliverable of the assignment
3. Identification of potential stakeholders for the training and capacity building activities
4. Any other issues that were missed during the consultation meetings, which are relevant for the assignment

These activities will help provide the revised methodology including the work plan, flood and institutional issues, existing skill strengths of the key institutions, and a broad outline of the training plan for the entire project.

3 Task 2: Flood forecast and warning service design

3.1 Design the Flood Forecasting System

Prior to commencing on the detailed design and development of the flood forecasting system as agreed upon based on interactions with IUFMP and other stakeholders as part of Task 1 activities, RMSI will start collecting new topographic data and updated data required for the warning system that will throw further light on the impacts of historical and projected inundation on the city such as vulnerable infrastructure and population pockets as well as potential shelters that can be included in the warning services to help in quick evacuation.

The figure below shows the layout of the proposed flood-forecasting system.

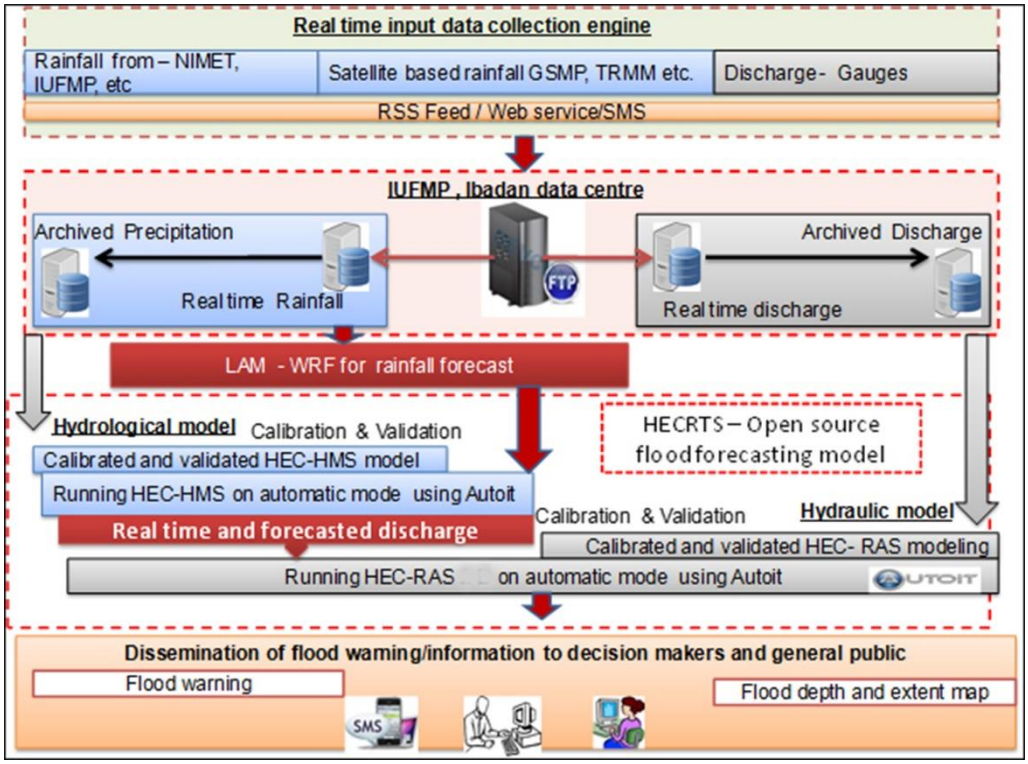


Figure 4: Layout of the proposed flood forecasting system

The typical flow of the proposed flood forecasting system will be as follows:

1. Rainfall and discharge data from various sources such hydro-meteorological network, radar rain gauges and satellite based rainfall will come to IUFMP data center's server through RSS-feed, web services, or SMS based protocol.
2. These rainfall inputs will be picked up by LAM model, which is the Weather Research and Forecasting model (WRF). This model will predict the weather based on current weather conditions. The Weather Research and Forecasting model (WRF) is one of the meteorological Limited Area Models (LAMs) widely used in numerical weather prediction. It requires lateral boundary conditions, which are normally obtained from a global model.
3. This current and predicted weather will act as inputs to the flood forecasting model. RMSI proposes to use HEC-RTS, the Hydrologic Engineering Center's Real-Time Simulation program, which is a publicly available modeling software.
4. A flood warning dissemination system to disseminate flood warning over the web, e-mail, SMS, and other means to decision makers and community.

Based on the above, this task can be further sub divided into four sub tasks:

- Design of meteorological and hydrological observational networks for Ibadan Metropolis
- Development of LAM Model
- Design and development of flood forecasting model HECRTS which includes
  - Design and development of Hydrological model - HECHMS
  - Design and development of Hydraulic model - HECRAS
- Design and development of web-based flood warning system

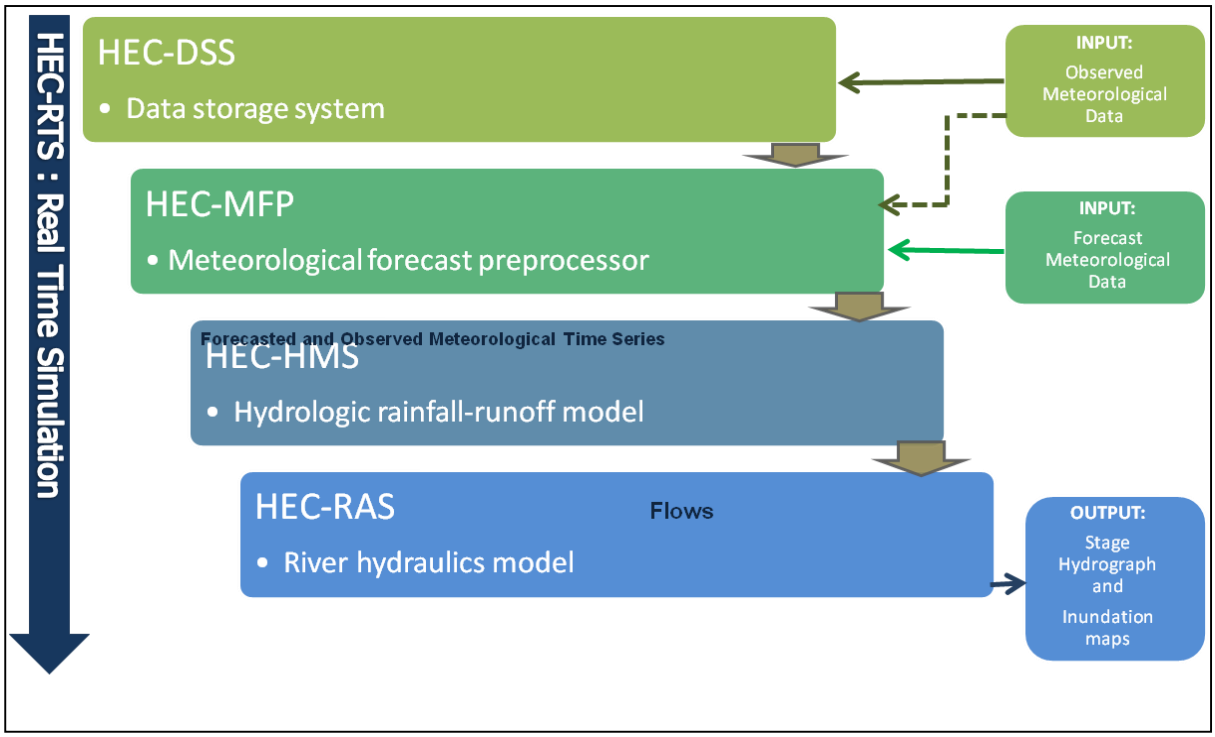


Figure 5: Flood Forecasting Modeling System: Model Schematics

3.2 Develop procurement packages for the system components

The procurement expert of the project team will work closely with the hydrological forecasting system expert and the ICT experts to get an understanding of the system requirements and the required specifications. System requirements and the WMO guidelines will be reviewed to understand the system specifications as part of best practices. The procurement expert will prepare procurement tender package following the guidelines of the Nigerian National Procurement Policy as well as the World Bank procurement policy for goods.

The procurement packages will essentially have system specifications, quantity, warranty and service specifications, delivery and installation, documentation, payment mode, tax details, etc. The procurement package will also provide a guidance note to ensure transparency and fairness in the procurement without compromising the quality aspects of the system. The expert will also review options of import regulations and duty exemptions, if any, and explore possibilities of including international bidders to participate.

The procurement expert will help the IUFMP in preparing the tender documents, carryout the bidding process, evaluation of the tender response and, if required, selection of vendor for providing the system for the installation.

The procurement expert has extensive experience working in this domain in Nigeria for has a good understanding of the rules and policies of the Bureau of Public Procurement and the relevant acts governing the procurement activities of IT systems.

3.3 Design of meteorological & hydrological observational networks for Ibadan Metropolis

Ibadan lies completely within the tropical forest zone but close to the boundary between the forest and the derived savanna. The city ranges in elevation from 150 m in the valley area, to 275 m above sea level on the major north-south ridge which crosses the central part of the city. The mean total rainfall for Ibadan is 1,420.06 mm, falling in approximately 109 days. There are two peaks for rainfall, namely, June and September.

The measurements of precipitation for flood forecasting in the city require denser networks. As per WMO Guidelines (Guide to Hydrological Practices, 2008), recommended minimum densities of observing stations in densely populated urban centers should ideally be one station per 10-20 km^2. Ideally, this optimum network should make it possible to derive required information for flood forecasting with the desired accuracy. As per this guide line, for 3,080 sq. km area at the rate 20 sq. km per gauge, about 150 plus gauges are required.

To get the optimum solution for IUFMP's needs, RMSI will carry out the three below mentioned activities:

- Review of existing hydro-meteorological network to get total number of required gauges
  - Cost of procurement, installation, operation, and maintenance of these gauges
- Cost benefit analysis of various types of gauges and their applicability for the study region

Based on the outcome of the cost benefit analysis, RMSI will propose the most suitable procurement plan.

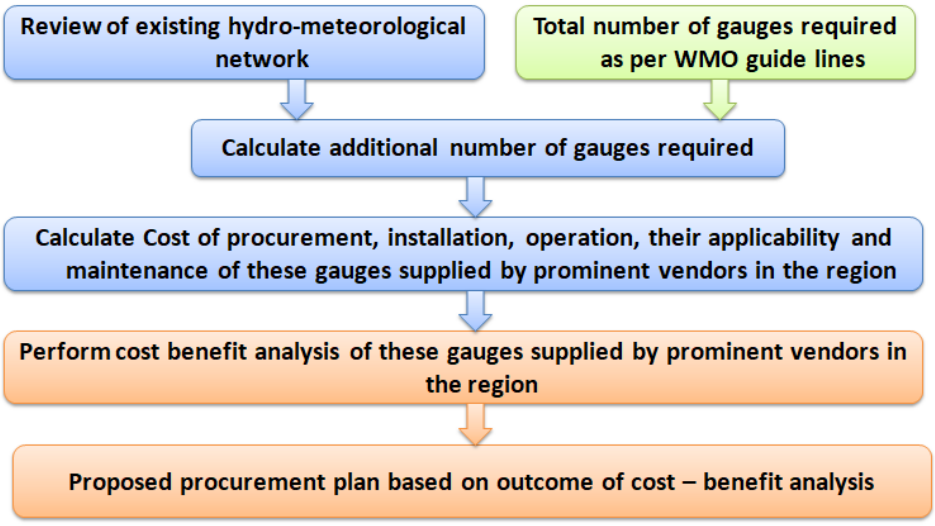


Figure 6: Flow diagram for arriving at an optimum solution for the Design of hydro-meteorological network

3.4 Review of existing Hydro-meteorological Network

Our team of experts will assess the existing network of hydrological monitoring stations within the metropolitan area, the temporal and spatial characteristics of rainfall within the city, and review the city layout plans to propose an improved monitoring network of both meteorological and hydrological stations in close consultation with the Nigeria Meteorological Agency and Oyo State Emergency Management Agency.

3.5 Optimum number of rain-gauges required

RMSI team will calculate the optimum number of rain gauge stations that should be in place in order that the mean rainfall can be estimated with an assigned percentage of error as given by:

$$N = \left(\frac{C_v}{\varepsilon} \right)^2$$

where N = optimal number of stations,

ε = allowable degree of error in the estimate of the mean rainfall, and

Cv = coefficient of variation of the rainfall values at the existing m stations (in percent), which can be calculated as

$$C_V = \frac{100\sigma_{m-1}}{\overline{P}}$$

$$\sigma_{m-1} = \sqrt{\left[\frac{\sum_1^m (P_i - \overline{P})^2}{m-1} \right]}$$

where standard deviation Pi = precipitation magnitude in the ith station

$$\overline{P} = \frac{1}{m}\left(\sum_1^m P_i \right) = mean - precipitation$$

3.6 Design of Automatic Rain Gauge Network

RMSI proposes to design the network by carrying out the following activities:

- Site Selection
- Selection of Instruments
- Selection of Data logger
- Selection of Telemetry equipment
- Installation
- Selection of Sensor Specification
- Cost Estimations
- Operation and Maintenance

The site selection for installation of gauges is governed by factors such as security at site, availability of telemetry window, options available for power, accessibility to the site, and land ownership. The best site can be government office buildings, schools, universities, dams and barrage sites. Preference should be given to those sites where manpower is available. The figure below shows a sample of an automated rain gauge installed at a dam location.

Plate 17: Sample gauge location – gauge installed at dam site

Primarily, the location should have reliable power for continuous and smooth operation of instruments. AC power for 2-3 hours a day is enough to recharge the battery. For remote locations, where AC power is not available, solar power can be considered as a viable option. For solar power, we will have to check availability of enough sunlight. Normally, a 100 AH battery with a 40-watt solar panel satisfies this power requirement. However, final specifications will be derived based on detailed site analysis.

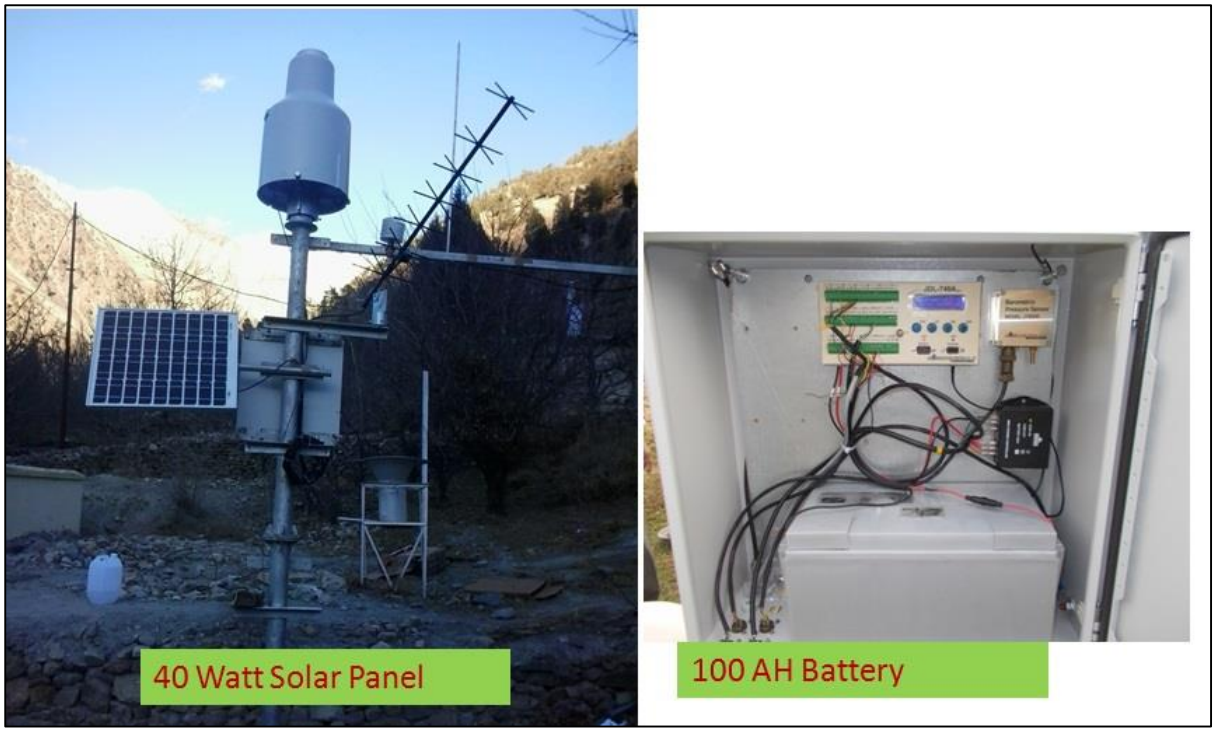


Plate 18: Sample solar panel and battery

General functions of these highly configurable Automatic Weather Stations we propose to use are:

- Supplies power to sensors,
- Read and record data
- Passes on data to telemetry unit for transmission
- Support GSM transmitter or should have inbuilt GSM transmitter
- Data logger as an integral part of the sensor

General Specifications for data logger we propose to use are as follows:

- Sensor Interface
  - 8 analogue channels
  - 8 digital input/output channels, 2 inputs for rain gauge impulses, 6 bidirectional
  - Minimum 1 serial port for digital input SDI-12
- Input/output interfaces
  - One for the satellite radio
  - One for the addition of GSM radio
  - One Serial Port (RS232) for communication with Laptop or programming
  - USB Stick option for Data transfer
  - Flash memory minimum 32 MB
  - Non-volatile flash memory
  - A/D resolution ≥16 bit
  - Individual recording intervals for each sensor/parameter
  - Multi-tasking operating system - must log data and transmit at same time
  - Digital Display for viewing current data and setting values
  - Power supply 12V DC, low current drain (quiescent ≤10.0mA)
  - Monitoring of battery voltage level
  - Internal battery backup for clock
  - Software

- Windows software for system configuration / communication
- English language version
- All required licenses included
- Different user levels, system of user rights / passwords, access restricted to authorized personnel

AWS units also require a telemetry device to transmit data to the central server location. This can be a One-Way (Push method) or a Two Way Communication (Push and Pull Method). The communication medium can be GSM towers or satellites.

Table 3: General specification for Rain gauges

Sensor Type	Tipping Bucket with reed switch
Range	0-500 mm/h
Bucket Capacity	0.2, 0.5 or 1.0 mm

The size depends on peak rainfall Intensity

- Accuracy (Intensity) 2 % or better
- Output Interface as specified in Data logger
- Rain collector material

Corrosion resistant metal (stainless steel/ aluminum) or UV stabilized fiber plastic

- Enclosure IP65
- All openings of the rain gauge shall be covered with a screen to protect against insects
- Syphon system to eliminate over accumulation or under accumulation of precipitation collecting funnel diameter 200 mm
- Ability to service tipping buckets without involving the re-levelling of the gauge

3.7 Flow Monitoring Stations

Flow monitoring stations are recommended to be installed in Ibadan's flood prone areas for monitoring the hydrological water conditions. Hydrological measurement data is essential in the prediction and solution of flood, drought, erosion, and water pollution problems and reliable real-time data is necessary in hydrological forecasting and modeling. Flood monitoring stations in Ibadan should preferably be installed / refurbished in the areas near to water bodies, rivers and streams, and areas which receive higher rainfall such that the network has good geographical coverage across the Oyo state's most productive and/or populous regions. With high quality observations and a suitable selection of measurements, an exhaustive hydrological information database can be built.

The flow meter preferably should be automatic, specifications of which are given in Table 4. The advantages of having an automatic flow meter are that it requires less maintenance, can be operated in flood situations with less supervision and automatic installation angle correction. The sensor can be easily mounted on bridges, superstructures of channels or the ceilings of closed channels.

The main criteria for measurement sites are the properties of the riverbed, the water surface and flow conditions. The riverbed must not change to ensure a consistent measurement. The water surface must not be flat. Wavelets should be visible and stones, maelstroms or standing waves should not occur within the measuring area.

Table 4: Characteristics and specifications for automatic flow meter

Parameter	Specification
General	
Dimension in mm	338 x 333 x 154 mm 2 brackets for pipe diameter 34 - 48 mm
Total weight	5.4 kg
Protection	IP 67
Power supply	6 to 30 V
Consumption at 12 V	Standby approximately 1 mA active measurement about 140 mA
Operation temperature	- 35° to 60°C
Storage temperature	- 40° to 60°C
Lightning protection	integrated lightning protection
Level measurement	
Level range	0 to 15 m - Standard version 0 to 35 m - Extended measuring range (optional)
Resolution	1 mm
Accuracy	± 2 mm
Radar frequency	26 GHz (K-Band)
Radar opening angle	10°
Velocity measurement	
Detectable measurement range	0.30 to 15 m/s
Accuracy	± 0.02 m/s; ± 1 %
Resolution	1 mm/s
Direction recognition	downstream flow or tide (±)
Measurement duration	5 to 240 seconds
Measurement interval	8 seconds to 5 hours
Measurement frequency	24 GHz (K-Band)

Radar opening angle	12°
Distance to water surface	0.50 to 35 m
Necessary minimum wave height	3 mm
Automatic vertical angle compensation	
Accuracy	± 1°
Resolution	± 0.1°
Interface	
Analog Output	3 x outputs 4 - 20 mA for level, velocity and discharge
Interface	Interface: 1x SDI-12 1x RS 485 Transfer rate: 1.2 to 19.2 kBd Protocol: various ASCII-Protocols, Output: discharge, flow velocity, level, quality parameter

3.8 Finalization of product

A cost benefit analysis will be performed for gauges with similar specifications available with prominent vendors in the region. As stated earlier, this cost will include procurement, installation, operation and maintenance of the available devices. A detailed consultation would also be held with Nigeria Hydrological Services Agency (NIHSA). Setting up a station requires investment for infrastructure equipment, logistics, and for operation and maintenance. Scientific planning is necessary for network design so that the desired results are achieved with minimum cost.

These factors would also be considered to optimize a robust solution to achieve timely flood forecasting with desired accuracy.

3.9 Development of LAM Model

RMSI proposes to use the Weather Research and Forecasting model (WRF) - one of the meteorological Limited Area Models (LAMs) widely used in numerical weather prediction. The WRF model is a next-generation meso-scale numerical forecasting system designed for research and operational weather forecasting.

The open source WRF-ARW (Advanced Research WRF) model was chosen based on literature survey and past experiences. The recently published research article by Agogbuo et al. 2017 found regional WRF model predicted higher critical success index for rainfall forecasting over central and southern Nigeria as compared to the global models, such as ECMWF, UKMET and GFS. Another recent study conducted by Mugume et al. 2018 found the regional COSMO model has higher magnitude of errors in rainfall forecasting as compared to regional WRF model over the African country of Uganda.

The WRF-system is a community-based, open-source model, where the latest advances in physics and numerics are incorporated in a modular way. Its development is led by NCAR, NOAA/ESRL, and NOAA/NCEP/EMC in partnerships and collaborations with universities and other government agencies in the USA. It is designed to be a flexible, state-of-the-art

atmospheric simulation system that is portable and efficient on available parallel computing[3] platforms.

Primary reason behind the selection of WRF-ARW model for Ibadan rainfall forecasting is because of its open source availability for both research, training and operational use. The WRF model is accepted widely because of its robustness on predicting the regional weather phenomena with good accuracy (noted from most of the National Meteorological Agencies including NOAA/NCEP, NHC, NWS, IMD, KMA, etc.) at high resolution convection permitting cloud resolving scales 1-3 km. The advantage with WRF model is that the user can do rigorous research and optimization of the domain selection and suitable physics parameter tuning based on the specific weather phenomena (historical events can be used for training) and impact based forecasting with high resolution grid (1-3km) downscaled from the global NWP models. The recent study on comparison of various NWP models for precipitation forecasting over central and southern Nigeria by Agogbuo et al. 2017 suggests that dynamical downscaling a global model using the regional WRF model added value and predicted a better skill of precipitation forecast for the wide spread rainfall events.

In addition to the high resolution (1-3 km) tuned physical parameterized regional WRF model, it can further improve the precipitation forecasting by adding sophisticated data assimilation techniques (Three dimensional variational data assimilation-3DVAR) with high resolution/high quality regional weather observations with high frequency (1-3 hr) assimilation cycle update. It should be noted that those data assimilation exercises at high temporal/spatial resolution require huge amounts of high performance computational resources to deliver the real-time operational forecasts much before the forecast dissemination time.

The high resolution (1-3 km) ensemble prediction system can be implemented towards the uncertainty quantification on precipitation forecasting. This would again require high performance computational resources to deliver the real-time operational forecasts much before the forecast dissemination time. The alternate solution, consultant can buy the robust ECMWF high-resolution global forecast rainfall available at 9 km resolution from deterministic model and at 18 km from ensemble models for direct use in HEC-models for flood forecasting over Ibadan.

We agree that the recent development on high resolution global forecasting products (ECMWF-9km deterministic and 18km ensemble) are able to achieve the accuracy on precipitation forecasting and other weather parameters as compared to regional WRF models running at the same or near higher resolutions. However, these global products from ECMWF are not freely available.

3.10 Sources of Input Data for WRF Modeling System

The WRF model requires land-use and different categories of soil data at different resolutions (as per model domains). The United States Geological Survey (USGS) land-use (LU) data are divided into 24 categories and soil (available in 16 categories), which are available at different horizontal resolutions of 30 arc seconds, 2 minutes, 5 minutes, and 10 minutes on a global basis. Although an alternative LU dataset of Moderate Resolution Imaging Spectroradiometer (MODIS) satellite is available in the public domain, this data is

[3] Agogbuo C N, Nwagbara M O, Bekele E, Olusegun A (2017) Evaluation of Selected Numerical Weather Prediction Models for a Case of Widespread Rainfall over Central and Southern Nigeria. J Environ Anal Toxicol 7: 491. doi: 10.4172/2161-0525.1000491

[3] Mugume I, Basalirwa C, Waiswa D, Nsabagwa M, Ngailo T J, Reuder J, Ulrich S, and Semujju M (2018) A comparative analysis of the performance of COSMO and WRF models in quantitative rainfall prediction. International Journal of Marine and Environmental Sciences, Vol-12 (2), ISNI:0000000091950263

only available at 30 arc second resolution. Besides, this data contains only 20 categories. Data on both USGS and MODIS can be downloaded from the website.

To calibrate and validate the WRF model, initial and boundary conditions necessary to run the WRF can be obtained from the global model NCEP-NCAR Final Analysis (FNL) at 1° X 1° grid resolution. The FNL data can be further interpolated at model grid resolutions using the dynamical downscaling technique. Dynamical downscaling is a method for obtaining high-resolution weather information from relatively coarse-resolution global models. The sources of these datasets are available every six hours for download from the website. For real-time forecasting, the initial and boundary conditions necessary to run WRF model can be obtained from NOAA Global Forecast System (GFS) at 0.5º x 0.5º grid resolution. The GFS data sets are available every three hours for download.

In addition to this data, the RMSI team will collect the observed hourly/daily meteorological weather data (wind speed, temperature, rainfall, and relative humidity) from NIMET and NIHSA. These datasets will be used for validation of WRF model simulated parameters of wind speed, temperature, and relative humidity.

Model configuration details and model input data sources will be finalized with close consultations with the concerned stakeholders and NIMET. The data and data sources mentioned above would be utilized in the analysis. However, the same is subject to change, if better sources are found / made available.

3.11 Proposed configuration details of the WRF model

There are various options for physical parameterizations for the better representation of the key boundary layer phenomena and cloud properties in this model, such as:

Cloud microphysics,

Cumulus parameterization (CP)

Surface layer (SL)

Land surface model (LSM)

Planetary boundary layer (PBL)

The real-time WRF forecasting system will utilize all the above physical parameterizations in various options available with the WRF modeling framework. The model will use the Kain-Fritsch (new Eta) scheme for cumulus parameterization, the Yonsei University (YSU) scheme for boundary layer parameterization, the WRF double moment, 5-class scheme for microphysics and Rapid Radiative Transfer Model (RRTM) for longwave and Dudhia for the short wave radiation scheme. The overview of the WRF grid structure and component programs of the WRF modeling system are shown in Figure 7 and Figure 8 respectively.

The WRF Software Framework consists of several assimilation and parameterization schemes for physicochemical variables, to which pre- and post-processing modules are connected. The pre-processing phase (WPS) includes three routines, Geogrid, Ungrib, and Metgrid that sequentially handle the data that drives the model. Geogrid creates static data that includes geographic data and land use data; Ungrib reads GRIB data and extracts meteorological variables collected from global forecasting models, while Metgrid intercepts the horizontal weather data, scaling them to the domain originally defined.

Pre-processed data is passed to other calculation routines, and specifically to the WRF-REAL component, that vertically interpolates the non-isobaric/isobaric data to the constant number of model levels. It also prepares land surface fields

The final phase of the process is the production of output data originating from the WRF model and subsequent post-processing production.

Table 5: Proposed physics and dynamics for WRF model

Physics	
Cumulus Parameterization	Kain-Fritsch (new Eta) scheme (J.S. Kain, 2004)
PBL	YSU scheme (Hong et al., 2006)
Surface Layer Parameterization	Monin Obukhov scheme
Cloud Microphysics	WRF double moment, 5-class scheme
Long Wave Radiation	Rapid Radiative Transfer Model (RRTM) (Mlawer et al., 1997)
Short Wave Radiation	Dudhia Scheme (Dudhia, 1989)
Land Surface Processes	Unified Noah Land Surface Model

Dynamics	
Time Integration	3rd order Runga-Kutta time integration
Vertical Differencing	Arakawa's Energy Conserving Scheme
Time Filtering	Robert's Method
Horizontal Diffusion	2nd order over Quasi-pressure, surface, scale selective
Spatial difference scheme	6th order centered difference
Horizontal grid	Arakawa C-grid

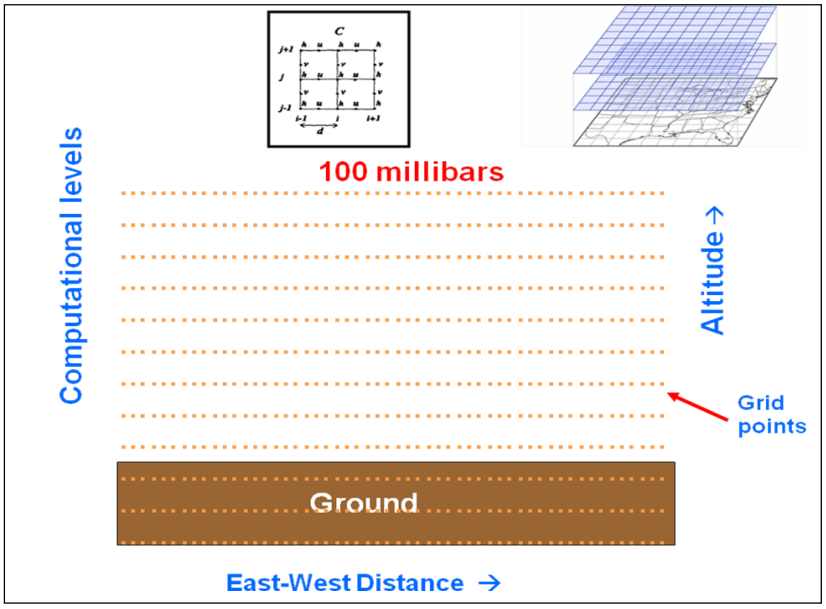


Figure 7: Overview of grid structure for WRF model

(Source: http://www.mmm.ucar.edu/wrf/users/model.html)

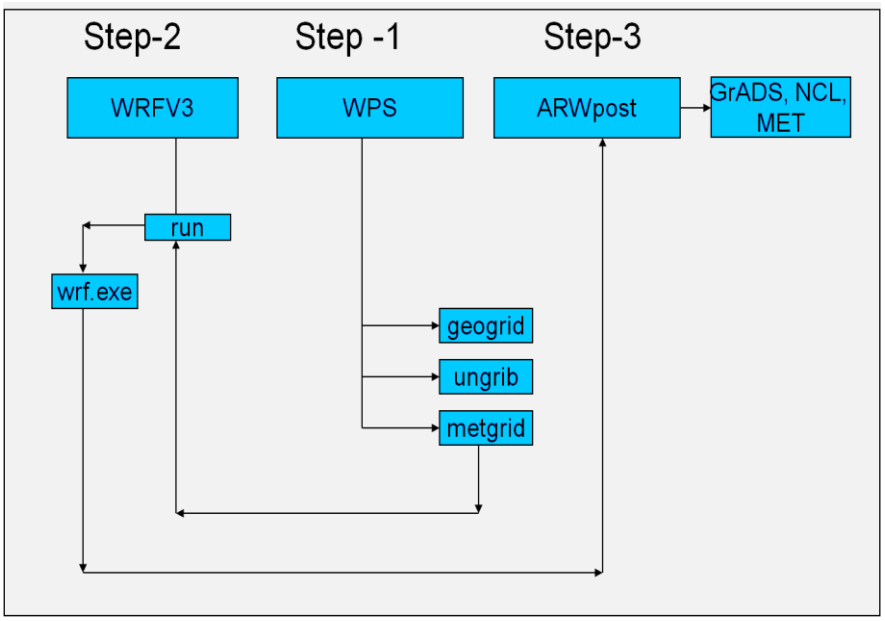


Figure 8: WRF model processing steps (Source: RMSI)

3.12 Salient features of the WRF model:

The WRF Numerical Weather Prediction model is probably the best model for forecasting the day-to-day weather changes at a regional scale. Forecasting the weather using WRF requires two basic ingredients to produce accurate forecasts:

1. Initial Conditions: The current conditions of the atmosphere over a wide area
2. Governing Equations: Mathematical equations that can be solved by computers to forecast into time

   - Conservation of momentum (Newton's 2nd law)
   - Conservation of mass (Continuity Equation)
   - Conservation of energy (Thermodynamic Equation)
   - Relationship among p, V, and T (Ideal Gas Law)

The governing equations of hydrodynamic variables are integrated by numerical methods subject to specified initial conditions. Accurate forecasts with the numerical model simulation depend on the initial conditions used.

The WRF model is fully compressible, non-hydrostatic model (with a hydrostatic option). Its vertical coordinate is a terrain-following hydrostatic pressure coordinate. The grid staggering is the Arakawa C-grid. The model uses higher order numerics. This includes the Runge-Kutta 2nd and 3rd order time integration schemes, and 2nd to 6th order advection schemes in both horizontal and vertical directions. It uses a time-split small step for acoustic and gravity-wave modes. The dynamics conserves scalar variables.

The WRF model Version 3.8.1 supports a variety of capabilities. These include:

- Real-data and idealized simulations
- Various lateral boundary condition options for both real-data and idealized simulations
- Full physics options
- Non-hydrostatic and hydrostatic (runtime option)
- One-way, two-way nesting and moving nest
- Applications ranging from meters to thousands of kilometers

The model can be used to predict/simulate rainfall and atmospheric motion during the summer monsoon, tropical cyclones, west-coast disturbances, thunderstorms, windstorms, squall lines, and dust storms. The model can be utilized at cloud-resolving scale simulations

over small areas. The WRF model is being used with the USGS elevation data with 24 categories of vegetation/land use.

3.13 Design and development of flood forecasting model HECRAS and HECHMS

RMSI proposes to use the HEC Suite models mainly (Listed in the sequence of execution):

- HEC-HMS, a hydrologic rainfall-runoff model
- HEC-RAS, a river hydraulics model (Flood Inundation model) developed by U.S. Army Corps of Engineers4.

The data flow for the models is shown in Figure 9.

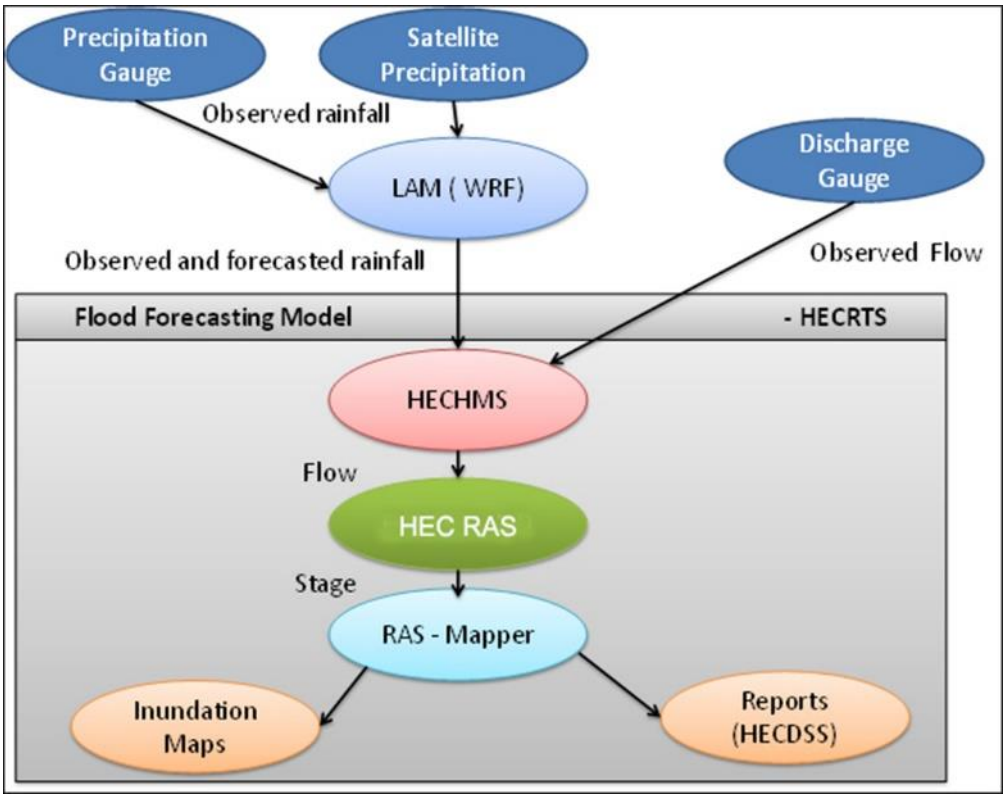


Figure 9: Flowchart for modeling process

The main governing factor for the choice of a method or model for flood forecasting is the understanding and correct definition of the purposes for which the method or model will be used. Each category of models has its own advantages and disadvantages. As a general rule of thumb, the forecasting model must be used to reduce the forecasting uncertainty. There are also practical considerations to be taken into account, such as the limitations introduced by the financial means available and the commercial availability of a particular "off-the-shelf" model.

A brief comparison of some of the numerical models as available has been given in the table below:

[4] (https://www.hec.usace.army.mil/software/default.aspx)

Function	Numerical Application Software			
	Delft 3D	HEC-RAS	Mike Hydro/Mike Flood	Sobek
Mesh	1-D,2-D,3-D: Curvilinear and spherical grids	1-D, 2-D, Couple 1-d/2-D	Coupled 1-D/2-D: Cartesian and flexible grid	1-D, 2-D with Coupled 1-D/2-D: rectilinear grid
Discretization	Finite Difference	Finite Difference	Finite Difference	Finite Difference
Rainfall-Runoff	Sacramento RR Model, WFLOW	HEC-HMS	NAM, Unit Hydrograph, FEH	Sacramento RR Model, Sobek RR model
Structures Types	Barrier, bridge, culvert, deflection wall, floating structure, gate, weir, user defined	Bridge, culvert, dam, gate, pump, siphon, weir, user defined, Rule structure	Bridge, culvert, dam, gate, pump, siphon, weir, user defined, Structural Operation (SO) Module	Barrier, bridge, culvert, deflection wall, floating structure, gate, weir, user defined
Output	Water levels, water surface profiles, flow velocity, flow quantity, Flood maps, 2-D animations and Frequency analysis	Water levels, water surface profiles, flow velocity, flow quantity, Flood maps (GEORAS), Frequency analysis (HEC-SSP)	Water levels, water surface profiles, flow velocity, flow quantity, Flood maps, Frequency analysis	Water levels, water surface profiles, flow velocity, flow quantity, Flood maps, Frequency analysis
Program Manager	Delft-FEWS	HEC-RTS	Mike 11 RT	Delft-FEWS
Licensing	Registration with Deltares	Open Source	Licensed	Licensed

As HEC-suite of Software is cost effective (open sourced) and performs almost all the functionalities for carrying out flood forecasting studies, it has been proposed to use the HEC software for the present project.

The schematic representation of the proposed flood forecasting and inundation-mapping model for the proposed system is shown in Figure 10.

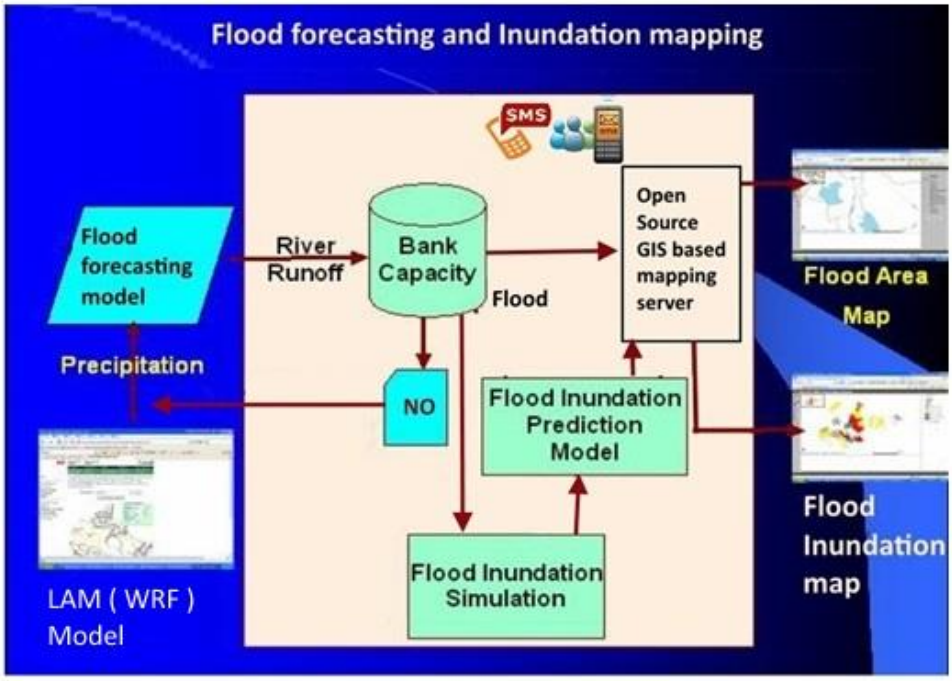


Figure 10: Schematic representation of the proposed flood forecasting and inundation-mapping model for the proposed system

Flood forecasting and inundation mapping involves the following steps:

- Meteorological analysis – this part will be done through LAM (WRF) model
- Hydrological modeling, Flood forecasting
- Hydraulic modeling, and Flood inundation/extent mapping

3.13.1 DESIGN AND DEVELOPMENT OF HYDROLOGICAL MODEL (RAINFALL – RUNOFF MODEL) – HEC-HMS

A hydrological model establishes flow behavior of the watershed or basin by converting the rainfall into runoff. To develop the model, the following steps are generally implemented:

- Basin Delineation using high resolution DEM and river network creation of Basin Model (including all elements such as sub-basins, channels and reservoirs) and estimation of Physical Loss, Routing and Transformation Parameters (for each sub-basin element)
- Addition of Time-Series Data (for various meteorological parameters) and Setting Control Specifications (for running the model)
- Calibration and Validation
- Interpretation of Flows at Critical Locations

RMSI will ensure that the proposed model allows the user to select from a number of methods to represent catchment characteristics for Rainfall Loss and Infiltration, Rainfall-Runoff Transformation, Stream Flow Routing, Base flow Methods, and input of meteorological data (USACE, 2009). The flowchart (Figure 11) explains the systematic approach to be adopted for hydrological modeling. The sample snapshot of HEC HMS modeling interface to be developed for the study area is shown in Figure 12.

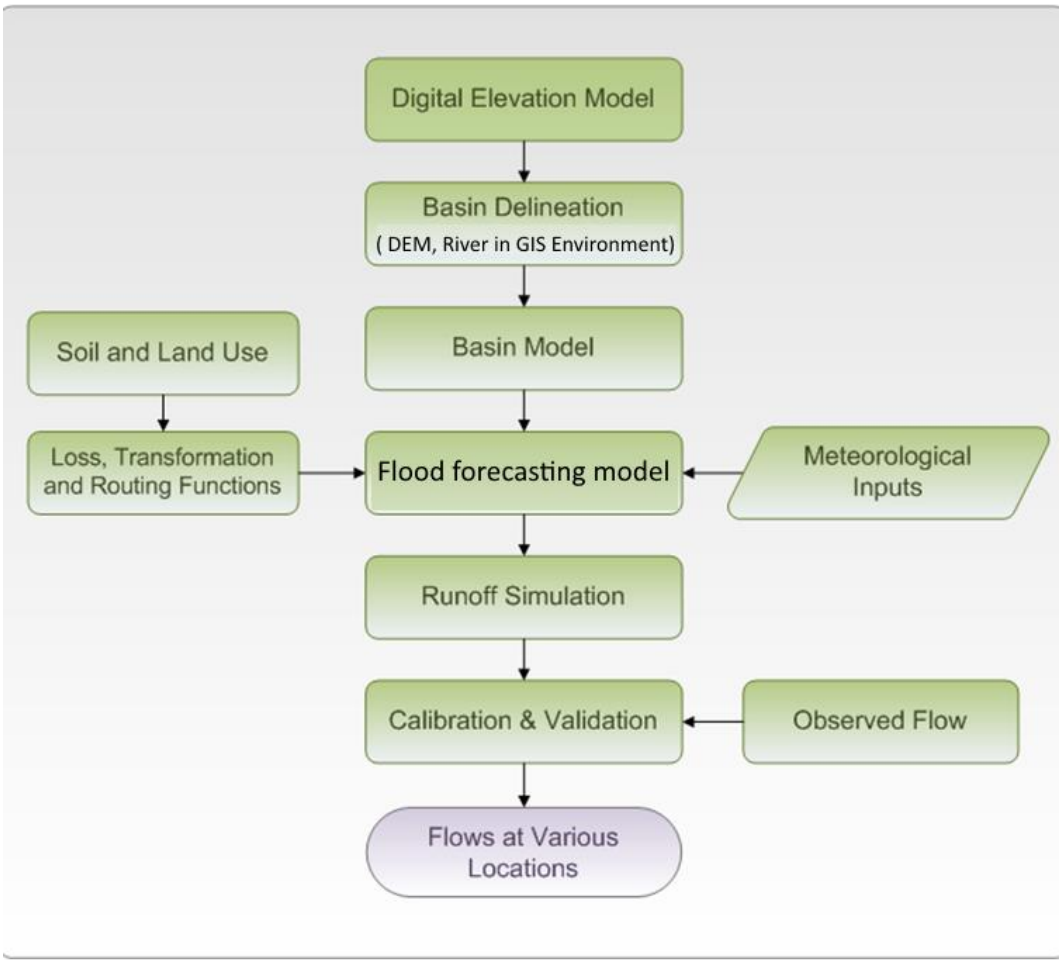


Figure 11: Flowchart for hydrological modeling

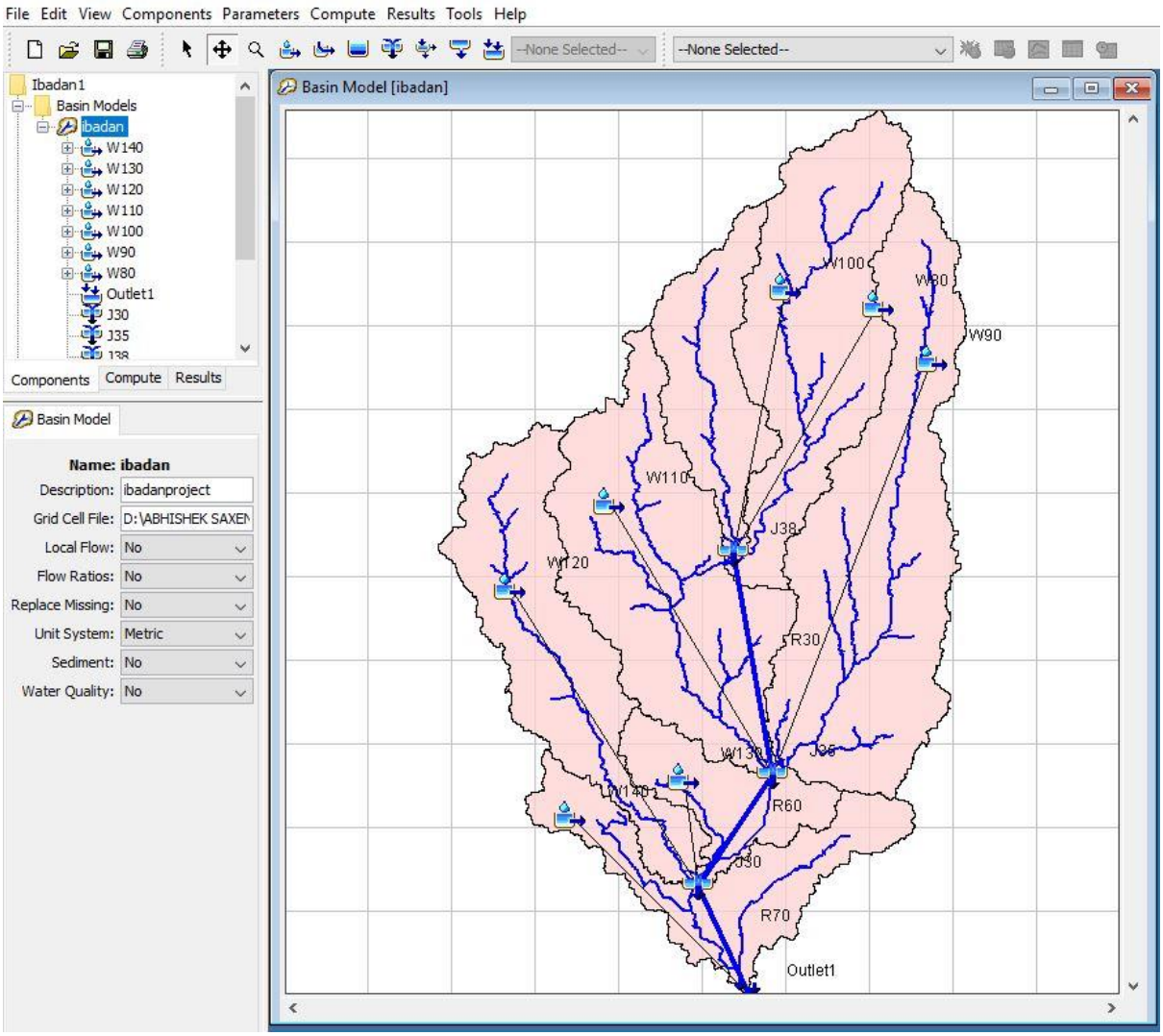


Figure 12: Hydrological model (HEC-HMS) Interface

3.13.2 CALIBRATION AND VALIDATION OF HYDROLOGICAL MODEL

The calibration and validation process is intended to ensure that the model parameters are well set to reflect the physical nature of the entire basin and its sub-basins.

An independent sample of events will be used to calibrate and validate the Flood forecasting model in terms of soil behavior (losses and imperviousness), which exerts a fundamental role over the runoff volume for the episode, and flood wave celerity in the main channels of the catchments, an important factor owing to the high flow velocities. Protocol followed for calibration and validation of model will be:

- Subjective Assessment: Visual inspection is a fundamental approach to assess model performance in terms of its behavior. Systematic behavior like over or under prediction and dynamic behavior like timing, rising and falling limb, base flow etc. of the model will be identified in the initial stages of calibration using this approach, which will extend till model validation.
- Objective Assessment: This approach requires the use of mathematical estimates of error between observed and simulated hydrological variables. Nash-Sutcliffe Efficiency (NSE) and R square correlation would be employed as a mathematical measure of how well the simulation fits in the available observations.

3.13.2.1 Nash–Sutcliffe Efficiency criterion (NSE):

Nash–Sutcliffe efficiency criterion (NSE; Nash and Sutcliffe 1970), is a "goodness-of-fit" measure widely used in hydrological model validation (Jasper and Kaufmann 2003; Dolciné et al. 2001). The NSE values can range from - ∞ to 1, with higher values indicating a better agreement of the model results with observations. NSE is defined as,

$$NSE = 1 - \frac{\sum_{I=1}^{N}(X_I - Y_I)^2}{\sum_{I=1}^{N}\left(X_I - \overline{X}\right)^2}$$

where xi and yi are the observed and model-simulated discharged values at flow gauge site at time i respectively, and ¯x is the mean observed value.

The NSE assesses the ability of a model to correctly simulate stream flow during periods when observed stream flow deviates significantly from the mean stream flow. A perfect model would produce an NSE of 1. However, Moriasi and others (2007) indicate that the performance of a model is considered to be "good" if the NSE is between 0.65 and 0.75 and "satisfactory" when the NSE is above 0.5. NSE values will be derived using observed and simulated flows corresponding to multiple rainfall forecast models. Higher preference will be given to the forecast model, which gives NSE value closer to 1.

A typical discharge calibration plot at a particular gauge location is shown in Figure 13.

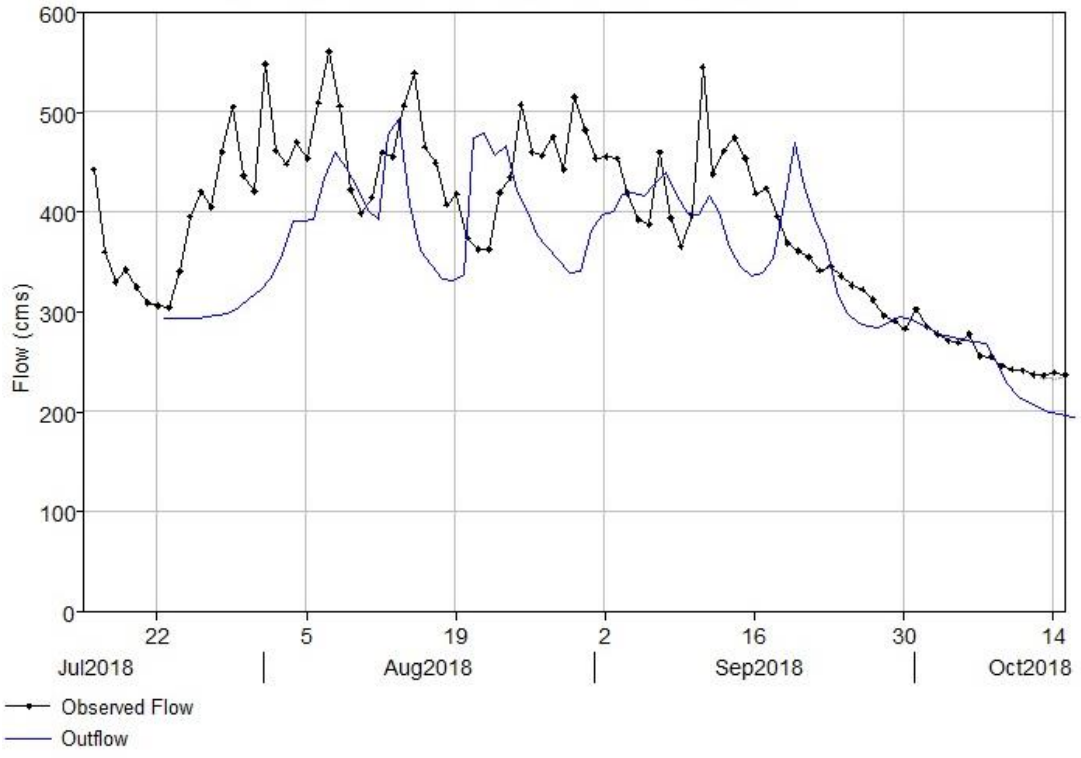


Figure 13: Sample of typical calibration of gauge data

In case of unavailability of time series gauge discharge data, peak discharge data of various flood events will be used in calibration and validation of the hydrological model. The peak discharge data will be collected from the client, historical storm data, and other sources like internet and research publications.

3.13.3 DESIGN AND DEVELOPMENT OF HYDRAULIC MODEL – HEC-RAS

Hydraulic modeling will be performed for the Ona River basin with specific focus on the Eleyele dam using HEC-RAS model. The dynamic maps generation and flood inundation will

be created at smaller scale (e.g. focus will be on exposure areas for all the urban areas of Ibadan situated in the flood zone).

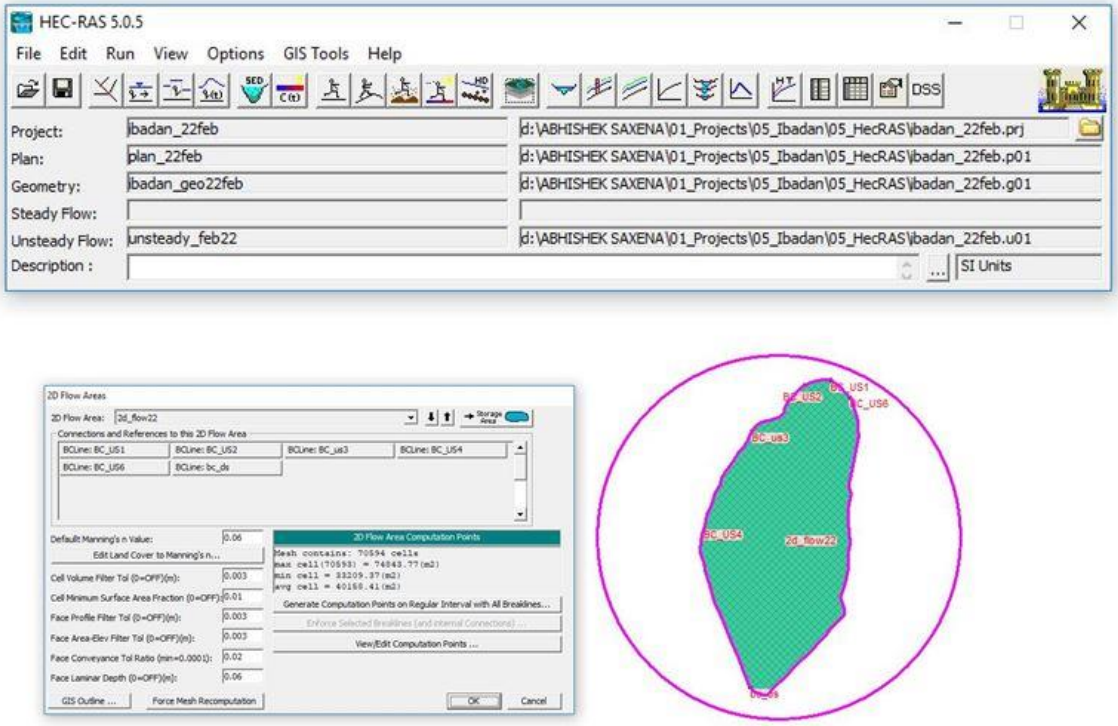


Figure 14: HEC-RAS 2 D Flood Model Interface

The flood discharge will be generated in HEC-HMS module utilizing real time physical and meteorological data inputs. The main dynamic real time/forecasted meteorological variable, namely rainfall, will be input to the model to generate real time/forecasted flood flows. The real time/forecasted flood flows will be the main input to the HEC-RAS module to generate flood depths and inundation maps, which will be able to illustrate the effect of extreme rainfall events.

3.13.3.1 Calibration and Validation of Flood Extents

Calibration and validation of a flood forecasting model requires flood extent and/or depth measurements (spatial distribution) for particular events based on real time observed and real time flood forecasting. High flood marks will be used to calibrate and validate the hydraulic model for the flood events. The real time and forecasted scenarios of flash floods and flood depth maps would be a great asset for the user prior to estimating the severity of future events. The RAS Mapper tool in HEC-RAS enables the modeler to visualize the flood inundation areas. Computed model results can be displayed dynamically on the fly. A sample of RAS output flood map has been shown in Figure 15.

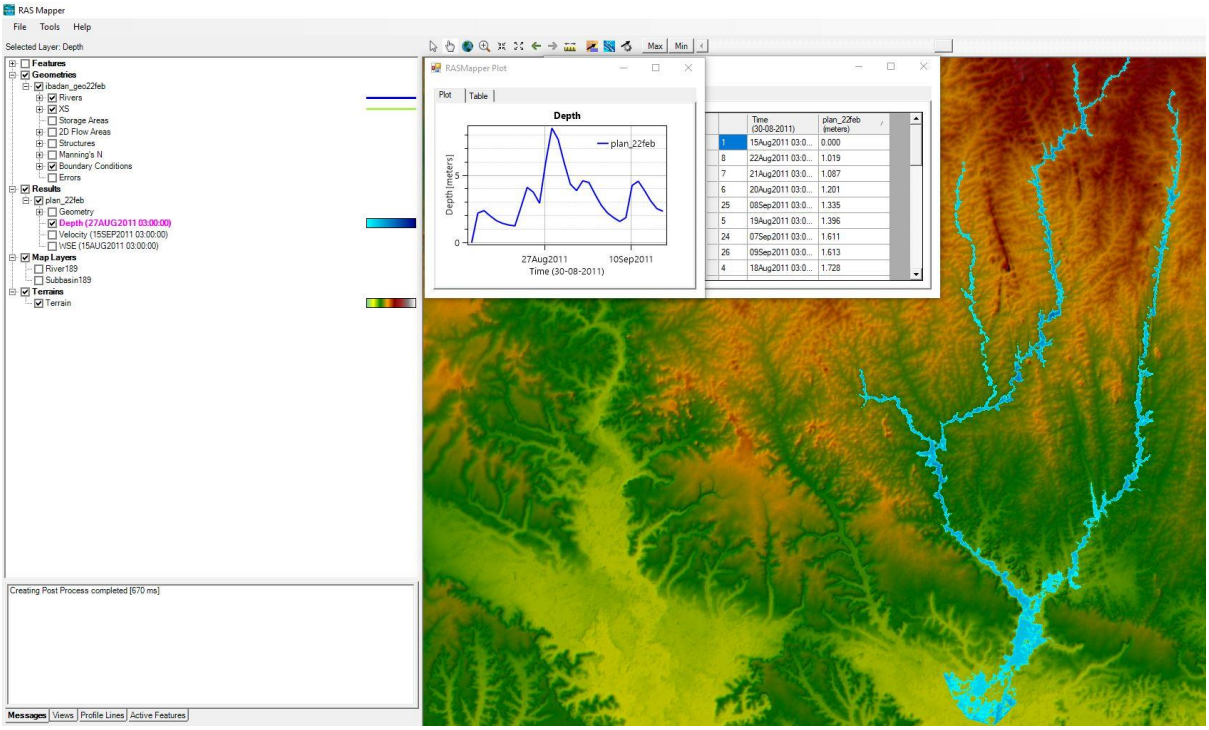


Figure 15: A sample of RAS output flood map.

3.14 Design and development of web based flood warning system

The following are the major engines of the proposed real-time flood forecasting and inundation model.

1. Real Time Input Data Collection Engine: This engine will have functionality to collect input data such as rainfall/discharge from the various sources (NIMET, TRMM, GFS etc.) on real time basis through RSS feed, web services and SMS and store that in FTP server located at data center. The engine will collect data from the above sources as well as take rainfall forecasts from the WRF Local Area Model.
2. IUFMP Data Center: From FTP Server on real time the data will be replicated to rainfall sever and discharge server for archiving.
3. Flood Forecasting Engine – Flood forecasting engine will use HEC-HMS Model to forecast flood (Convert rainfall to run off) real time basis. Here the HEC-HMS Model will be calibrated on the basis of archived rainfall and discharge data. The AUTOIT software will be customized to run calibrated and validated HEC-HMS model to perform flood forecasting tasks on a real-time basis.
4. Flood Inundation Engine – Flood inundation engine will use the flood inundation model to forecast flood inundation depth and extent (Hydraulic modelling) on a real-time basis. Here the flood inundation model will be calibrated on the basis of archived discharge data. The AUTOIT software will be customized to run the calibrated and validated flood inundation model to perform flood inundation tasks on a real-time basis
5. Flood Warning Dissemination Engine – This engine will be developed to perform dissemination of flood warnings to decision makers and general public through websites, media and mobile SMS.
6. Flood Situation Analysis Engine – This engine will have the functionality to provide flood situation information such as the urban areas inundated and number of people affected on a real-time basis. This engine will utilize the information from IUFMP GIS system through web service. This information will be overlaid on the flood inundation map

(output of the flood model) to perform this analysis. The engine will also generate the situation report and map and send it to target users through e-mail.

Figure 16 shows the high-level architectural design for the IUFMP Flood Forecasting System. The high-level design is influenced by the requirements discussed above. The whole architecture is modular. The major modules are user Data Warehouse, Model Components, Platform Components, Trigger/Scheduler and User Interface. The model components are stand-alone and are not dependent on the platform components. Both perform their respective tasks working with the same data on the backend and being guided by the same user interface on the front end. The following sections discuss the various modules in detail and showcase how all the requirements will be delivered by the IUFMP Flood Forecasting System:

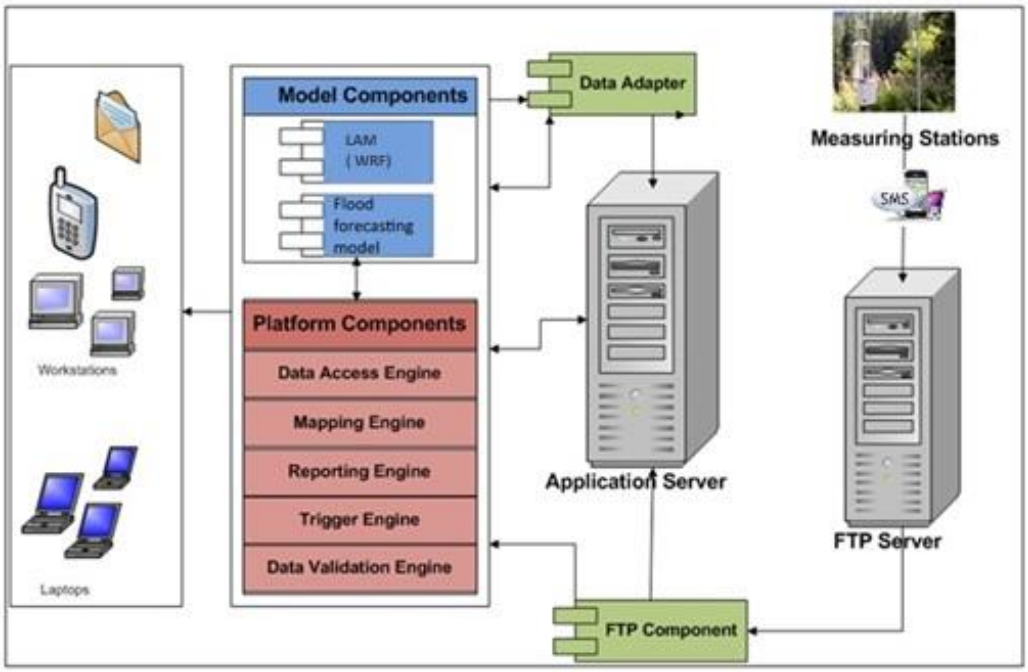


Figure 16: Architecture diagram for flood forecasting system

Salient Features of the proposed model are:

1. Browser-based client application built on .NET Framework 3.5 utilizing the GIS capabilities of an open source GIS platform (Geoserver)
2. Multi-tier system architecture that follows the Object Oriented Programming (OOPS) model with the following objectives:
   a) Loose coupling between the various tiers – presentation, business and data
   b) Ease of development and deployment
3. A powerful reporting engine that enables a set of pre-formatted reports and various views of the output
4. A thematic map generator that provides output as predesigned thematic maps using GIS platform
5. Connection of proposed application to one or more external systems, if required (e.g., that of IUFMP. NIMET etc.) through web service, over the internet to display information or to receive information

3.14.1 PROPOSED PHYSICAL ARCHITECTURE:

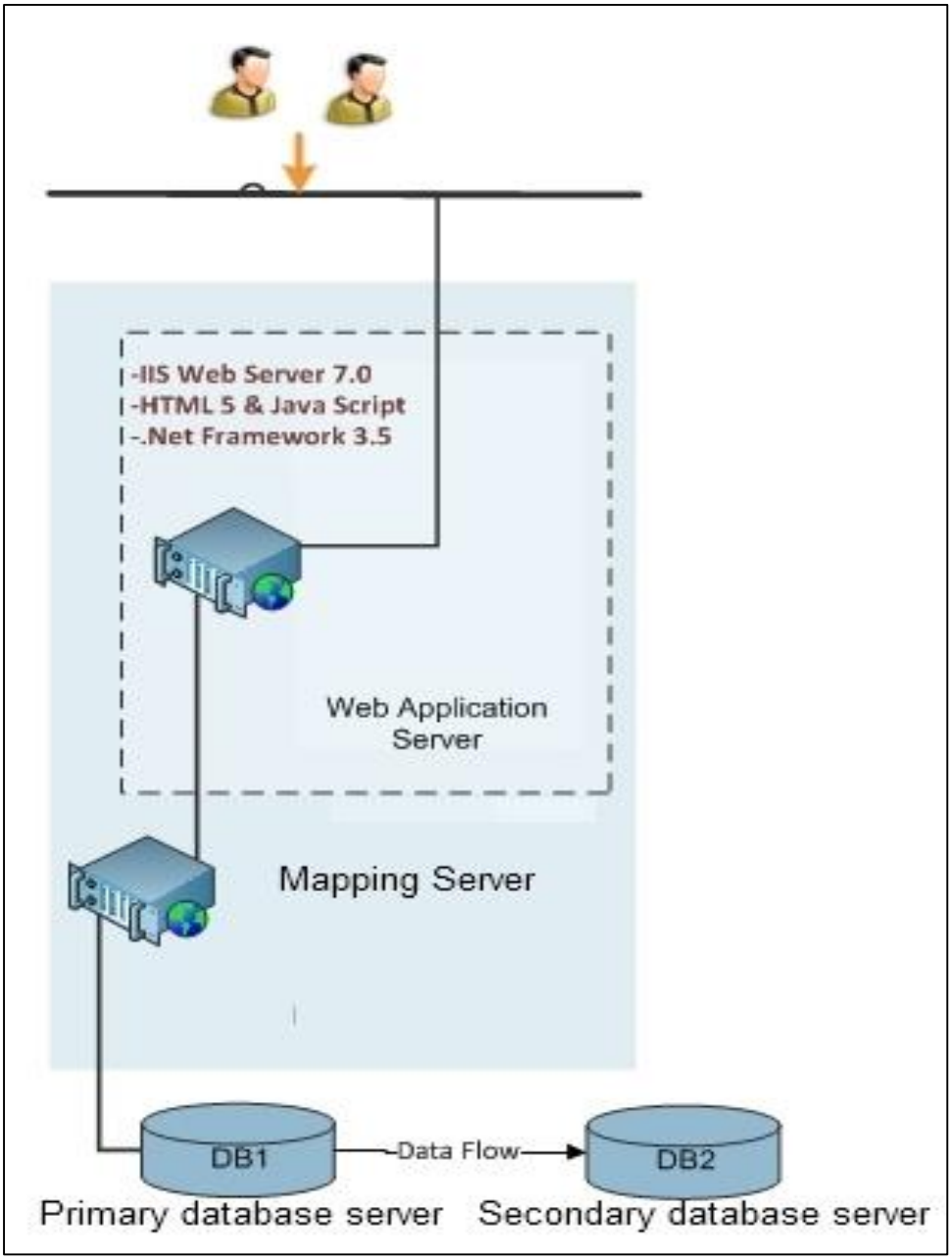


Figure 17: Schema showing physical architecture

3.14.1.1 Security

3.14.1.1.1 Integrated Authentication and Authorization

The authentication strategy will be implemented for the security and reliability of the web applications. Since the presentation and business layers are deployed on the same machine, resources will be accessed based on the original caller's Access Control List (ACL) permissions. The services will be secured by authenticating users, taking advantage of the features of the underlying Microsoft .NET platform. Secure protocols such as Secure Sockets Layer (SSL) will be used during Basic authentication, or when credentials are passed as plain text. Message-level security mechanisms supported by the WS* standards (Web Services Security, Web Services Trust, and Web Services Secure Conversation) will be implemented with SOAP messages.

The authorization strategy will provide the security and reliability to the web applications. Resources will be protected by applying authorization to callers based on their identity, account groups, roles, or other contextual information. For roles, the granularity of roles will be minimized as far as possible to reduce the number of permission combinations required. Role-based authorization will be implemented for business decisions, resource-based authorization for system auditing.

The authentication, authorization, and profile provider web service will provide security services to the web applications with central web based management application to manage users, roles and users in roles.

3.14.1.1.2 Audit Trail

The audit trail mechanism will track all changes to the systems' underlying data so that it can be examined by an auditor at some later point in time.

1. For each database table that requires an audit trail, another table will be created that will have the exact same schema as the parent table with four additional fields:
2. AuditID - a primary key, IDENTITY field
3. Deleted - a bit field that defaults to 0 that indicates if the record has been deleted.
4. CreatedOn - a date time field that defaults to the current date and time.
5. CreatedBy - a field that records who changed the data.
6. A trigger will be created on the parent table for UPDATE and INSERT that inserts the contents from the inserted table into Audit table.
7. Similarly, a trigger on parent table will be created for DELETE that inserts the contents from the deleted table into Audit table, putting in a value of 1 into the audit table's Deleted field.

3.14.1.1.3 Passwords Encryption

For Password Encryption, Microsoft's .NET framework inbuilt support for encryption will be utilized. The following encryptions are part of the .NET framework such as Hashing, Symmetric and Asymmetric Encryption.

The Hash based encryption will be implemented by adding a salt (unique string) to every password before hashing it. Hash based encryption is optimized for speed.

3.14.1.1.4 Database Mirroring:

The proposed deployment will consist of database mirroring. Database mirroring maintains two copies of the single application database and will reside on different server instances of PostGRES/PostGIS Server Database Engine.

Out of the two databases, one database server instance will serve the database to clients (the primary server). The other secondary instance will act as a hot or warm standby server (the mirror server), depending on how it is configured as well as the state of the mirroring session. The database mirroring provides a hot standby server that supports quick failover without any loss of data from committed transactions when a database mirroring session is synchronized. When the session is not synchronized, the mirror server is typically available as a warm standby server (with possible data loss).

The technology which will be used to develop the proposed Flood Forecasting System is given in Table 6.

Table 6: Technology to develop the proposed Flood Forecasting System

Technology	Description
.Net	A high-level programming language developed by Microsoft.
PostGreSQL (Database Server)	PostgreSQL is a powerful, open source object-relational database system. It has more than 15 years of active development and a proven architecture that has earned it a strong reputation for reliability, data integrity, and correctness.
Geoserver	GeoServer is an open source software server written in Java that allows users to share and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards. GeoServer is the reference implementation of the Open Geospatial Consortium (OGC) Web Feature Service (WFS) and Web Coverage Service (WCS) standards, as well as a high performance certified compliant Web Map Service (WMS). GeoServer forms a core component of the Geospatial Web.
Geowebcache	GeoWebCache is a Java web application used to cache map tiles coming from a variety of sources such as OGC Web Map Service (WMS). It implements various service interfaces (such as WMS-C, WMTS, TMS, Google Maps KML, Virtual Earth) in order to accelerate and optimize map image delivery. It can also recombine tiles to work with regular WMS clients.
IIS Server	Internet Information Services (IIS) is an extensible web server created by Microsoft for use with the Windows family. IIS supports HTTP, HTTP/2, HTTPS, FTP, FTPS, SMTP and NNTP

RMSI will provide the following deliverables under this consultancy:

1. Customized application software for extracting and inputting data, and to interface the inundation and forecasting model with other IUFMP databases and information systems. Both the flood inundation model and the inundation forecast model will have the facility to dynamically update the input data file
2. System enabled to convert the inundation model outputs to SMS alerts and customized maps to disseminate to designated recipients;
3. Comprehensive reports on flood model, user manual, and installation manual

RMSI will discuss with IUFMP regarding the possibility of implementing ArcGIS Server in place of Geoserver and MSSql server database in place of PostgreSql based on their license availability and cost effectiveness. If it is found that ESRI ArcGIS Server based solution is better than the proposed solution, RMSI will implement the ESRI based solution.

3.14.2 COMMUNITY USER GROUP ASSESSMENT

Since the communities of the Ibadan metropolis are eventually going to benefit from the EWS that is proposed to developed under this program, it is critical to understand the community perception and needs while designing this system.

RMSI will use the flood vulnerable locations identified and documented by SEMA for any community based activities. Community based activities include understanding of community needs, issues and their perceptions towards improved flood warning system, any preference in the mechanism for information dissemination, etc. The community consultations will also help in assessing the capacity and means of local communities to access EWS information and their ability to react to warnings.

For this, we proposed to conduct a series of community consultation meetings and key information interviews in different localities of the city. We will organize this with the support of local elected representatives and local community organizations. A list of locations in the city will be identified in consultation with the PMU and a schedule for consultations will be planned. The consultations will be carried out using a set of guiding questions. We will have multimedia presentations of some of the flood issues of the locality and interventions required to reduce the flood impact and some best practices elsewhere will be demonstrated during the consultation to sensitize the community. For instance, solid waste management is one of the key issues triggering flood problems in many localities, therefore good practices of handling solid waste (particularly domestic waste) at its origin will be demonstrated.

All community consultation discussions will be documented and analyzed to understand the community needs, issues and perceptions. We will give importance to gender and children while assessing the issues and needs of the communities.

3.14.3 DEVELOP PROCUREMENT PACKAGES FOR THE SYSTEM COMPONENTS

RMSI will prepare a procurement package based on the design and World Bank procurement guidelines. The table below shows the sample plan for procurement of various systems/sub-systems for the Ibadan Flood Warning System. The final procurement package will be based on discussions with the IUFMP and other stakeholders.

Table 7: Sample procurement plan for Ibadan Flood Warning System

Items	Activity No.	Activity	Type	Proc. method	Pcks.	Post/Prior	Issue	Bids received	Ctr. Signed	Ctr. Complete	Contract amount in USD	Disbursed amount in USD	Difference between cost estimate and contracted amount in %	Note
Component: Ibadan Flood Early Warning System														
	1.A.3	Purchase of incremental equipment (automated flow/level gauges) and ICT software and hardware	CS	QCBS	1	Post	August -2019	Nov-2019	Jan - 2020					
	1.A.3.2.1	ICT-hardware, server	G	SH	1	Prior	August -2019	Nov-2019	Jan - 2020					
	1.A.3.2.2	ICT-software (license, basic server software, 2 client applications+automation module), installation and training at customer's site	G	DC	1	Post	Sept - 2019	Nov-2019	Jan - 2020					

After the creation of the procurement plan, finalized based on discussions with IUFMP and other stakeholders, the team will assist in taking the following steps as part of the procurement process:

1. Creation of ToR
2. Estimation of cost involved
3. Creating a tentative schedule
4. Preparation of an EOI document
5. Based on EOI responses, selection of suitable firms for RFP

6. Creating a detailed RFP
7. Evaluating the responses to RFP and submitting recommendations to IUFMP

The procurement specialist in the team will assist in creating the procurement plan and the bidding documents for procurement of various hardware, software and services in accordance with well laid out guidelines. The team and specialist will also assist PIU, IUFMP or other stakeholders responsible for the procurements in the actual process.

3.14.4 HOSTING OF APPLICATION

There are two options of hosting i.e. physical hosting or cloud server hosting. Physical hosting environment requires procurement of all IT infrastructure, servers, server room, Network, etc. and needs to be managed by IUFMP. In cloud hosting, the client just needs to take the services of any good cloud service provider with required server configuration. The cloud service provider will provide the required configuration server in a short timeframe ranging from a few hours to a day.

The advantages of cloud hosting versus physical hosting are enumerated in the subsections below.

3.14.4.1 Server uptime

Server uptime is directly proportional to the performance of your website. Cloud hosting provides maximum network uptime and guarantees no single point of failure. As it is a system of interconnected servers, if at any point one server is unable to take your request then another one out of the multiple servers will take over the workload of the failed server by default.

In contrast, in traditional hosting, a single server set up risks hardware failure and downtime for your website and applications.

3.14.4.2 Pay as per our requirement only

In the cloud hosting model, the client does not have to incur capital expenditure. There is no need for investing in expensive infrastructure and operating expenses are also lower as one needs to pay only for the resources/services which are actually utilized.

In traditional hosting model, one needs to pay a fixed amount for the services whether they are utilized or not.

3.14.4.3 Scalability

Instantaneous allocation of resources with the emerging needs of the website is quite easy and simple with cloud hosting. A cloud hosting set up allows sites and accounts to add or reduce resources like bandwidth, storage, RAM etc. from the bank of resources maintained by the network of multiple servers.

Physical machines in a traditional hosting set up have limited resources and rigid specifications that cannot be ramped up or down without additional capital expenditure.

3.14.4.4 Location Independence

Traditional hosting servers are confined to a fixed place and thus you need to be specific while choosing your server as the location of server plays an important role in loading speed of a website. The cloud hosting servers are present across the world. They are accessible globally via an internet connection and with any device: PC or mobile.

3.14.4.5 Backup & Disaster Recovery

Cloud hosting provides disaster recovery features as data is automatically backed up in inter-connected servers (cloud being a multi-server setup).

Traditional hosting does not offer disaster recovery as there is only one single server where you can host your data and applications. You need to arrange for backup of your data yourself.

3.14.4.6 Performance

The performance of application hosted in a cloud environment is far better compared to a system hosted on a traditional server. For those who require speed of loading pages, flexible and immediate resource allocation, disaster recovery, energy saving and climate-friendly server set up and above all, value for investment, the cloud is a perfect solution.

In view of the above, the RMSI team proposes to install the LAM (WRF) model on cloud platform for real time forecast of rainfall over Ibadan. For real time forecasting, we need 24X7 power supply and hardware and software maintenance to avoid any kind of interruption in real-time flood forecasting. To keep the above conditions in mind we strongly propose the cloud platform option.

3.14.5 DEVELOPMENT OF WARNING SERVICE

The warning service is envisaged as a web-GIS based visualization tool to assist stakeholders at all levels to quickly visualize the flood situation in the area of interest. The tool will be accessible on/through modern browsers as well as smartphones seamlessly or through a parallel smartphone app for mobile phones alternatively.

RMSI expert team will use global best practices for flood early warning, which is based on a color coded system and can be tailored for a specific city such as Ibadan or a region such as the Ona river basin. These color codes will be decided based on flood levels at the site and in close consultation with the client. The sample color codes are given below:

- Yellow for Flood Level 1 and Standby
- Orange for Flood Level 2 and Preparation
- Red for Flood Level 3 and Evacuation

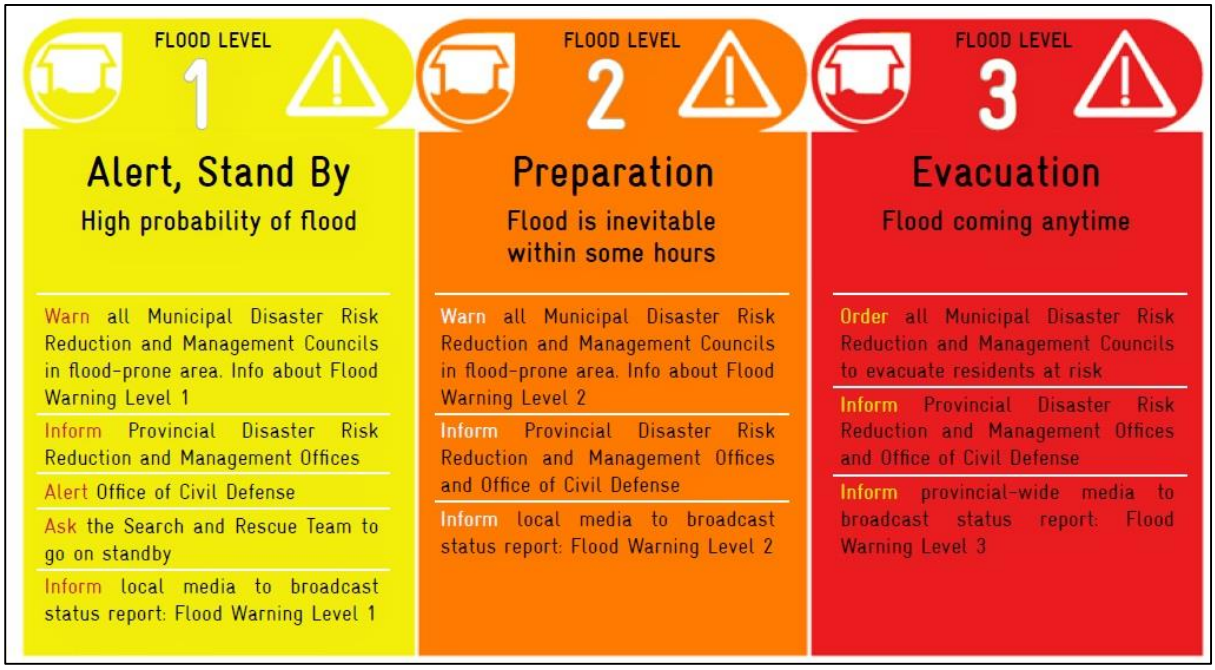


Figure 18: Color coded Flood Warning and Alert levels

These color coded flood warnings will be communicated to stakeholder and government users as well as the general public via the web GIS based warning system, through preformatted e-mail and SMS, automatically forwarding warnings to media (TV and

Newspaper), and where necessary and possible, printing pre-organized pamphlets for further dissemination. An overview of the web implementation is described in the subsequent sections.

3.14.5.1 Dissemination of flood warning and maps through web

The user interface of the web application will provide the ability to view results on maps, graphs or tables by utilizing the Mapping Engine, Data Access Engine, and Reporting Engine components from the Application Logic tier. The UI will offer the following functionalities:

- Display of the following layers by default as the application is loaded:
  - Rainfall/ River station points
  - River basin maps
  - Water channel network
  - Ibadan administrative boundary map
  - Flood alert locations and status with impacted demography and flood control and other essential infrastructure, safe routes and areas etc. (demography and flood control assets to be mapped from existing data provided by national census, IUFMP and other stakeholders)
  - Oyo state boundary map
  - Nigeria Country boundary map
- Basic GIS tools like zoom, pan, zoom to selection, zoom to entire layer, location attribute information and calculate distance.
- Observed and forecasted flow levels from various hydrological/hydrodynamic model as tables and charts in map
- The flood forecasting tool will provide functionality for viewing actual and forecasted river flows at each river gauge stations in the form of hydrographs and tables.

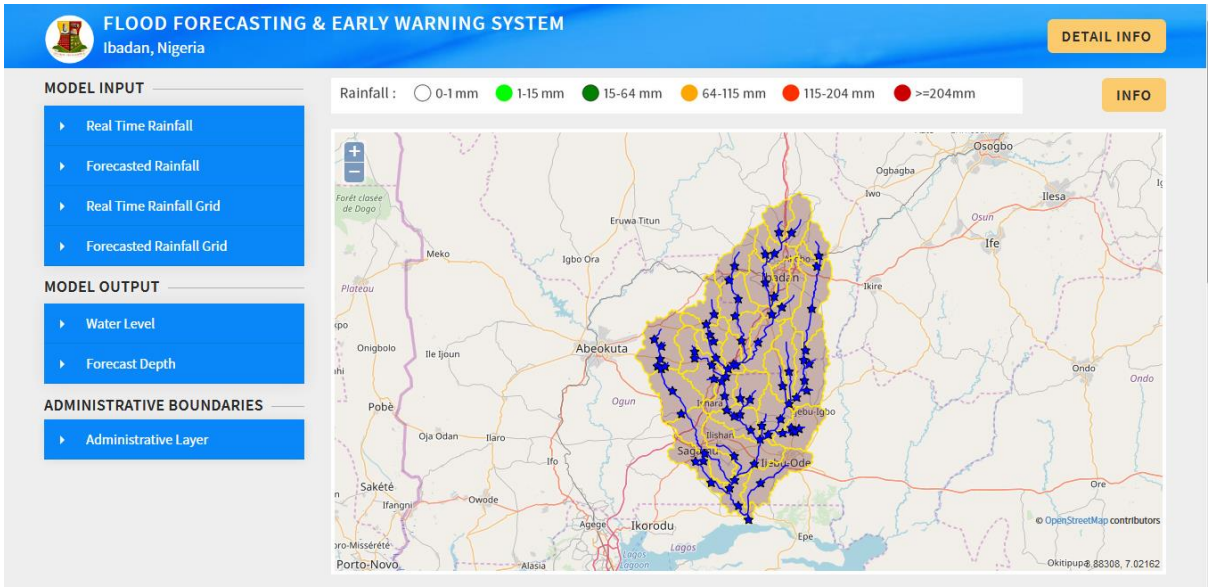


Figure 19: Sample user interface – Ibadan flood forecasting system

3.14.5.2 Functionalities of the Ibadan Flood Forecasting System

- Highlighting the stations in the form of tables and graphs for which data is not telemetered in real time
- Displaying the last recorded flow or rainfall intensities on mouse over any specific location
- Showing user supplied trigger values in graphs and tables.

- Highlighting stations' missing data on the map with different colors
- Generating error logs and their information to the user in the form of reports

3.14.5.2.1 Flood warning Communication through SMS, Email, and other media

To implement timely flood warning dissemination and communication requirements, the following functionality will be incorporated in the system:

- Sets users' supplied 'trigger values – danger level' for river levels/flows for the gauge stations, at bridges or any other locations along the river path in the study area.
- Provides the ability to communicate to the user when these 'trigger values' are breached.
- These 'trigger values' shall initially take the form of forecasted river levels and/or flows from the model outputs
- Communications from the flood forecasting tool to the users in the following formats:
  - Text to multiple mobile phone numbers
  - E-mails to multiple accounts
  - The format of communication forecasts will be - dd: mm: yyyy, hh:mm, level and or flow
- Functionality to the user to define the mobile phone numbers and E mail accounts to be communicated with

Figure 20: Sample showing flood alert message broadcast across mobile network

3.14.6 DEVELOP STANDARD OPERATING PROCEDURES FOR THE SERVICE AND FOR KEY STAKEHOLDERS

Standard Operating Procedure (SOP) is a predefined set of directives used by different organizations to guarantee the expected outcome without any error. In the case of flood risk management, SOPs are required for all the different phases of the disaster cycle – pre-disaster (preparedness and warning ideally before the start of the rainy season), during disaster, and post disaster.

SOPs essentially are a "set of directives, covering those features of operations that lend themselves to a definite or standardized procedure. Such procedures are applicable unless prescribed otherwise in a particular case. Thus, the flexibility necessary in special situations is retained without the loss of its effectiveness". Standard Operating Policies and Procedures can be effective catalysts to drive performance improvement and improving organizational

results. Every good quality system is based on its standard operating procedures (SOPs). In terms of disaster management, a Standard Operating Procedure (SOP) is a set of written instructions that is to be followed by an organization to mitigate and manage any disaster event.

The objective of a good SOP includes:

- To minimize the loss of life and damages to property and to ensure restoration and rehabilitation.
- To illustrate a concise chart, listing major executive actions required in response to urban flooding
- To list necessary tasks for preparedness, response relief and restoration required to be undertaken by the line agencies and departments involved.
- To ensure effective integration of tasks/events of each department at every stage of the disaster management process and enable continuous coordination of all actions.
- To enable reporting of actions taken by each agency / department for further review and updating of the existing SOP from past learnings.

A good understanding of the Disaster Management Act of the country and the institutional aspects of the organizations involved in flood management are critical to develop a robust set of SOPs for the Oyo State. The Disaster Management Expert will review the DM Act, SOPs, if any exist in any other State of Nigeria. In case there are any SOPs that already exist, the team will carry out consultations with the stakeholders who are part of the operation of the SOPs. The key objective of this interaction would be to understand the institutional issues and benefits of using the existing SOPs and how effective the SOPs were during the recent events. We will also review the SOPs in perspective of the inter-institutional collaboration in addition to the directives that are passed down within the organization.

For the purpose of alerts and warnings, internationally accepted color coded uniform system will be suggested. The SOPs essential need to have a designated nodal agency, coordination departments, ensure last mile connectivity, etc.

The project team will also review the existing institutional framework for the dissemination of information including availability of Emergency Operation Centers (EOC) and different administrative levels (National, State and City levels). For SOPs to be operational and effective EOCs at different levels in the hierarchy are essential.

The SOPs developed as part of this assignment will need to be reviewed periodically, particularly after and during flood events. The review of activities and SOPs after a flood event will help in analyzing the success or failure which will help in refining the SOPs further.

The outcome of this exercise will be the preparation of SOPs for line departments involved in different activities during different phases of flood disasters, and separate SOPs for institutional collaboration and information dissemination. The SOPs essentially should address the actions to reach up to ground to ensure that they are effective and achieve the objectives of the SOPs.

3.14.7 DEVELOPMENT OF COMMUNICATION PLAN FOR DISSEMINATION OF WARNINGS

Development of an effective communication plan for information (warnings) dissemination is as critical for setting up of an effective EWS. As discussed in the earlier section, we are proposing an automated system, which is easy to operate and suitable for a country like Nigeria where several installed systems failed to perform well due to lack of skilled human resources and financial resources to maintain and operate them. Automated EWS, once installed, are easy to maintain with less human resources thus making it error free.

As part of the communication plan development, the disaster management experts will review the existing communication plans available in the country (if any) with NEMA or any

other organizations. NEMA has developed a good framework and sound documentation on almost all aspects of disaster management.

For a good communication plan, particularly for flood hazard, all the aspect of the hazard need to be considered. This includes forecasts, short range forecasts and nowcasts, which are different ranges of forecasting required for flood (hydro meteorological) hazard. For instance, a nowcast is basically for thunderstorms and information for warning will be available during the last minute. In such cases, any communication plan that needs to reach the community should be short so that the information is easily followed and action is taken. The communication plan needs to cover all these, which should be clearly defined.

The disaster management expert will review the existing communication technology in the State and country and its future growth path. The plan will take into consideration the growth path and will leverage on existing technologies. For instance, mobile phones are widely used in the country. In the Oyo state they can be an effective and cheap means of information dissemination to communities and the administrative machinery. Communication plan will also have to define channels of information dissemination – for the administrative machinery and for the public. The format and style of content will be carefully designed to improve the effectiveness of information dissemination. The plan will include the following:

1. Last mile connectivity
2. Use local language and short format
3. Multiple media for information dissemination
4. Technology and private partnership for information dissemination

The outcome of this sub task would be communication plan which will be circulated among the stakeholders and presented during the interim workshop for feedback. During the training program, the communication plan will be discussed and we will carry out drills during the testing phase of the system to ensure that the communication plan is robust and takes into consideration all the complex aspects of information dissemination.

3.14.8 DEVELOPMENT OF TRAINING PLAN AND SCHEDULE

Training and capacity building is a key component of this assignment, which is very critical for the sustainability of the project. Our training and capacity building model involves the identified stakeholder representatives to be part of project activities with repeated formal trainings on different aspects during various phases of the project.

During the inception phase of the assignment, we will work with the PIU to identify various stakeholders that should be engaged in various phases of the assignment as part of the knowledge transfer and capacity building. The project team will be divided into sub teams and we will work with these identified stakeholders. For instance, the Disaster Management Expert will work closely with NEMA, OSEMA and LEMA related to SOP development, communication plan, etc., while the hydrologists and flood forecasting experts will work closely with NIMET, NIHSA, etc. This gives focused attention and domain specific discussions with respective departments, which will trigger interest in the stakeholders to actively participate in project activities. The project team will take utmost care that the project activities do not disrupt any of the stakeholder's routine institutional operations.

During the inception phase of the project, the team will take a stock of the existing institutions, their capacity, data availability, level of technology used, and skills of the stakeholder. Based on this, the team will design a training plan and schedule. As discussed above, we will design and use an on-job training approach, where stakeholders get a chance to work on the live project at different phases of its development. We will focus on some of the effective learning techniques tested and proven elsewhere, which are detailed in the below section. The training plan will also include designing content, schedule, presentation style and other documentation, which can add to the effectiveness of the training activities.

The outcome of this exercise would be a training plan, which will be circulated among the stakeholders and will be presented in the stakeholder workshop for feedback and comments. All feedback and comments will be reviewed by the team carefully and will be including in the training plan as required to finalize this. The training plan thus finalized will be used to guide all the training activities suggested elsewhere in the assignment. However, it should be noted that this training plan may be revisited in the course of the project to make necessary modification, if required. Any modifications in the training plan will be carried in concurrence with the client and will be documented.

3.14.8.1 Capacity building and training to local staff

Our philosophy of training and capacity building activities will be based on our strong domain expertise; experience in capacity building, and strong project management skills gained by implementing projects across the world. A mix of international and national experts from different domains will ensure that we transfer the knowledge and enhance the skills of the stakeholders for the sustainability of the system after the project. A high-level view of the key activities in the training and capacity building process are shown in Figure 21.

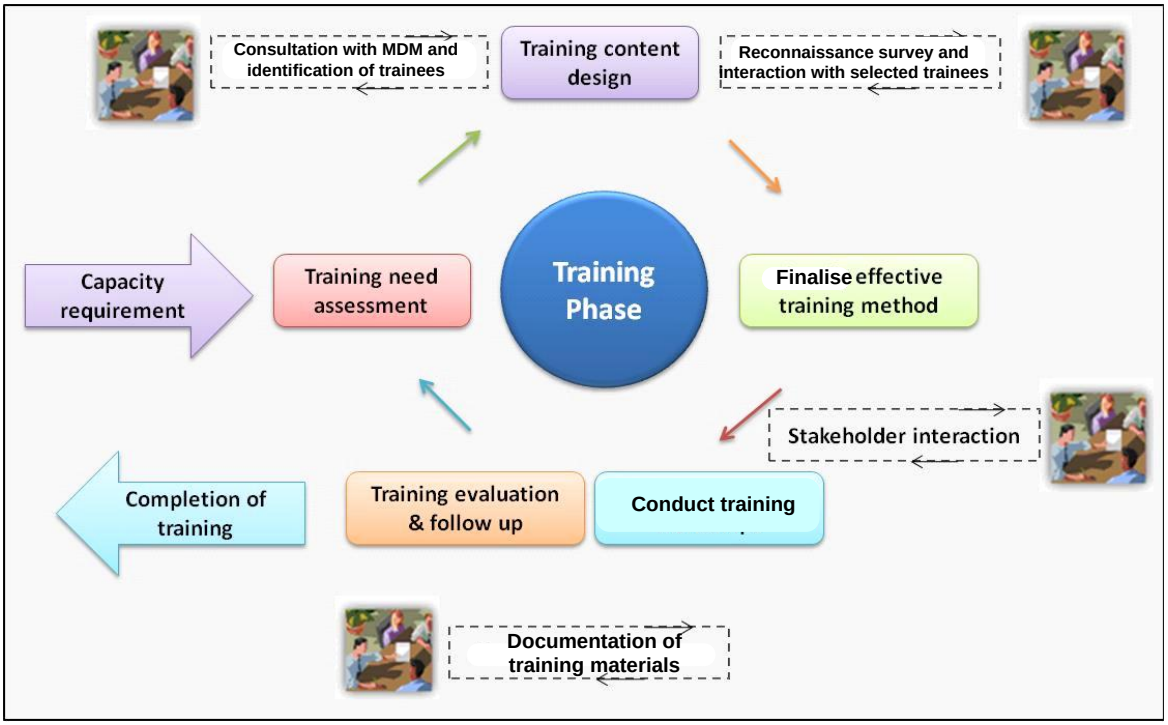


Figure 21: Proposed approach of the training and capacity building for stakeholders

We will follow internationally accepted and tested training principles, which include the points mentioned in the table below.

Table 8: Training practices to be followed

Training process	Hands-on and live training: We prefer that the selected stakeholders are involved in the key project activities as part capacity building and training. We will identify the right department staff for specific activities based on their job role and the institution's mandate. The specific skilled and experience people will work with the international project team in critical phases of the project to get hand-on and live training on operation of the system.
Approach	Active and problem centric learning: Formal training programs will be designed in a way that they involve more than just listening. They will involve problem solving exercises, discussions, and presentations. The

	trainees will be divided into small groups for exercises and problem solving. Taking into consideration the size of the training groups, each session will be handled by a technical expert, training expert and training assistance.
Resource persons	Resource persons: mix of highly experienced international and national experts will provide the training. Several of the experts have extensive experience in the setting up national level EWS and DSS in India and elsewhere. Some of the senior experts are also former faculties of renowned educational institution and have good teaching skills.
Materials	Content of the training materials: the content of the training materials will be designed carefully taking into consideration the skills and capacity of trainees. The materials will be user friendly, with case studies, exercise and success stories, and illustrations and will be related to State context.
Training	Training: content and components will be carefully designed to ensure active participation of participants throughout the training session. This will include avoiding lengthy lectures and concentration on problem solving exercises, group-activities etc.
Post training evaluation	Post training evaluation: All formal training sessions will be followed by post training feedback which will cover all aspects of the training including content, organization of the training, experts, materials, etc. Appropriate steps will be taken to address the feedback in the subsequent sessions and also the feedback will be documented for future reference for the State while conducting future training.
Andragogy	Adult learning strategies: Engaging the trainees in all phases of the training activities. This will include intermittent lectures, contextual examples, group activities, problem solving, participatory learning, and evaluation and feedback.

Even though the overall approach of the different training sessions will be the same, we will customize the content and structure of actual training sessions considering the nature of the domain and stakeholders. For instance, modeling needs extensive hands-on approach while implementation of SOPs and communication plans need mock drills to be part of effective knowledge transfer.

Our models are developed in open sources and will be free of licensing issues and the stakeholders can download the software on their computers so that they can try doing own their own. We also propose to develop a digital knowledge platform and all the stakeholders interested to be part of the training will be registered to it under separate groups. The knowledge platform will be moderated by one of the senior international technical experts. The registered stakeholders can post questions on the knowledge platform and the moderator will review the questions and will provide the response and post it in the system. Once the response is posted, the system will trigger a message to the registered mail ids of the user group so that all the members in the group can see the questions and the response. This platform will help in carrying out effective discussions on the subject without disturbing the professional work. The platform will be compliant to mobile devices as well. All the questions posted and responded to will be compiled and stored on a common platform. The knowledge sharing platform will go live from the inception phase of the assignment and will be maintained till the consultant formally exits the project.

3.14.8.1.1 Training Methodology

Keeping in mind the key objective of training to make sure that the flood forecasting system be functional, productive and exploitable by its users, RMSI will carry out the formal training activities as per the training plan and schedule prepared and agreed upon with the IUFMP. RMSI will impart hands on training as per the training needs identified during various phases on the project implementation including institutional assessment and system requirements analysis phase of the project.

Plate 19: Training and capacity building

The training phase will be executed as per the following methodology:

- Training needs will be identified/detailed based on discussions with client during the requirements analysis phase of the project.
- Training content will be designed --- tutorials and system documentation will be developed.
- Training methods will be identified and will include the following:
  - List of participants for the training programs will be identified.
  - Faculty from RMSI project team will be identified to provide the training.
  - The team will initiate working on the contents of training course material.
- Training will be delivered as per the training plan prepared and agreed upon. Training program schedules will ensure that all trainees/identified stakeholders from client team receive the necessary training for their designated roles as per the procedure.

3.14.8.2 Training Evaluation and Feedback

At the end of the training session, RMSI project team will seek feedback from the trainees about the training. Trainees will be able to provide feedback on the following parameters:

1. Quality of training contents used
2. Knowledge of the trainer
3. Ability to address queries of the participants
4. Coverage of the intended topics for the training
5. Arrangements made for the training

The training expert of the project team will evaluate the feedbacks given by the trainees and take appropriate actions so that the feedback points are addressed in the subsequent training activities.

3.14.8.3 Software Manuals and Training Material Standards

As a standard IT practice following international ISO and CMMI standards, RMSI will follow standard procedures for preparation of software manuals. In the present case we will also consider the WMO standards, if any need to be followed.

RMSI will provide two primary software manuals relevant to the end-user - an operations manual and a detailed user manual on the web portal and mobile/SMS application. The former is for the reference of operational staff who in the later stage maintain the portal and the latter is for the reference of users of different levels to use the portal. Training material, as presently conceived, will mainly consist of presentations in PowerPoint and or documents with explanatory notes and exercises.

The general standards these deliverables will adhere to are:

- All material will be provided in English language using current standards in SW documentation, e.g. the Microsoft Manual Style
- Documents and training material will be explicit in simple language and describe all steps involved in using, updating, management and extracting.
- All steps will be fully illustrated with screenshots. Complex steps will be illustrated further in detail, dialogue box by dialogue box so that end users can use the controls as detailed in the manuals/training material and actually see the functions taking place on the screen.
- The user manual, and for any training material where it may be understood to be beneficial, will view the portal from two different perspectives, namely, descriptive and functional.
- A descriptive perspective will simply divide the user interface into its logical parts and describe the parts.
- On the other hand, the functional perspective will describe the system as a set of functions that the user can perform through the portal. For example, a function such as updating data in the portal by an authorized user will be described as a series of steps. This will help users of all levels to understand what steps need to be taken in the portal to perform different functions. Material will be primarily provided in soft format.

An online help system will also be integrated to help the user for smooth operation of the system.

RMSI will submit a draft final report which will include details of all the models, tools developed, manuals and details of reporting protocols. RMSI will also submit a report on implementation of the system at IUFMP infrastructure.

4 Task 3 – Implementation of the flood forecast and warning service for Eleyele Dam and Ona River Basin

4.1 Supervision of installation and calibration of the observation networks

Once the procurement steps mentioned earlier have been completed and an agency has been contracted, RMSI envisages the following steps as part of installation and calibration of the enhanced observation network.

- Plan the entire implementation with the agency contracted for installation
- Explain the design in detail
- Work with agency/contractor to identify the exact locations for installation
- Finalize the schedule for installation
- Depute RMSI resources to monitor installation process

As a part of this task, RMSI will provide the below mentioned services:

- Technical supervision for the design and installation of the Automatic Hydrologic Information
- System Identification for Automatic Hydrologic Information System
- Support for the selection of basic infrastructure for the Automatic Hydrologic Information System
- Technical studies for installation support
- Control and monitoring of the installation
- Installation of network checkpoints in the river basin
- Mathematical models for hydrological and hydraulic management
- GIS application AWIS operation services

4.2 Supervise the installation of the system at data center

The below mentioned activities will be covered as a part of this task:

- Oversee capacity planning, perform power audits and ensure appropriate supply of power to all equipment.
- Analyze and determine appropriate layout of all equipment in data center with help of balancing and cooling.
- Monitor and supervise all data center solutions.
- Monitor installations of data center hardware as per requirement.
- Document all power and space schematics and ensure accuracy in the same.
- Ensure effective layout of all tools as per industry practices.
- Monitor all data center assets for tracking information.
- Coordinate with vendors and resource engineers and ensure effective completion of all installation hardware at various data centers.
- Monitor all issues and escalate issues to appropriate department to ensure effective resolution.
- Supervise installations of all equipment such as alarm system and firefighting tools.
- Ensure compliance schedule for everyday operations.
- Maintain standards of service levels at all times, ensure response within timeframe and manage all available services

4.3 Installation of LAM: WRF Model for Quantitative Rainfall Forecasts (QPF)

For the present assignment, WRF model (version 3.8.1, ARW dynamical core) will be configured with three interactive nested domains from coarser to finer resolution to forecast rainfall over Oyo state, Ona River basin and Ibadan metropolitan areas for the next 24 to 72 hours.

The flowchart illustrates the component programs of the WRF modeling system.

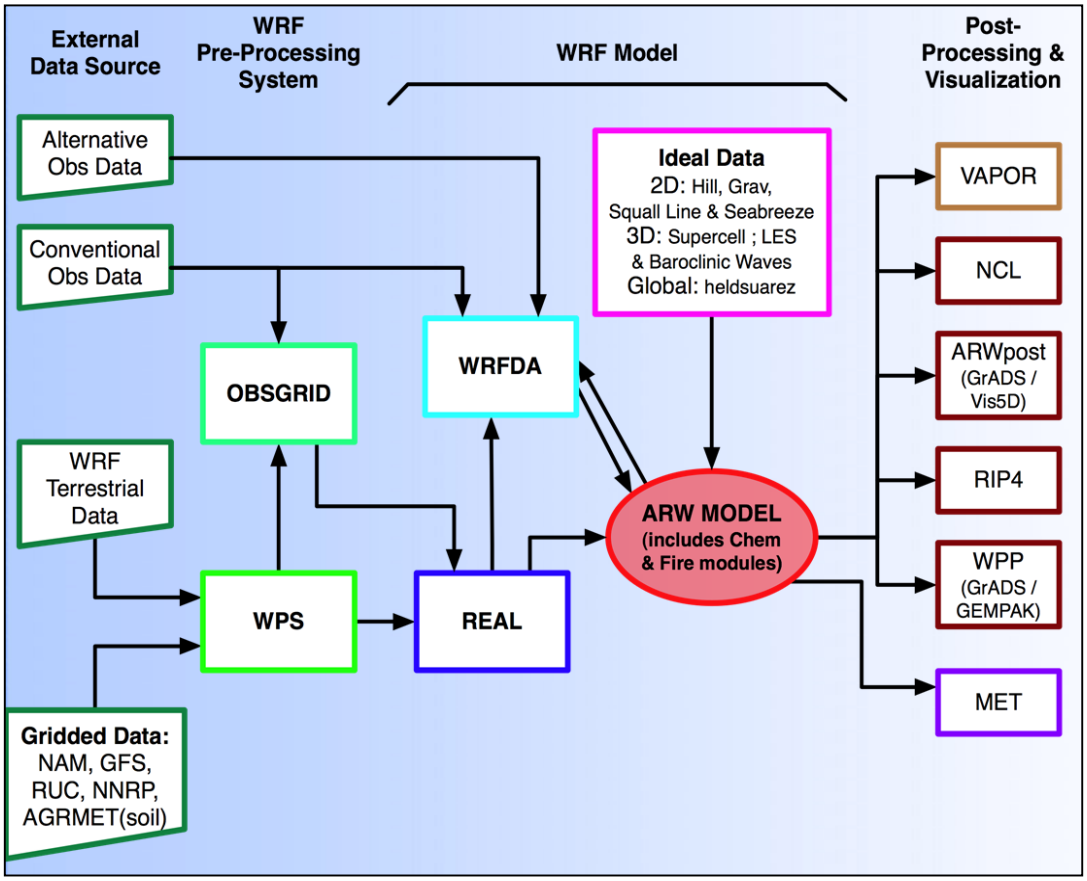
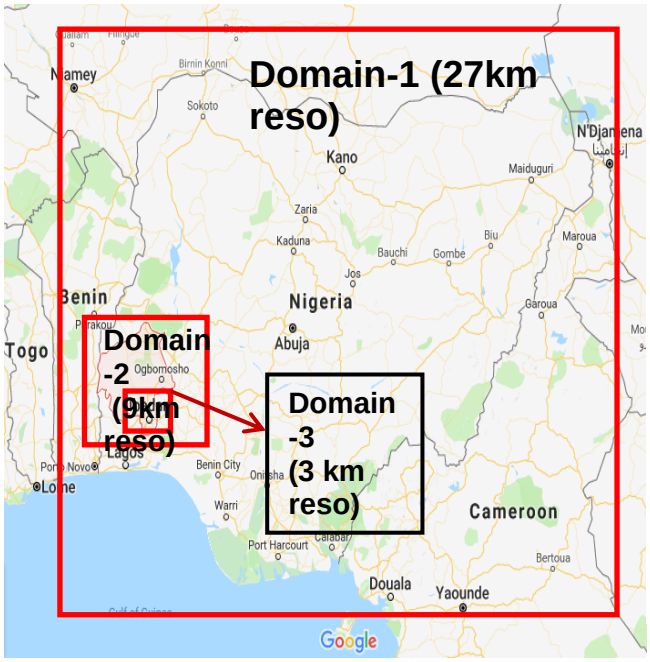


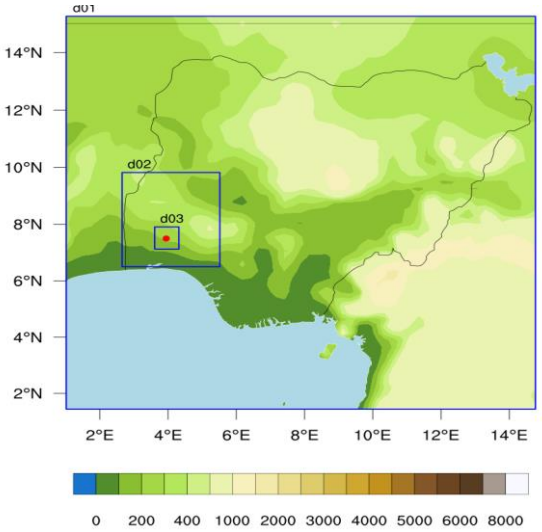
Figure 22: WRF modeling system flow chart

(Source: http://www.mmm.ucar.edu/wrf/users/model.html)

Nesting will be performed at 27 km, 9 km, and 3 km, each resolution adequate for different scales and characteristic phenomena included in the WRF model. The innermost domain will be centered over Ibadan with high-resolution grids of 3 km x 3 km to represent the regional scale circulations and to solve the complex flows over this region. Thus, the WRF model would provide output variables at each of the 3 km x 3 km grid points and therefore no interpolation methods will be applied for generating the final results over the city. Each of the grid points will be directly written to the final files avoiding any error or truncation issues deriving from interpolation techniques. The WRF model is capable of modeling the rainfall at different resolutions and each of the scales is treated accordingly with the Navier-Stokes equations and the corresponding Planetary Boundary Layer (PBL) and Surface Layer schemes' parameterizations available in the model. An example of RMSI's recently developed/customized WRF model with nested domains setup for Ibadan is presented in Figure 23.



Model Domains



Domains topography- USGS, 10 min, 5 min and 30 arc sec

Figure 23: Example of WRF model with nested domains developed by RMSI

The customized WRF modeling system will provide outputs for several meteorological parameters such as rainfall, wind speed, temperature and pressure among other variables at each of the 3 km x 3 km grid points over the city/basin and any height between ground level and the troposphere at every one-hour interval. This will allow us to estimate real time flood forecasting by making use of the estimated rainfall intensity at every hourly time step. The WRF model will use land-use and different categories of soil data at different resolutions (as per model domains). The initial and boundary conditions necessary to run the real-time WRF forecast will be obtained from NOAA's GFS model at 0.5° X 0.5° grid resolution. The GFS data will be further interpolated at model grid resolutions using the dynamical downscaling technique.

Here we proposed to implement the analysis nudging technique (Stauffer and Seaman, 1990) within WRF modeling system to improve the rainfall simulation over Ibadan metropolitan area. Nudging (Newtonian relaxation) technique is a simple form of data assimilation, that adjusts dynamic variables of global models using meteorological reanalysis data to give a realistic representation of the atmosphere at a given time. Nudging technique carries out two main operations: (i) bringing the analysis data onto the model grid and time-steps and (ii) relaxing the dynamic variables to this data. The Analysis is introduced into the model by addition of a non-physical term to the model equation.

The change in a variable (Δx) after Analysis Nudging is given by:

$$\Delta x = F(x) + G(X_{ana} - X_{mod})$$

Where, $F(x)$ – All the physical forcing terms of the model (advection, Coriolis, etc…)

X_{ana} - is the value of the nudged variable in the analysis

X_{mod} – is the value of the variable in the model

G – Relaxation parameter (Constant = 3×10^{-4} s^{-1})

The 3DVAR data assimilation technique (Barker et. al. 2004) available within the modeling framework can also be used to assimilate the real-time output available every 30 min/hourly for surface and upper air weather observations such as, temperature, dew point temperature, wind speed/direction, relative humidity, and surface pressure to forecast heavy rainfall and associated meteorological parameters with better accuracy.

4.3.1 MODEL CALIBRATION & VALIDATION AND UNCERTAINTY:

The calibration and validation process consists of systematically comparing the model's simulated meteorological parameters such as rainfall, temperature, wind speed and humidity etc. within the study area against the observed parameters. This process generally incorporates comparisons between simulated and observed parameters. For the present consultancy, model simulated rainfall and other meteorological parameters such as wind speed, humidity and temperature etc. at different heights would be validated with the available data from weather station networks and satellite imagery (e.g. NIMET and NIHSA etc.). Further, the validated model will be used to forecast the rainfall extent and intensity that would be one of the inputs to the HEC-RTS model.

Uncertainty of the model outputs will be estimated by running some different configurations of WRF model that has different turbulent schemes and slightly different initial conditions which perturb the model and give an indication on how sensitive the studied region is to some changes in the model. The generated results by the different configurations will then be post processed and mixed up in order to get an idea of how wide/uncertain the rainfall distribution is.

Model configuration details and model input data sources will be finalized with close consultation between RMSI and NIMET, NIHSA, and other concerned stakeholders. The data and data sources mentioned above will be utilized in the analysis. However, as mentioned earlier in this submission, the same will be subject to change if better sources are found or made available by the client.

4.3.1.1 Archiving of data

All the data will be archived every Friday (Every 7th day) through an automatic agent in the secondary storage device. This backup will run in the automatic mode and will be available for users for future analysis.

4.4 Develop a procedure to test the system components and testing

RMSI is CMM5i level company and follows a very robust and detailed process to ensure quality of the development.

4.4.1 SYSTEM TESTING

The objective of system testing is to validate that the software built conforms to functional and non-functional requirements specified in the Software Requirement Specifications so that it works as expected. Thus software testing ensures the quality of product built.

To ensure that adequate efforts are made towards producing quality software, a separate team for system testing comprising of full-time test engineers will be formed. Iterative builds will be released to testing team.

RMSI will carry out the following activities in this step:

4.4.2 TEST CASE PREPARATION:

The purpose of preparing test cases is to have a documented way of validating specified functionality in a structured and exhaustive manner. Test case preparation will involve the following activities:

- Study of Software Requirement Specifications document
- Documenting test cases detailing the steps to be carried out to validate specified functionalities
- Review of test cases to ensure adequate coverage

4.4.3 TEST ENVIRONMENT PREPARATION:

The output of this step will be a well-isolated environment suitable for system testing.

4.4.3.1 Test Case Execution and Defect Tracking:

This step involves performing the actual testing of the system and includes performing the following activities: Test site links, execute test cases to test business logic and functional requirements, test overall site, test template with target browsers, logging of defects found in a defect tracking tool, and assignment of defects to appropriate developer for rectification. The output of this step will be a test report giving details on defects validated and new defects found with their severity and priority.

Non-functional testing: The purpose of this step is to test whether the system meets the non-functional requirements including response time, throughput and load. It may involve one or more of the following activities: Recording of test scripts, Simulating load on system using the test scripts, and Taking measurements of response time. The output of this step will be a test report detailing the measurements recorded and identification of potential bottlenecks.

User Acceptance Testing: The purpose of User Acceptance Testing is to establish whether the system developed meets the expectations of the system users or not. This will involve carrying out of following activities: Deployment of system at the operation environment for testing by its users, Execution of user acceptance test cases by the users, and Reporting of defects/issues by users and fixing of the same. The output of this step will be the issuance of an acceptance certificate by the client.

4.5 Training on operation of the systems and services

The objective of providing trainings will be to ensure effective use, maintenance and on-going improvements of services at the operational level while also ensuring overall management and support of the system for long-term sustainability.

RMSI will conduct two types of trainings for the stakeholders of the flood forecasting system:

1. Structured training for the personnel from IUFMP and other organizations
2. On-job training for engineers (maximum 05 no's) at India for five days under train the trainer program

4.6 Structured Training for Engineers from IUFMP (10 Days program – 8 hours daily)

This program will be designed to train at least 10 selected resource people from IUFMP as trainers who can act as further resource personnel within the various departments involved in running the flood forecasting system.

The train the trainer manual will be designed around the following points:

- Various aspects of hydrologic forecasting including
  - Precipitation analysis,
  - Theory and operation of hydrologic model,
  - Use of GIS & geospatial data sets and tools,
  - Sediment transport,
  - Hydraulics, meteorology (especially QPF),
  - Probabilistic forecasting,

- Remote sensing, statistics,
- Communications, community participation, and
- End to end hydrologic forecasting

The tentative training program is given in the table below:

Table 9: Training program schedule

S. No.	Days	Theme	Topics
1.	Day 1	Over view of flood forecasting model and Inundation model	Principles of flow in hydro systems, flow processes and hydrostatic forces, fluid kinematics, energy and momentum equations
2.	Day 2		Energy and momentum principles in open channel, uniform flow, gradually varied flow, channel transitions, spatially varied flow, unsteady flow, flow in mobile boundary channels, pollutants transport in open channels, flow measurements, fluid flow machines
3.	Day 3		Hydrology – hydrologic system, rainfall, evaporation, infiltration, surface runoff, unit hydrographs, s-hydrograph, reservoir and stream flow routing
4.	Day 4	Basics of GIS and Remote Sensing	Remote Sensing in water resources engineering
5.	Day 5		Geographical Information Systems (GIS) in water resources engineering
6.	Days 6	Flood forecasting model	Overview, input output format
7.	Day 7		Sample input creation for flood forecasting model in GIS environment
8.	Day 8		Importing data into model, providing required inputs (rainfall etc.) and running the model
9.	Day 9		Calibration and validation of model and interpretation of results
10.	Day 10	Flood inundation model	Overview, input output format
11.			Sample input creation for flood inundation model in GIS Environment
12.			Importing data into model, providing required inputs and running model
13.			Calibration and validation of model and interpretation of results
14.		Flood warning	Flood warning dissemination to communities
15.			Flood warning dissemination to key stakeholders

Training on all the above subjects, to the extent feasible, will emphasize practical, hands-on exercises, which will help in quick ramp-up of the trainers and other stakeholder users in using the potentialities of the system to the best possible extent.

4.6.1 ON THE JOB TRAINING TO IUFMP ENGINEERS (5 DAYS PROGRAM)

This program will be designed to train at least 05 selected resource people from IUFMP as trainers who can act as further resource personnel within the various departments involved in flood forecasting.

We strongly believe, an exposure visit and experiencing an operational system which has similarities to the proposed one will help the client to gather invaluable information for the operation of the Ibadan system implemented as part of this assignment. RMSI is planning to involve these participants with the RMSI team and will work in India for a minimum of five days. As part of this training, these people will get trained in similar systems implemented in India such as Bhakra Beas Board Real time flood forecasting system, Uttar Pradesh Irrigation Departments flood forecasting system. During the project inception phase we will

coordinate with the IUFMP and institutions in India to work out the modalities of the exposure visit and training outside the country.

The Training the Trainer (TOT) manual will be designed around the following points:

- Training on similar systems implemented in India which include the below mentioned topics:
  - Overview of the Software and hardware technologies employed by the application
  - Handling of complex workflows
  - GIS and Modeling Basics
  - Input data formats
  - Functionality to update data in the system
  - Selection and packaging input data
  - Continuing model validation
  - Running model in the offline and online mode
  - Generating output and analyzing results
  - Linkages with other information systems and databases
  - Special emphasis on trouble shooting
  - Trainee evaluation with certification from client to declare successful participants as Authorized Trainers

Training on all the above subjects, to the extent feasible, will emphasize practical, hands-on exercises, which will help in quick ramp-up of the trainers and other stakeholder users in using the potentialities of the system to the best possible extent.

5 Task 4 - Operational testing

5.1 Routine collection and archiving of data

The data will be archived every 7 days in the secondary storage by the system using automatic agent software.

5.2 Operate the hydrological and hydraulic models for Ona River Basin

In the first season, the model will be operated and based on the outcomes the model parameters will be refined to satisfy the quality aspects of this assignment.

5.3 Test the flood warning systems

To determine the effectiveness of the hydro-meteorological system will be analyzed for the lag time between the sending and receiving of SMS messages from each gauge location to the server.

To test this, RMSI will make sure the selected vendor for the hydro-meteorological network will test the system at least for one season.

It is necessary that under normal conditions the lag time between sending SMS from existing instruments in the field and the receiver should be within 5 minutes for 90% average.

5.4 Test the flood warning services

Testing the Ibadan Flood Early Warning System time is very important before the telemetry system can be considered suitable for stated use. This telemetry software testing includes:

- Are telemetry system functions of rainfall and water level able to work well, such as telemetry data transmission system settings, data processing systems, data storage, etc.
- System testing for 24 hours for 1 week continuously to determine the reliability of telemetry system hardware and software

6 Task 5 – System delivery and handover

6.1 Documentation on operation and maintenance of the system and service

RMSI will provide operation and maintenance manuals and all other required software manuals to assist PIU and IUFMP users to operate and maintain the systems provided under this consultancy. These will include, but will not be limited to, operation and maintenance manuals for the Flood Forecast and Warning Service system, Limited Area Model, warning and visual display (web-based) system/service etc. All system documentation will be provided in English and will follow the Microsoft Manual of Style standards wherever applicable.

6.2 Technical support

6.2.1 Onsite Maintenance and Warranty

Once the Flood Forecast and Warning Service is successfully deployed, RMSI will provide maintenance support for 18 months from the time of final delivery and acceptance. After this period, if PIU, IUFMP would like to proceed for Annual Maintenance, RMSI would continue the phase at additional cost.

RMSI will be providing full maintenance support to PIU, IUFMP to maintain the functionality and resolve bugs or any problems with the functionality for the period of 18 months.

This section focuses on the process to be followed in order to address the requests raised by various users of the Flood Forecast and Warning Service. It also explains the process of communication between RMSI and PIU, IUFMP to facilitate maintenance support through bug fixing and user support activities.

Maintenance services will be triggered by Flood Forecast and Warning Service user, raising a defect/bug/issue regarding the system. Request will be assigned to an RMSI resource and addressed accordingly.

Figure 24 below explains the proposed process.

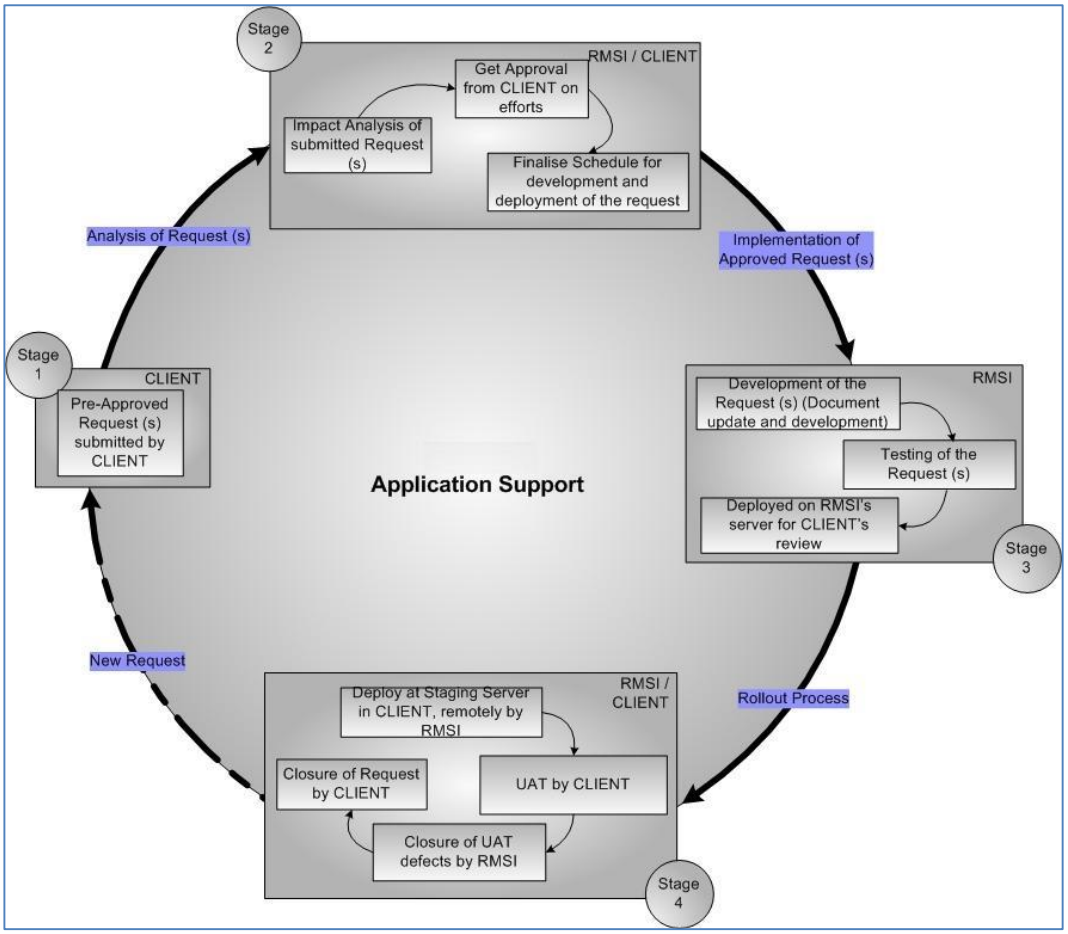


Figure 24: Proposed process for support

6.2.2 Overview of Proposed Maintenance Approach

RMSI will assign a dedicated resource for software/model related services to cater to the following support services:

- Resolution of bugs /issues reported by PIU/IUFMP users
- Day to day administration for the system/models
- Handling of support requests raised by the system users
- Proactive system and database checks to ensure system availability and performance
- System maintenance activities like clearing of log files and junk data etc.

All issues reported by system users will be recorded by the RMSI maintenance team in an issue tracker application and will be assigned a priority on the basis of business criticality. This issue tracker application will be available to PIU/IUFMP as well to track and check status of reported maintenance issues.

RMSI will agree for a Service Level Agreement (SLA) with PIU/IUFMP for response, update, and resolution time of support issues, which will be finalized at the project initiation.

RMSI will respond to all requests concerning service(s) as per the priority of the request as detailed below:

Table 10: Request related resolution times

S. No.	Priority	Request Details	Resolution Time (Permanent/Alternate Solution)
1.	Critical	This category will include requests pertaining to system unavailability.	1 day
2.	Very High	This category will include requests due to which system crashes and which are show stoppers and are business critical for IUFMP	3 days
3.	High	This category will include functionality or part of functionality that are not deemed to be business critical for IUFMP	Will be mutually agreed between IUFMP and RMSI
4.	Medium	This category will include functionality or part of functionality that are not deemed to be business critical for IUFMP.	Will be mutually agreed between IUFMP and RMSI
5.	Low	This category will include small discrepancies creating user inconvenience and will require enhancements to the functionality	Will be mutually agreed between IUFMP and RMSI

Requests will be categorized as defined below:

- Operational Request: Do not have any software development activity involved.
- Development Request: A request will be considered as a development request if it requires any change in the software code and involves a software development activity or if it requires any changes in the models.

Defect – hot fixes / corrective repairs will be performed to correct discovered problems in the system.

6.2.3 TRAINING FOR OPERATIONAL STAFF

RMSI will conduct four (4) Operational and Maintenance trainings during the Maintenance and Support period of 18 months at a mutually agreed schedule or at regular intervals. This will help PIU IUFMP and other staff to keep abreast with any system changes that might have taken place as well as dwell on any problems that the staff encounters, besides using the train-the-trainer concept to train new staff, if needed.

7 Project management

RMSI understands that the proposed EWS system will be used by a large number of users spread across Ibadan, Nigeria. These will be diverse users with varied skills and a wide range of problems may be encountered at work, and thus, they will have different expectations from the proposed solution.

RMSI proposes the “Spiral Model” methodology for project execution, considering the objectives and deliverables of this multifaceted project. We will adopt the SEI-CMMi 5 and ISO 9001 framework to ensure best output quality.

RMSI will designate a Project Manager who will also be the Team Leader for this project. The Team Leader will be responsible for overall project management. RMSI Project Manager will create a project management plan and ensure its successful execution. Project management will include resource identification, task allocation, commitment definition, project schedule finalization, project risks identification, mitigation measures identification, coordination with IUFMP stakeholders, quality assurance, timeliness adherence, regular review meetings, performance reporting within the team and to the client, and issue resolution.

7.1 Initiation

The purpose of this step is to discuss the project plan and set the stage for the entire project including EWS software development and Model development (LAM, Hydrologic and Hydraulic) and monitoring of installation of gauges as per the procurement plan. RMSI team will undertake the following activities under this step:

1. Project Kick-Off Meeting
2. Identification of focal point of contact from both sides
3. Core Team finalization
4. Identification of roles and responsibilities
5. Infrastructure Establishment
6. Review of project size estimation
7. Identify Project Closure activities
8. Initial Project planning

7.2 Development of Project Plan

An integrated project plan will be created, in close consultation with the client, after project initiation.

This plan will include the following:

- Identification of project phases with delivery schedule
- Core team and the roles and responsibilities
- Communication and reporting protocol
- Definition of key milestones, assumptions, constraints, task dependencies & budget
- Anticipated risks and RMSI risk mitigation plan
- Estimation of project size, effort, cost, resources
- Quality management plan
- Change management Plan
- Pre-commissioning, Operational and Final Acceptance Testing Plan

7.3 Development Model

We propose to follow the Spiral Model for EWS development.

7.3.1 SPIRAL MODEL

The spiral model is a development process combining elements of both design and prototyping-in-stages, in an effort to combine advantages of top-down and bottom-up concepts. This model of development combines the features of the prototyping model and the waterfall model. The Project is executed in different stages with each stage addressing a set of project risks based on their priority, e.g., high probability and high impact risks will be addressed in the first iteration of the life cycle.

Each phase starts with the feedback of the previous phase (Requirement Specification in 1st Stage) a design goal to address the risks at top priority at that stage of project and ends with the client reviewing the progress so far. Analysis and engineering efforts are applied at each phase of the project, with an eye towards the ultimate goal of the project.

Salient features of the Spiral Model:

- Risk-reduction oriented model
- Breaks up a software project into mini-projects, each addressing one or more major risks.

Strengths of the Model:

- Risks addressed at lowest cost
- Reduced redundant work
- Each iteration can be tailored to suit the project needs

Weaknesses of the Model

- Requires attentive and knowledgeable management to pull it off

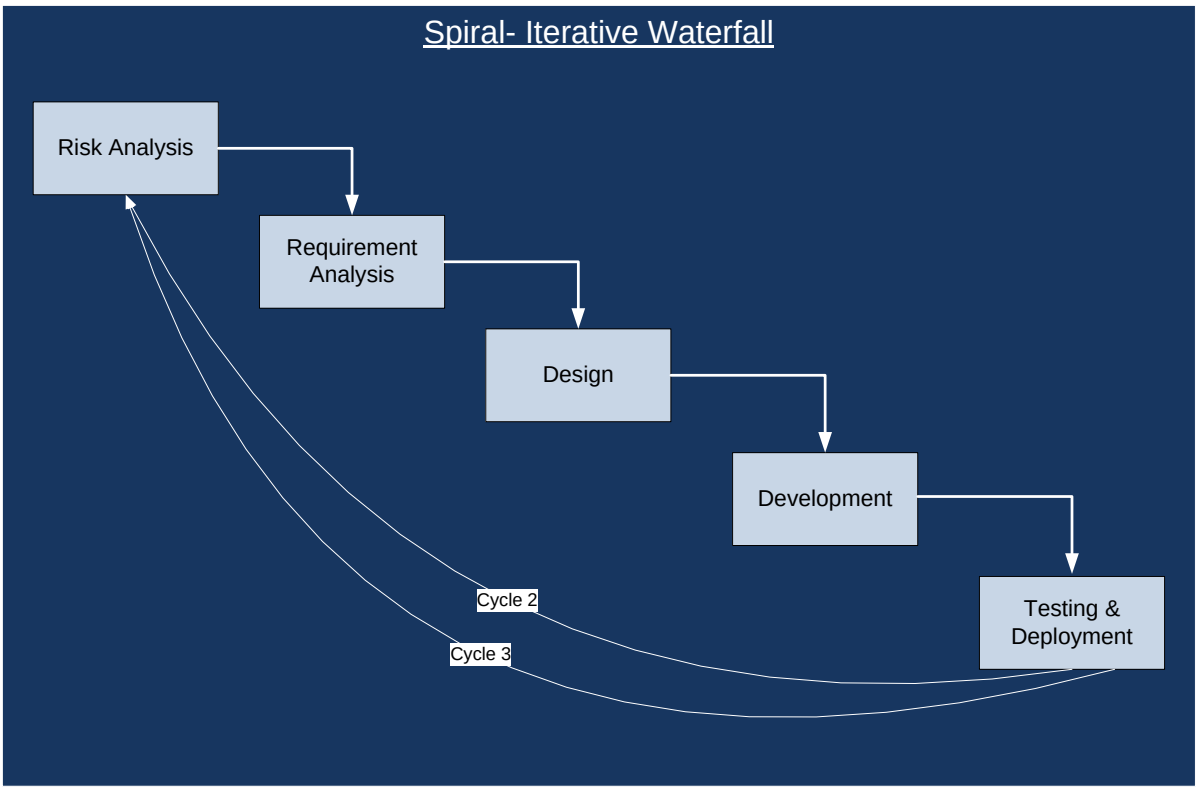
The steps in the spiral model can be generalized as follows:

1. The new system requirements are defined in as much detail as possible. This usually involves interviewing a number of users representing external and internal users and other aspects of the existing system.
2. A preliminary design is created for the new system.
3. A first prototype of the new system is constructed from the preliminary design. This is usually a scaled-down system, and represents an approximation of the characteristics of the final product.
4. A second prototype is evolved by a fourfold procedure: (1) evaluating the first prototype in terms of its strengths, weaknesses, and risks; (2) defining the requirements of the second prototype; (3) planning and designing the second prototype; (4) constructing and testing the second prototype.
5. The existing prototype is evaluated in the same manner as the previous prototype, and, if necessary, another prototype is developed in accordance with the fourfold procedure outlined above.
6. The final system is constructed based on the refined prototype.
7. The final system is thoroughly evaluated and tested. Routine maintenance is carried out on a continuing basis to prevent large-scale failures and to minimize downtime.

A simplistic model of various project phases and sequence of their occurrence in complete project cycle is detailed in below diagram.

7.3.1.1 Project Development Life Cycle

The following activities will be conducted for project development.



7.3.1.1.1 Phase 1: Risk Analysis

After project initiation and approval of the project plan by the client, a detailed risk analysis will be carried out. Risk analysis will include risk identification, probability of occurrence and impact on the project. This will also include a risk mitigation plan for each risk.

All the risk analysis activities will be carried out in consultation with the client and will finally be approved by the client.

Exit Criterion: The risk register having risk identification with risk mitigation plan will be the exit point of the phase and the same will be an input for the next phase.

7.3.1.1.2 Phase 2: Requirements Analysis

Requirement analysis will be performed to define project requirements, in a concise and unambiguous form. These requirements will form a written agreement of requirements for the system between RMSI and IUFMP for the application.

The objective of this phase is to transform the requirements into functional specifications for the system. It produces a layout of the system that fulfills the agreed & required functional requirements. The functions defined for the application will form the vision of the software & will be applicable during the entire SDLC.

During this phase, RMSI team will meet the end users identified by the client. The requirements to be analyzed include both functional and non-functional requirements. Another important aspect of this phase is to understand the project scope in line with the client's objectives.

The requirement analysis phase will be carried out in the following steps:

- Understand existing procedures
- Identify business rules
- Understand user requirements

- Convert user requirements into Software Requirement Specifications (SRS)
- Identify the non-functional requirements which will include software performance and security issues (e.g., throughput requirements, memory limitations)
- Identify functional aspects of integration with other existing / to-be-developed modules
- Update Project Plan

Exit Criterion: The Approved SRS and updated plan will be the exit criterion of this phase and entry point of next phase.

7.3.1.1.3 Phase 3: Design Phase

This phase is critical for the successful execution of the entire project activities. The objective of this phase will be to produce module level designs that will conform to the agreed standards and the requirements of the client.

The design documents will convert the functional requirements of the system into implementation logic and the physical layout of the system. The phase will cover details of the various process flows, implementation logic, system architecture, etc. required to cover functional and non-functional requirements. These various design elements will be delivered in the form of a High Level Design (HLD) and a Low Level Design (LLD). This Phase will also cover the risks to be addressed in the current cycle and how the designed system will take care of associated risks.

The above process will be carried out in consultation with client and will finally be approved by the client. This phase will be carried out in the following steps:

- SRS Analysis
- Team meetings and brainstorming sessions of the technical team
- Evaluation of various possible solutions
- Selection of a solution
- Disintegration of the selected solution into various components
- Product integration plan
- Updating of requirement traceability matrix to track if all planned requirements have been covered
- Updating project plan
- Test case preparation

Generation of EWS Work Product: RMSI team will develop the software architecture within the constraints of the technology used, in consultation with the IUFMP team. They will also document the software design applicable, including:

- Flow charts
- Data Flow Diagrams (DFDs)
- Architectures
- Module identifications
- Entity Relation (ER) diagram
- Component diagrams, etc.

Exit Criterion: The approved HLD and LLD will be the exit criterion of the phase and the entry point for next phase of the project.

7.3.1.1.4 Phase 4: Development Phase

This phase will consist of coding, unit testing, and system testing.

Coding will be done in accordance with the HLD and the LLD. Coding guidelines shared with client will be followed while the code is written by the team. The developers will also perform unit testing of the code in this phase. The unit testing will be done at peer level by the development team based on the created unit test cases. The code will also be reviewed at

peer level and by a Technical Specialist. Builds are sent to the testing team to check the quality of the code and if the output matches with the requirements specified in the SRS.

The following activities will be carried out during execution of this phase.

- Coding by the development team
- Code review by peers and Technical Specialist
- Unit testing by the development team
- RTM Updates
- Project integration
- Preparation of Deployment manual

Exit Criterion: The executables of the written codes with unit test reports will be the exit criterion for this phase. The executables will be accepted by the QC team only if the defect density in unit test report is within permissible limits as defined in project plan.

7.3.1.1.5 Phase 5: Testing and Deployment Phase

The testing phase is one of the most important phases of project lifecycle to ensure that the delivered product meets the desired quality. This phase also ensures that the output is also fit for its intended use. Testing will be carried out prior to the deployment activities and will be undertaken offsite and onsite.

This Phase will include the following major activities:

- Test Case preparation and approval.
- Acceptance criterion specifications and approval.
- Unit testing by development team.
- Deployment at RMSI's test servers
- Testing by RMSI's QC team
- Deployment at client test server
- User acceptance testing by the client

Testing Team:

The required QA/ QC activities at various stages will be done by a unique team to cover the different aspects of testing. The following teams will be involved in quality assurance.

QA Team: The Quality Assurance team will work towards quality control throughout the project life cycle at both product and process level. The QA team assures the software development process complies the CMMi 5 quality process. The QA team will verify that the developed product meets all requirements.

Development Team: The development team will be involved in white box testing and unit testing during construction phase of the project. Unit testing will be carried as peer level testing using unit test cases.

QC Team: QC team will develop the test cases and acceptance test criterion during design phase of the system. The developed test cases and acceptance cases will be shared with client for their approval. Before deploying or releasing the system, the QC teams will go through the various tools based testing to ensure the required quality is delivered to the end user. A test report based on approved test cases will be provided with software release.

The following types of testing will be carried out by the testing team:

- Functional Testing
- Integration Testing
- Regression testing

Deployment:

The tested code will be then sent to the client for deployment. The RMSI team will deploy the system at client test servers.

User Acceptance Testing: This code is then tested by the client for any bugs by running the acceptance test cases. The acceptance test cases will be developed and delivered by RMSI and will go through a cycle of review by the client and revision at RMSI. The finally approved test cases will be used for user acceptance testing of the system. Once the application is successfully tested, training sessions will be initiated for the end user.

Deliverables:

- Code
- Deployment Manual

UAT will consist of following testing based on agreed Acceptance Criterion:

1. Functional testing
2. Disaster Recovery Testing
3. Operability testing

Bug Fixing: The fixing of any defects identified during User Acceptance testing will be carried out in parallel by development team. The releases will be updated as a significant amount of defects resolution.

Exit Criterion: The successful User Acceptance Testing report will be the exit criterion of the test and deployment phases. The UAT report will be the exit criterion of the test and deployment phases. The UAT reports along with the SRS and project plan becomes the entry point for next cycle of project development. Once all agreed requirements are met and user acceptance testing results come within the agreed permissible limit, the project will enter into its final activities of knowledge transfer and maintenance through warranty agreement.

8 Risks and issues

Risk Management takes into consideration the issues that could endanger achievement of critical project objectives. Effective Risk Management includes early and aggressive risk identification through collaboration and involvement of stakeholders. RMSI's Risk Management can be divided into three parts:

1. Defining a risk management strategy;
2. Identifying and analyzing risks;
3. Handling identified risks, including the implementation of risk mitigation plans, when needed

Managing risk is the responsibility of the RMSI Project Manager/EWS Team Lead, and an escalation mechanism with IUFMP would be set up during the inception stage which is planned in the third week of Feb 2019. RMSI EWS Team Lead will keep IUFMP regularly updated on the Risk Management aspect of the project during the monthly reviews or as desired by the IUFMP. RMSI will also request swift feedback from the IUFMP when any concerns regarding risks (current/ expected) are brought to the notice of the IUFMP.

8.1 Preparation of Project Risk Management Plan

A project specific strategy for identifying, analyzing and mitigating risks will be established and maintained. This will consist of:

- Preparation of a list of anticipated risks and their sources
- Review the list and prioritize
- Risk Management Plan including relevant risk categories, scope of risk management effort, a threshold based tracking criteria for relevant risk categories, and appropriate mitigation measures for major anticipated risks

8.2 Risk Identification and Mitigation Planning

RMSI team will regularly identify risks at each stage of the project, prioritize, identify risk reduction techniques, develop contingency plans, and identify the measures to track the risks. These measures will be discussed with the client and applied for prevention/ mitigation.

Once a particular type of risk is identified, RMSI team will develop a risk mitigation strategy for avoiding further such risks.

8.3 Risk Documentation

RMSI team will create a database of all identified and anticipated risks, and the mitigation measures. Once a particular type of risk is identified/ encountered, it will be documented in this database with the lessons learned. The Project Manager will review the risk database weekly to ensure that all entries are complete, accurate, and up-to-date, along with the risk summary page of risk database. A risk log will also be maintained, within this database, including the following information.

- ID: Risk Identification number
- Head: Classification of the issue
- Description of the Agenda Item
- Author - Person identifying the risk
- Risk Category - Relatively insignificant/ Minor/ Significant/ Serious
- Status of the risk - Open/ Closed
- Dependencies/ Implications: Impact of the risk on project function / deliverable(s)
- Agreed Resolution: Resolution agreed with client
- Person(s) responsible for action: Responsibility settled for resolving the risk

- Date to complete: Date to complete action agreed to resolve the risk
- Date Closed: Date on which the risk actually got mitigated
- Date last reviewed: Date on which the RiskID was last discussed

A spreadsheet will be shared every month to IUFMP as part of the monthly progress report, so that there is transparency in communication between both organizations. The open items marked on the risk log will become the agenda item for a monthly teleconference between RMSI project manager and IUFMP's project manager.

8.4 Risk Monitoring and implementing Risk Mitigation Plans

The purpose of this procedure is to monitor the status of risks and take corrective actions whenever required. The procedure covers periodic monitoring of risks, thereby leading to reassessing the risks, or revising risk mitigation plans.

9 Deliverables and schedule for completion of tasks and services

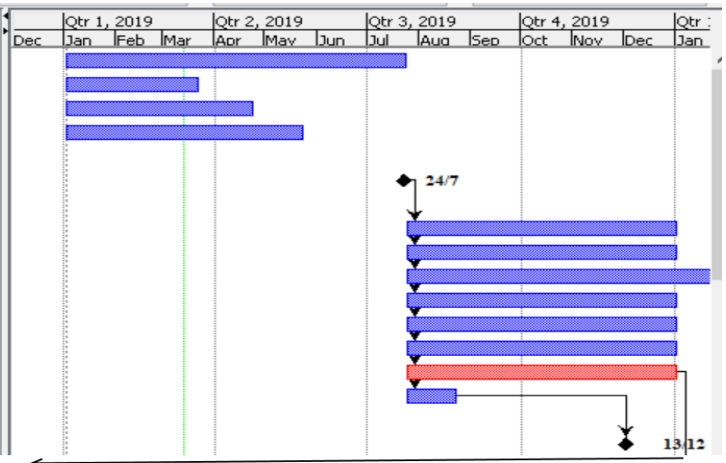
The following are the key deliverables and timeline of the project:

S. No.	Deliverables	Submission date as per contract	Payment Terms
Task 1	**Inception, Scoping and Concept**		
1.1	Inception Report	24th March 2019	20%
1.2	Evaluate the flooding and institutional issue	24th April 2019	
1.3	Preliminary concept of flood forecast and warning service	24th May 2019	
1.4	Stakeholder workshops	24th July 2019	10%
Task 2	**Flood Forecast and Warning Service Design**		
2.1	Design of flood forecast system	2nd Jan 2020	20%
2.2	Procurement plan and packages	2nd Feb 2020	
2.3	Warning service plan	2nd Jan 2020	
2.4	Topographic and related inundation data	2nd Jan 2020	
2.5	Standard Operating Procedures	2nd Jan 2020	
2.6	Communication plan	2nd Jan 2020	
2.7	Training plan	24thJuly 2019	10%
2.8	Training of trainers	24th July 2019 - 2nd Jan 2020	
Task 3	**Implementation of the Flood Forecast and Warning Service for Eleyele and Ona river basin**		
3.1	Install observing networks	2nd Jan 2020 - 2nd July 2020	20%
3.2	Supervise installation of computer network and communication network	2nd May 2020	
3.3	Install LAM, hydrological models, inundation models	2nd July 2020	
3.4	Archive of NIMET data	2nd July 2020	
3.5	System test plan	2nd Jan 2020	
3.6	Train operational staff	2nd July 2019 - 2nd July 2020	

S. No.	Deliverables	Submission date as per contract	Payment Terms
Task 4	**Operational Testing**		
4.1	Routine data collection from observational network	2nd Jan 2020 - 2nd July 2021	10%
4.2	Operate models	2nd Jan 2020 - 2nd July 2021	
4.3	Test warning systems	2nd July 2020 - 2nd July 2021	
4.4	Test warning services	2nd July 2020 - 2nd July 2021	
Task 5	**System Delivery and Hand over**		
5.1	Provide documentation operations and maintenance	2nd Jan 2021	10
5.2	Provide technical support including software updates and remedying any faults	2nd July 2020 - 2nd July 2021	
5.3	Provide training to operational staff	Quarterly from 2nd July 2020 - 2nd July 2021	

10 Work plan

	Name	Start	Finish
1	Task 1 - Inception, Scoping and Concept	2/1/19 8:00 AM	24/7/19 5:00 PM
2	1.1-Inception Report	2/1/19 8:00 AM	22/3/19 5:00 PM
3	1.2-Evaluate the flooding and institutional issue	2/1/19 8:00 AM	24/4/19 5:00 PM
4	1.3-Preliminary concept of flood forecast and warning service	2/1/19 8:00 AM	24/5/19 5:00 PM
5	1.4-Stakeholder workshops	23/7/19 8:00 AM	24/7/19 5:00 PM
6	Task 2- Flood Forecast and Warning Service Design	25/7/19 8:00 AM	2/1/20 5:00 PM
7	2.1-Design of flood forecast system	25/7/19 8:00 AM	2/1/20 5:00 PM
8	2.2-Procurement plan and packages	25/7/19 8:00 AM	3/2/20 5:00 PM
9	2.3-Warning service plan	25/7/19 8:00 AM	2/1/20 5:00 PM
10	2.4-Topographic and related inundation data	25/7/19 8:00 AM	2/1/20 5:00 PM
11	2.5-Standard Operating Procedures	25/7/19 8:00 AM	2/1/20 5:00 PM
12	2.6-Communication plan	25/7/19 8:00 AM	2/1/20 5:00 PM
13	2.7-Training plan	25/7/19 8:00 AM	23/8/19 5:00 PM
14	2.8-Training of trainers	2/12/19 8:00 AM	13/12/19 5:00 PM



	Name	Start	Finish
15	Task 3-Implementation of the Flood Forecast and Warning Service for Eleyele and Ona river basi	3/1/20 8:00 AM	2/7/20 5:00 PM
16	3.1-Install observing networks	3/1/20 8:00 AM	1/5/20 5:00 PM
17	3.2-Supervise installation of computer network and communication network	3/1/20 8:00 AM	1/5/20 5:00 PM
18	3.3-Install LAM, hydrological models, inundation models	3/1/20 8:00 AM	2/6/20 5:00 PM
19	3.4-Archive of NIMET data	3/1/20 8:00 AM	2/6/20 5:00 PM
20	3.5-System test plan	3/1/20 8:00 AM	2/6/20 5:00 PM
21	3.6-Train operational staff in India	22/6/20 8:00 AM	26/6/20 5:00 PM
22	Task 4 - Operational Testing	3/1/20 8:00 AM	5/7/21 5:00 PM
23	4.1-Routine data collection from observational network	3/1/20 8:00 AM	5/7/21 5:00 PM
24	4.2-Operate models	3/1/20 8:00 AM	5/7/21 5:00 PM
25	4.3-Test warning systems	3/7/20 8:00 AM	2/7/21 5:00 PM
26	4.4 - Test warning services	3/7/20 8:00 AM	2/7/21 5:00 PM
27	Task 5-System Delivery and Hand over	3/5/21 8:00 AM	2/7/21 5:00 PM
28	5.1-Provide documentation operations and maintenance	3/5/21 8:00 AM	2/7/21 5:00 PM
29	5.2-Provide technical support including software updates and remedying any faults	3/7/20 8:00 AM	2/7/21 5:00 PM
30	5.3-Provide training to operational staff	3/7/20 8:00 AM	2/7/21 5:00 PM

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