Terms of Reference { P_k-1 (1.1)}
for

Consultancy for developing, implementing and operationalizing a Customized Meteorological Framework in Bagmati-Adhwara (B-A) and Kosi basins in Bihar State.

1. Background

The Flood Management Information System (FMIS) Centre in Water Resources Department (WRD) of Government of Bihar (GoB) aims to generate and disseminate timely and customized information to move from disaster response to improved disaster preparedness and to effectively support flood control and management in the flood-prone areas of the State. Conceptual flood models are being developed in Bagmati-Adhwara (B-A) basin and Kosi basin to enhance the traditional system of stage-level warnings based on gauge-to-gauge correlation in order to transform it to flood forecasting services for effective flood management strategy and planning. A flood forecasting and inundation mapping model, using a proprietary software, has been developed in the B-A basin. An alternate model using public domain and license-free software is being developed under a different separate consultancy. Both model development is constrained by poor availability of hydrologic data in the basin, as the implementation of Real Time Data Acquisition System (RTDAS) is scheduled at a later period. Satellite-based ensemble rainfall estimates from multiple satellite missions and sensors may provide a credible alternative in regions of poor rainfall network and to spatially better represent the rainfall patterns in the basin. Improved forecast capacity is planned with ensemble short-to-medium range ensemble weather forecasts using deterministic and probabilistic approach and downscaled and re-gridded for the basin. The rainfall estimate and precipitation forecast results would be evaluated using meteorological stations network data for further assimilation. The goal is to build capability and capacity at FMISC center in Patna so that these rainfall estimates and short (1-3 days) and medium (7-10) days range weather ensembles forecast products can be evaluated and integrated in the forecast models in B-A and Kosi basins in Bihar State.

2. Objective of the assignment

The objective is to equip Flood Management Improvement Support Center (FMISC) under Water Resources Department, Govt. of Bihar with a comprehensive and customized meteorological framework to generate ensembles of satellite based rainfall estimates and short-to-medium range rainfall forecasts for plugging into the flood forecast models in the Bagmati-Adhwara and Kosi basins.

3. Technical inputs and systems those are available to support the assignment

3.1 Current Hydrologic network

The current network includes: real-time hourly rainfall from Automated Rain Gauge (ARG) stations in Nepal, hourly rainfall from ARGs from the State network available with time delay, rain gauges maintained by IMD, rainfall and stage/discharge from rain gauges and river gauges maintained by Central Water Commission (CWC), available three times a day and hourly during high flood, forecast of river stage from CWC available with one day lead time or twice or more in a day during rising flood levels.

3.2 Ensemble Rainfall Estimate

High Resolution Precipitation Products (HRPP) include NASA TRMM and NOAA CMORPH[1] and GPM[2] (Global Precipitation Measurement) Mission multi-satellite data. These would be optimally combined to generate an ensemble product, customized for the selected basins

3.3 Operational Numerical Weather Prediction Systems of IMD

The India Meteorological Department (IMD) is the nodal agency for providing weather forecasts/ warnings to all sectors of activity. IMD's short range forecast system is based on synoptic method. However, the forecast products available from various numerical models available from within IMD and other global forecasting centers, all satellite observations such as Cloud Motion Vectors (CMVs), cloud imageries available from INSAT and METEOSAT and other satellite products are taken into consideration. IMD's operational Numerical Weather Prediction (NWP) system is based on a limited area analysis and forecasting system (LAFS), which consists of real time processing of data received on Global Telecommunication system (GTS), objective analysis by 3-D multivariate optimum interpolation (OI) scheme and limited area forecast model. (Source: Rama Rao et. al, IMD)

With the commissioning of High Performance Computing System (HPCS), Global Forecast System (GFS T574/L64) is in operation at the H/Q of IMD, incorporating Global Statistical Interpolation (GSI) scheme as the global data assimilation for the forecast up to 7 days. In addition to the meso-scale forecast system, data assimilation is being operated at 27 km, 9 km and 3 km horizontal resolutions for the forecast up to 3 days using initial and boundary conditions from the IMD GFS-574/L64 (horizontal resolution over the tropics ~ 22 km). Polar District Level Quantitative five days weather forecasts based on Multi-Model Ensemble (MME) system are being generated to support Agro- Meteorological Advisory Service of India, making use of model outputs of state of the art global models from the leading global NWP center.

3.4 Global Ensemble Forecast System (GEFS) by National Centre for Medium Range Weather Forecasting (NCMRWF)

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[1] Climate Prediction Center Morphing (CMORPH): merged data set quasi-operational, quasi-global precipitation estimates produced by combining input data from several sensor types, including satellite sensors and precipitation gauges. (0.25 deg/3-hourly with a latency of 18hrs).

[2] GPM piloted by NASA and JAXA with a constellation of national agencies including ISRO, achieves global coverage with a high sampling frequency by relying on both existing satellite programs and new mission opportunities from its partners.

Ensemble forecasting has emerged as the practical way of estimating the forecast uncertainty and making probabilistic forecasts. Based on multiple perturbed initial conditions, ensemble approach samples the errors in the initial conditions to estimate the forecast uncertainty (spread in member forecasts). The skill of the ensemble forecast shows marked improvement over the deterministic forecast when comparing the ensemble mean to deterministic forecast after a short lead time. A Global Ensemble Forecasting System (GEFS) at T190L28 resolution (70 km and 28 levels) with 20 members has been implemented at NCMRWF for forecasting up to 10 days.

Ensemble-based data assimilation techniques have shown promise of dramatic improvements over techniques such as 3- or 4-dimensional variation assimilation. The dramatic improvements in the forecast skill was attributed to the background-error covariance's which provide a different adjustment to the observations compared to methods such as 3- dimensional variation assimilation.

More recently hybrid techniques that use both ensemble and variation approaches have been developed. However it is still limited by climatological background error covariance. Recent studies indicate benefit of "hybrid" approach particularly for forecasting of high impact events. At NCMRWF efforts are already underway to implement the hybrid approach (using ensemble and 3D-Var) in data assimilation in the deterministic global forecast system. More so, NCMWRF is ensuring to improve this forecast by following enormous linkages with various organizations and systems in the country.

3.5 Multi-Model Ensemble Forecasts

NCMWRF weather ensembles forecast for 7-10 days will be tested for hydrological forecast by plugging it to Bagmati-Adhwara and Kosi river basins at FMISC of WRD of Govt. of Bihar. It also provides an opportunity to develop, compare and validate accuracy of the Probabilistic Quantitative Precipitation Forecasting. Ensemble weather forecasts from multiple centers (CMA, CMC, JMA, KMA, MeteoFrance, US NCEP, and UKmet in addition to the current ECMWF) would be used to prepare ensemble forecasts for the selected basins, to reduce uncertainty.

3.6 India-World Bank Flood Forecasting Project (https://gis.ucar.edu/india-world-bank-flood-forecasting)

Satellite based ensemble rainfall estimates and weather forecasts are being developed for the Ganges basin, and would be available from the web display. The interactive map displays satellite based rainfall estimates and precipitation forecasts for each watershed in the Ganga basin, more detailed sb-catchment data could be zoomed in. The satellite precipitation is a merged product of NASA TRMM, NOAA CMORPH, and JAXA GSMaP precipitation and is provided immediately after the 24-hr accumulation is complete. The forecasts are based on ECMWF control run predictions. The forecast data are provided on a 2-day delay such that the displayed Day 1 forecast (for the next available 0Z to 0Z period) is based on forecast model runs initialized two days ago. The highest resolution for ensemble weather forecasts is 0.25deg (roughly 25km) from ECMWF's "deterministic" forecast. The highest resolution of the ensemble forecasts is 0.5deg (roughly 50km). The satellite precipitation products (JAXA GSMaP, NASA TRMM, NOAA CMORPH)

are between 0.1deg (JAXA GSMaP) and 0.25deg (NASA TRMM and NOAA CMORPH). However, all of these products (all satellite precipitation products and TIGGE ensemble forecasts) are down-scaled to a common 0.1deg grid. The highest temporal resolution for the TIGGE data is 6 hr accumulations (all centers). Also, some centers produce 2X daily forecasts (00Z and 12Z, typically), while others produce 4X daily (e.g. US NCEP).

The JAXA GSMaP data is hourly and is released roughly an hour after measurement time, NOAA and NASA products are 3hr accumulations, and released between 3- to 8-hr after collection time (however, both of these centers also have higher sampling hourly data as well, that could be accessed). Solutions to speed up issue of rainfall forecasts from the current 2 day delay need to be found. For B-A and Kosi basins, we may need the highest spatial temporal resolution possible: hourly satellite estimate at 0.1 deg grid with short time delay, and ensemble forecast data at short to medium range that is at least 6 hourly interval, 0.1 deg, with short time delay of not more than one day and updated

4. Tasks

1. Understand and assess the requirements of monitoring (real and near-real time) and forecast rainfall data with particular reference to the Bagmati-Adhwara and Kosi river basins. This assessment will draw upon on earlier work including research and consultancy projects undertaken in the past. The assessment process shall also include consultations with key officials in WRD and FMIS, WRD to determine exact needs and agree on a meteorological framework to enable the FMIS to assimilate High Resolution Precipitation Products (HRPP) from an ensemble of sources, including gauge, remotely sensed monitoring data, and forecasts from Numerical Weather Prediction (NWP) models. The key benchmarks for prioritization will be the data availability for operational use in flood forecasting with minimal latency time, high spatial and temporal resolution, and the suitability (before and after bias correction and calibration) of NWP forecast data for hydrological applications.
2. Evaluate utility of the rainfall estimate and forecast products developed under the India-World Bank study[3] covering the Ganga river basin, and develop and evaluate re-gridded and downscaled products for the B-A and Kosi basins.
3. Evaluate available standard near-real time HRPP from global, regional and national in-situ and remotely sensed monitoring networks/platforms for the Bagmati-Adhwara and Kosi river basins. HRPP evaluation should include, without being limited to, JAXA/EORC GSMaP[4], NOAA CMORPH[5] and GPM[6] (Global Precipitation Measurement) Mission multi-satellite data, either as stand-alone or merged available rain gauge-based products.
4. Evaluate the skill in available forecast data for hydrologic applications from global and mesoscale NWP models covering lead times from 3hr to 15 days for the selected river basins from global, regional, and national centers including the India Meteorological Department (IMD) and the Indian National Centre for Medium Range Weather Forecasting (NCMRWF). The evaluation must cover both deterministic and ensemble precipitation forecasts available from individual centers and from

[3] Development of Flood Forecasting for the Ganges and the Brahmaputra Basins using Satellite based precipitation, ensemble weather forecasts and remotely-sensed river widths and height, details n Section 3.6

[4] GSMaP: Global Satellite Mapping of Precipitation (http://sharaku.eorc.jaxa.jp/GSMaP_crest/)

[5] Climate Prediction Center Morphing (CMORPH): merged data set quasi-operational, quasi-global precipitation estimates produced by combining input data from several sensor types, including satellite sensors and precipitation gauges..

[6] GPM piloted by NASA and JAXA with a constellation of national agencies including ISRO, achieves global coverage with a high sampling frequency by relying on both existing satellite programs and new mission opportunities from its partners.

multi-model ensembles like TIGGE[7], and should include an evaluation of the utility in the ensemble spread or dispersion, as well as an evaluation of the types, frequencies, spatial and temporal scales, and lead-times of the rainfall events that can and cannot be captured by these data

5. Apply appropriate down-scaling, bias correction, and calibration approaches to be applied to both monitoring and forecast products to enhance the confidence and skill of the products over the basin.
6. Based on the confidence and suitability level, prioritize a list of monitoring and forecast rainfall products at specified grid and sub-basin level that are of high spatial resolution and are available at sub-daily frequency suitable for assimilation into WRD Bihar's flood forecasting system for basins of the size of the Bagmati-Adhwara and Kosi and smaller.
7. Develop an automated system that can gather required data sets and generate the prioritized rainfall monitoring and forecast products in real-time in a format compatible for direct ingest into WRD Bihar's flood forecasting system. The user friendly interface to this system must be able to display dynamic confidence estimates using standard verification metrics used in 3 and 4.
8. Implement the automated meteorological framework system with customized interfaces in FMISC, conduct hands-on training for operational use, and provide operational manual.

5. Schedule and deliverables

- Inception report and data assimilation: within a month from the date of contract signed
- Interim Report on prioritized ensemble rainfall estimates and forecasts, meteorological framework, and initial results: within 4 months
- Draft Final Report: ensemble rainfall and forecast framework set up; testing and calibration, and readiness for operational use within 5 months
- Training to FMISC team – two working weeks, not less than 6 engineers from FMISC/WRD, and after implementation of framework in FMISC and before closure of contract
- Final report and delivery of operational meteorological framework: 6 months from the date of contract signed.

6. Reporting and Review

All reports should be submitted in hardcopy (5 copies) and soft copy (2) of each report in word format in DVD/ CD media.

The above reports will be reviewed and approved by a Standing Review Committee constituted by WRD.

Review Committee

SL No.	Designation	Position in Review Committee
1	Chief Engineer, Planning & Monitoring Patna	Chairman
2	Chief Engineer Muzaffarpur / Samastipur	Member

[7] The Thorpex Interactive Grand Global Ensemble (TIGGE)

3	Superintending Engineer, Monitoring Circle -1, Patna	Member
4	Superintending Engineer, Flood Monitoring Circle	Member
5	Joint Director, FMISC, WRD, Patna	Member
6	Deputy Director-1, FMISC, WRD, Patna	Member Secretary
7	Executive Engineer, Flood Control & Monitoring Division-1, Patna	Member
8	E-in-C (Retd.), WRD, GOB, Flood Management Specialist –cum- Project Advisor, FMIS	Member
9	Director, GFCC (Retd.), Embakment Specialist, FMIS	Member
10	Chief Engineer (Retd.), WRD, GOB	Member

Note:- The above review committee is expected to be reorganized which will be communicated in time.

7. Responsibilities of Consultant and Client

Consultant

- Conduct and complete the consultancy as per the agreed ToR and scope of the consultancy
- Access/Collect data as needed from concerned international and national agencies for developing customized ensemble rainfall estimate and forecast products
- Develop meteorological framework in consultant office, implement in FMIS Centre in Bihar, and provide training in understanding and using the framework including sources, products, validation and customization

Client

- Provide office space, computer hardware and software for implementing the meteorological framework customized for B-A and Kosi river basins
- Provide available historic and current data on hydrometeorology and hydrology,and available rainfall forecast and flood forecast from IMD and CWC respectively.
- Facilitate access to other State and central agencies and flood modeling consultants for data collection

8. Selection of Consultant Firm

The lead organization for the project will meet the following criteria

- Minimum five years of experience in providing ensemble satellite based precipitation estimates and ensemble weather forecasts services for flood forecasting, with particular emphasis on a track record of successfully delivering major analytical projects that involves assimilation of various satellite datasets to develop Basin and sub-basin level flood forecasting methods, processes, tools, and models.
- Track record of exceptional research relating remote sensing, GIS, GPS and technical partnerships on global short-to medium range weather forecast institutions.
- Experienced in technical assignments in developing countries; preferably including South Asia.
- Experience in the Ganges and Brahmaputra River Basins essentially covering the monsoon flood season including local-scale rainfall events, terrain conditions and trans boundary impacts is highly desirable.
- Ability to mobilize a team of highly qualified professionals ranging from atmospheric science, hydrologists, meteorologist, Remote Sensing expert, and GIS expert with relevant experience and qualifications either from the lead organization or through sub-contracting arrangements.

9. Payment schedule

20 percent after submission and acceptance of Inception Report

30 percent after submission and acceptance of Interim report

30 percent after submission and acceptance of Draft Final Report

20 percent after submission and acceptance of Final Report

The consultant is advised to optimize staff engagement in terms of time and use of national experts and other costs since the budget is expected to be not beyond US $ 100,000.

10. Duration of consultancy

6 (Six) months after effective contract date.