DEVELOPMENT OF SATELLITE RAINFALL BASED APPROACH FOR EFFECTIVE FLOOD DISASTER AND WATER RESOURCE MANAGEMENT IN TRANSBOUNDARY RIVERS -A CASE OF GANDAK RIVER BASIN

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ABSTRACT

Lack of real time hydro-meteorological measurements and information sharing between the riparian states poses challenge in effective Water resource and disaster managements in Transboundary Rivers. Benefits of Integrated water resource management (IWRM) can promote a policy shift from disputes to benefit sharing in Transboundary Rivers which needs reliable hydrological model and historical as well as real time meteorological data. To address this issue, this Study, proposes a general research frame work to quantify benefits of flood forecasting and IWRM with cost effective global Satellite Rainfall Estimates (SRE).The proposed Framework is applied in the Gandak basin, using Satellite Snow cover data and SRE inputs in Rainfall-Runoff Inundation (RRI) model. Multi-product and Multi-sensor based correction techniques were developed to remove regionally, topographically and seasonally varying biases in SREs, and real time rainfall and long term discharge data was generated and used in Water Evaluation and Planning Tool (WEAP). The results shows an increase of 17 hours forecast lead time, Additional 3200 Sq.km Rabi irrigated area in India and Additional 3000 GWh Hydropower Generation in Nepal using proposed diversion and hydropower projects, proving the scope of framework for application in Transboundary basins.

Keywords: Snow-melt, SRE, Multi-Product/Multi-Sensor Correction Techniques, IWRM

INTRODUCTION

Floods are one of the major natural disasters that affect many parts of the globe, causing loss of life, endangering human health and regional economy. Lower riparian countries of transboundary Rivers, which shares the catchment with different countries encounters floods due to heavy rainfall in wet season and faces issue of less availability of water for domestic and irrigation purpose during the dry season. The information about the approaching flood and seasonal water availability will lead to an effective disaster and water resource management in transboundary Rivers. But the lack of real time information sharing including rainfall and artificial discharge control due manmade structures such as reservoir in upstream catchment area, poses a major hurdle in solving the issues. In this study the solution to the above mentioned issues are approached using Rainfall-Runoff based Hydrological models and IWRM concepts. Though Rainfall-runoff models are effective tools for flood forecasting and water resources planning and management, it requires extensive real-time data and information about the hydrological obstructions in the catchment. These model should be capable of simulating important hydrological processes including snow melt. The issue related to influence of upstream manmade structures in upstream area is eliminated by choosing Gandak basin as study area, which has no major storage reservoirs in the upper riparian countries. The issue of lack of real time rainfall data is addressed by using remote sensing based satellite rainfall estimates, which are cost effective and available at near-real time. Even though usage of satellite rainfall estimates are very effective in predicting extreme flood events and provides increased lead time, especially in wide and long upstream catchment area, studies have proved that satellite rainfall estimates have seasonally, regionally and topographically varying biases, which makes the issues more complicated in complex Himalayan topography, where the study area is situated.

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Satellite rainfall products though basically generated from Microwave and Infrared based rainfall estimates, different products use different, frequency channels and algorithms to generate those rainfall estimates. This study uses the approach of identifying regions and rainfall intensities where one product performs better than other and developing purpose specific algorithms to merge rainfall estimates from multiple products and multiple sensors. The merged rainfall products are used in hydrological models for two purposes 1. Real time forecasting for increased lead time and 2. Generation of long term discharge data to manage the water resources in various sectors such as irrigation, hydropower and identify mutual benefits which can be harnessed by both upper and lower riparian countries. This study proposes a general research framework which involves capturing the hydrological response of upstream catchment, developing new merging techniques for SREs and using appropriate tools and models to strengthen forecasting system and quantify benefits of IWRM in transboundary rivers, which will provide key inputs for shift in policy from Riparian disputes/Conflicts into cooperation and benefit sharing among riparian countries/stakeholders in transboundary basins.

Objectives:

The objectives of the Study is to

1. **Strengthen the Flood forecasting by increasing Lead Time**
2. **Estimating the Multi-sectorial benefits of IWRM in Transboundary rivers**

In order to promote the policy shift from Transboundary disputes to Benefit sharing by developing satellite input based approach. To achieve the main objective following sub-objectives are to be fulfilled which are

I. Identifying the upstream dominant hydrological process, satellite parameters to model the process, and selecting the suitable model accommodating the major hydrological process in the basin.
II. Identifying the region specific biases in the satellite rainfall estimates and developing purpose specific improvement techniques
III. Quantification of the increase in forecast lead time and the quality of the model output
IV. Generation of Long term hydrological data and demand data to assess the impact of IWRM
V. Quantification of the increased benefits due to IWRM in Transboundary River using water resource management scenarios, appropriate tools.

Research Framework:

This Framework, involves in using satellite based rainfall products to develop purpose specific customized inputs, select of appropriate models and satellite parameters to supplement the modeling process to strengthen the flood forecasting tool and quantify the estimated benefits from Integrated Water Resource Management in Transboundary river basin by capturing the upstream hydrology, improving satellite rainfall estimates and finally achieving effective disaster and water resource management.

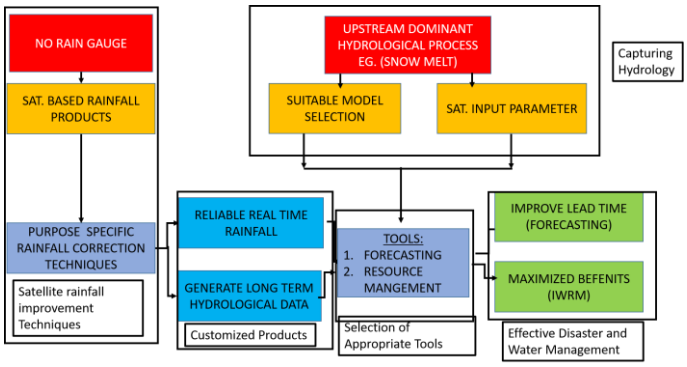


Figure 1. Research Framework

Study Area, Tools and Data:

Gandak basin, a tributary of mighty Ganges River is chosen as the study area where the river flow is generated by snow melt and monsoonal rainfall in upstream riparian countries of china and Nepal and frequent flooding and water scarcity in India, the downstream riparian country. RRI, a two dimensional model that can simulate rainfall-runoff and flood inundation simultaneously (Sayama et al., 2012) and WEAP (Stockholm Environmental Institute) a policy analysis tool for integrated water resource planning using basic principle of water Balance has been used in this study.

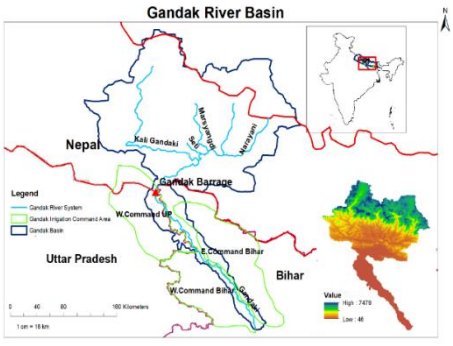


Figure 2. Gandak Basin

Table 1: Data used in the Study:

No	Type	Data	Remark
1	Snow	MODIS 10A2 – 8 day max. snow cover	500m grid
2	Sat. Rainfall	GSMaP (Real Time, Reanalysis, Reanalysis-Gauge) And TRMM (Real Time and Analyzed)	0.25 deg -daily
3	Obs. Gridded Rain	APHRODITE	0.25 deg
5	Obs. Rainfall	Libang gaon, Sitapur, Hanspur, Kanchikot, Phopli	Daily
4	Temperature	Libang Gaon, Bharatpur	Daily
5	Discharge	Triveni	Daily
6	DEM	HYDROSHEDs	30 arc sec

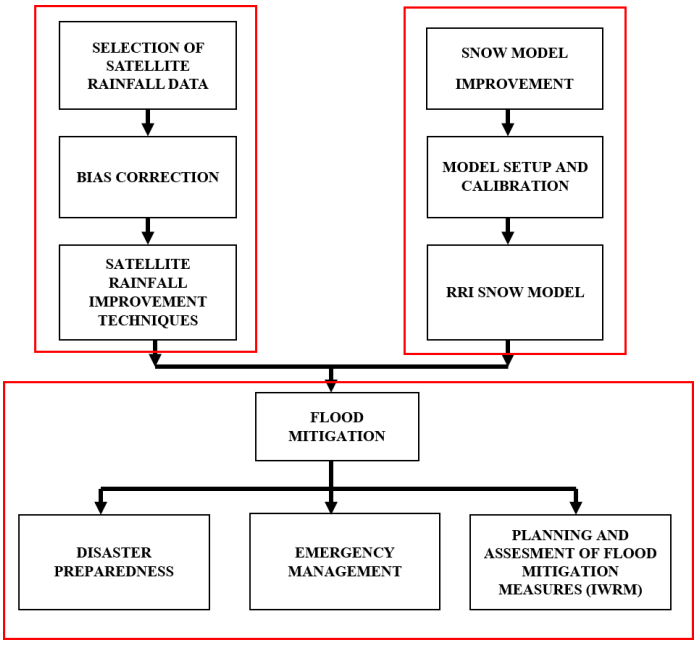


Figure 3 . Flow Chart of Methodology

METHODOLOGY:

The Methodology has been designed based on the proposed framework with three main components: (1) Investigation of Satellite Rainfall Product (2) Improving snow melt model and (3) Application of satellite rainfall estimate for Flood Mitigation activities. The overall Methodology is given in the Figure 3.

Investigation of Satellite Rainfall Products:

The Satellite Rainfall products and observed rainfall at stations given at Sl. No 2 and 4 of Table are compared for the corelation with Nash-Sutcliffe Efficiency (NSE), Coefficient of Determination (R2) and Index of Agreement (IA), to select the GSMaP NRT product as the most suitable product for the basin. Yearly and Monthly Bias Correction Factors has been evaluated for GSMaP NRT rainfall estimate using the same observed rainfall data from Rapti.It was found that yearly and montly factor based correction techniques are not suitable for Satellite rainfall estimates showing False alarms and underesitmation since it apply same correction for both the biases.

Multi- Product (GSMaP and TRMM 3B42) and Multi- Sensor (3B42 Microwave and 3B42 Infrared) has been analysed with APHRODITE data for year 2007 and the Bias trends has been observed at various elevation zones and event based analysis was carried out for microwave and infrared estimated for false alarm,

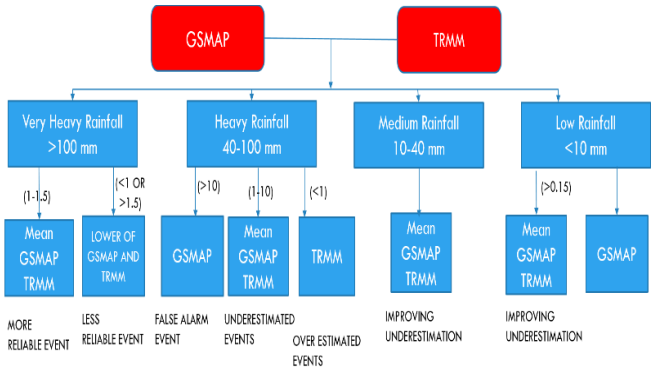


Figure 4 . Multi-Product Correction Algorithm

underestimated and overestimated event and the signals were captured in terms of TRMM to GSMaP ratio and Microwave to Infrared ratio at Different Rainfall Intensity and Elevation zones respectively.

Multi- Product based approach was developed using rainfall intesity for classification and TRMM to GSMaP as bias indicator as explained in the Figure 4, whereas the Multi-Sensor based approach was developed using Elevation zones for classification and Microwave to Infrared ratio as a bias indicator as given in figure 5. Multi-Product based products are developed to be applied on Real Time products especially for forecasting purpose which are more sensitive towards heavy rainfall events, where as Multi-Sensor based product are developed to applied on analysed products to generate long term rainfall data and subsequently long term hydrological data from reliable hydrological models.

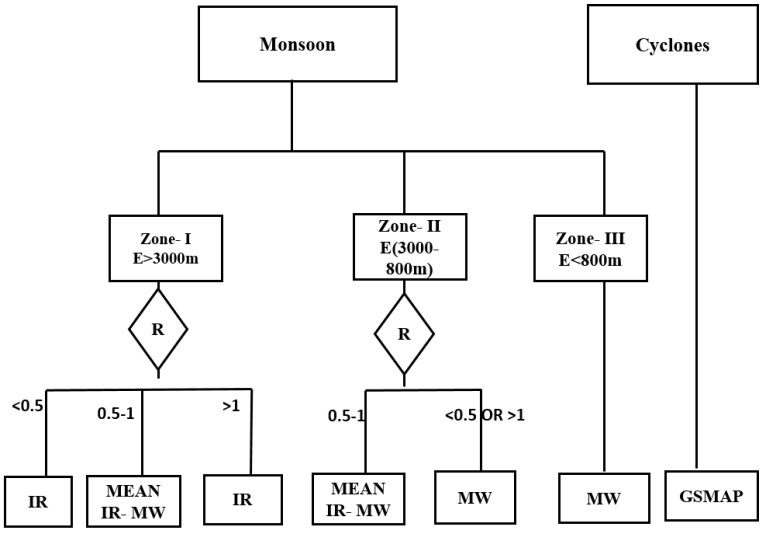
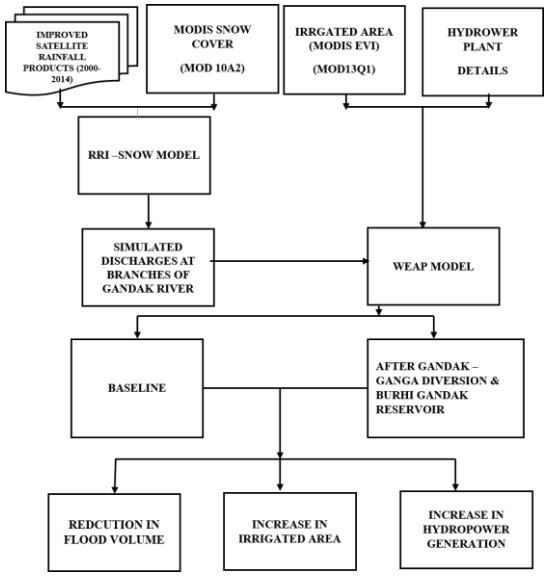


Figure 5 . Multi-Sensor Correction Algorithm

Improving snow melt model:

RRI model was set up using Hydrosheds DEM , GSMaP rainfall estimate, MODIS snow cover and tempreture data of Libang goan station. RRI –snow model (Irfanullah khan, 2016), uses Degree Day Factor method to generate the snow melt runoff with snow cover availability and Temperature data. The model uses single DDF and Temperature lapse rate, which has been modified to take time varible DDF and Lapse rate as input. Lapse rate Calculated using Libanggaon and Bharatpur station and DDF calculated based on trial and error method was used to calibrate the model for year 2013 and validated for the year 2012, which proves the reliablity of the hydrologic model.



F*igure 6. Assesment of Benefits of IWRM*

Application of satellite rainfall estimate for Flood Mitigation activities:

Multi-Product correction technique product Combined GSMaP and TRMM (CGT) was applied in RRI to find the forecast lead time,

whereas the Multi-Sensor correction technique product Combined Microwave-Infrared (CMI) was used in RRI model to simulate discharge for period (2002-2014) at different tributaries of Gandak river basin. The long term discharge, Irrigated area calculated using MODIS 13Q1 Enhanced Vegetation Index, monthly irrigation demand for Kharif, Rabi and hot weather season and hydropower plant details are given to WEAP model as a baseline scenario and two proposed projects for flood mitigation and hydropower generation (1) Ganga-Gandak Interlinking Project and (2) Burhi-Gandak Reservoir in Nepal are incorporated and new scenario has been created. The Quantity of water to be diverted from Gandak to Ganga is calculated as 40, 55 and 5% of 75% dependable flow at Indo-Nepal border, so that the demand of Gandak basin is not disturbed by diversion. The combined effect of BG

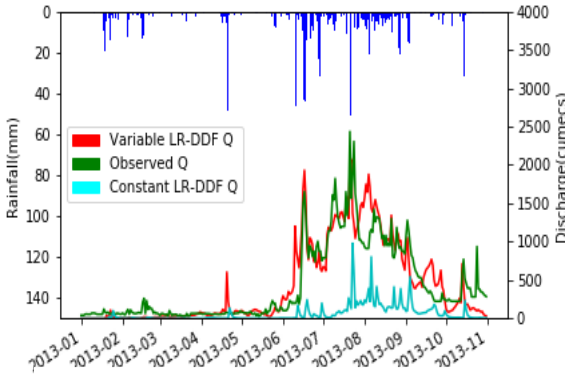


Figure 7. Effect of Time variable snow melt parameters

reservoir and Gandak- Ganga diversion in reducing the average flow volume, increasing irrigable area and increasing hydropower generation with long term discharge data is compared with baseline scenario to quantify the increased benefits.

RESULTS AND DISCUSSION:

Improvement of snow model and parameter:

As the RRI model was improved for taking variable DDF and Lapse Rate (LR) against the single 2 mm/Deg C /Day and 6.5 Deg C/km DDF and LR respectively, the model efficiency was improved dramatically as it can be seen the figure 7, the incorporation of realistic snow melt and temperature distribution parameters are the reasons behind the improvement of the result to reach more close towards the actual snow melt process.

Satellite Rainfall Improvements:

Biases in Satellite Rainfall Estimates:

From the Analysis of SRE with APHRODITE Data and Biases events from Simulations it was observed that GSMaP performs really well in the Snow cover regions and Medium rainfall events but underestimates heavy rainfall events whereas TRMM algorithm overestimates and creates False alarms of rainfall signals in Snow cover regions, but has good performance in Orographic warm rain process in mountainous regions and heavy rainfall events but it does not capture effect of the orographic barriers in Himalayan region . It was also found that GSMaP performs better in case of Fast moving events such as cyclones due to finer temporal and spatial resolution and Moving vector algorithm.

Improvement in Hydrological Models:

Multi-Product based products CGT and Multi-Sensor based Product CMI are given as input to the RRI model and the simulated (GSMaP and 3B42 respectively) and observed discharge at the Indo-Nepal border (Triveni) location was compared and the improvement in the simulation can be seen in the figure 8 for the year 2012 and the efficiency parameters are given in the table 2 for CGT and CMI products.

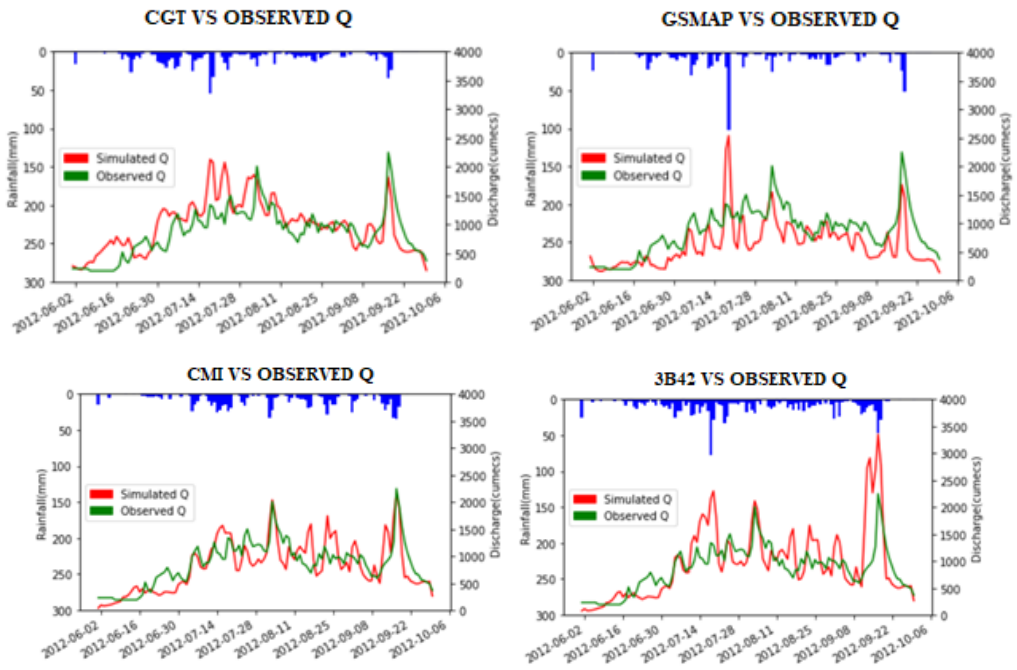


Figure 8. Performance of Raw and Improved Satellite products

Table 2: Efficiency of Satellite Products for observed and Simulated Discharge at Triveni

Year	2012			2013			2012		2013	
Product	**CGT**	**GSMAP**	**3B42RT**	**CGT**	**GSMAP**	**3B42RT**	**CMI**	**3B42**	**CMI**	**3B42**
NSE	0.74	0.65	-0.03	0.78	0.67	-0.04	0.52	0.43	0.78	0.54

R2	0.92	0.89	0.78	0.9	0.89	0.75	0.83	0.79	0.9	0.83
IA	0.95	0.90	0.83	0.94	0.93	0.8	0.87	0.85	0.95	0.9

Application of satellite rainfall estimate for Flood Mitigation activities:

The rainfall products CGT and CMI are used in RRI model to assess the increase in flood forecast lead time and generate long term discharge data (2002-2014) respectively. The long term discharge data generated was given as input to the WEAP model along with the irrigation demand quantity, monthly demand pattern and hydropower plant details in the Gandak basin. The net forecast lead time using the CGT product was calculated to be 17 hours (Figure 9) upto Indo-Nepal border, which is very crucial for barrage gate operation, evacuation and other emergency activities. The effect of diversion from Gandak-Ganga link, the Budhi-Gandak reservoir and additional irrigated area in Kharif season, it was evaluated using WEAP model and found that new scenario can reduce the average flow volume coming to Gandak is reduced by 65% during July and August month. The Burhi Gandak reservoir plays an important role in storing the water during the monsoon season and release during non-monsoon season after producing hydroelectric power. This water increases the Rabi season irrigated area from 20% to 60 % of total command area. Annual power generation due to the Burhi-Gandaki hydropower plant is computed to increase the total hydropower generation in Gandak river basin from existing: 2015 GWH to 5162 GWH, which is 2.5 times increase.

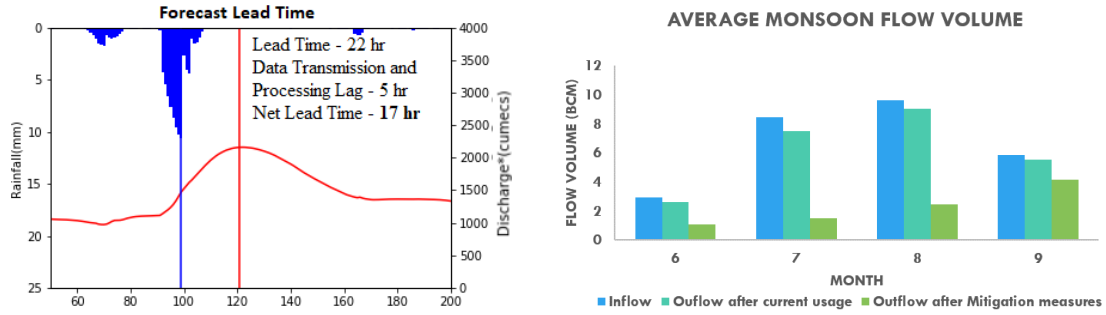


Figure 9. Increased Lead Time and reduction in flood volume by IWRM approach

RECOMMENDATION

Multi-Product and Multi-Sensor based correction techniques can be used to improve the reliability of the SRE. The study proves that the satellite based rainfall estimates are very effective tool to strengthen the forecast system by increasing valuable lead time, assess and quantify the benefits of Integrated Water Resource management in Transboundary basins. This will help the decision making process in more scientific manner in field of (1) Investment strategies (2) International co-operation to reduce the transboundary disputes by reducing the loss and sharing benefits by IWRM practices. It is recommended that a Comprehensive plan may be developed to carry out the study on IRWM in integrated system of river basins (Ghaghra, Gandak, Bagmati and Kosi) to address the issue in a holistic manner and employ the SRE correction techniques in new Generation GPM products.

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