Rainfall-Runoff Modeling of the Trans-Boundary Kabul River Basin Using Integrated Flood Analysis System (IFAS)

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ABSTRACT

The gauge data communication was disrupted from the control unit during the flood disaster 2010 in the Kabul River Basin, therefore, totally satellite rainfall data dependency is accounted in the present research. In this study an attempt is made to develop the non-structural countermeasures for the downstream reach of the Kabul River so that the losses and damages due to flooding could be minimized. The Satellite rainfall data set namely Global Satellite Mapping of Precipitation GSMaP_NRT (Near Real Time) has been used by the hydrological model, Integrate Flood Analysis System (IFAS), to conduct rainfall runoff modeling. The discharge calculated by the Satellite GSMaP_NRT (corrected) has showed good agreement with the observed discharge values from the ground discharge measuring station both in terms of flood duration and flood peak. The Satellite GSMaP_NRT (original) captured neither flood duration nor did the flood peak. The discharge data and the corresponding rainfall data of the upper catchment areas have been analyzed especially for the devastating Pakistan flood 2010 to check the feasibility of IFAS for the flood forecasting of the Kabul River. The IFAS showed the capability to generate sufficient lead time forecast for the local downstream population. This tuned IFAS model is practically helpful for the flood early warning and to save the lives and movable properties of the community.

Key Words: Satellite Rainfall, Kabul River, Flood Forecasting, IFAS, Pakistan

Introduction

Operational forecasting of river flow is becoming increasingly widespread, answering to several objectives such as the provision of early warning of floods to initiate a timely response (Krzysztofowicz et al., 1992; Haggett, 1998; Parker and Fordham, 1996; De Roo et al., 2003), or water resource predictions to support reservoir operation (Faber and Stedinger, 2001). Typically delivery of operational flow forecasting is the mandate of operational agencies at the national (Werner et al., 2009), or at the (trans-boundary) basin level (Plate, 2007). Real time observations, and in most cases model predictions, are used as guidance to decision makers on actions to be taken in response to an observed or forecast state of the water system.

In 2010, almost all of Pakistan was affected when massive flooding caused by record breaking rains hit Khyber Pakhtunkhwa (KP) and Punjab. At least 1985 people died in this flood and overall 20 million people were affected by it. Overall damage is estimated at PKR 855 billion which is 5.8 percent of 2009/10 GDP (NDMA, Annual Report 2010).

The torrential downpours in KP caused severe flash floods within the Kabul River basin and especially large scale flooding in the Peshawar Valley. On July 29, 2010 rainfall of 274 mm was recorded in Peshawar which was record-breaking rainfall at the location since 1961. The daily rainfall corresponds to five times the average monthly rainfall (47 mm) in July and almost 80 % in Peshawar was recorded by Pakistan Meteorological Department (PMD). These flash flooding killed as many as 1156 people and affected 3.8 million people in KP (WFP 2010). In cases of extremely severe disasters like the Pakistan flood, many towns and villages become isolated due to the disruption of both transportation and the communication network (Relief International 2010). Therefore, governments and related organizations have to evaluate the damage status based on limited information. There is a growing consensus that the impacts of climate change may well lead to an increase in both the frequency and magnitude of floods (Kennedy, 2004). Considering all the previous devastating floods and non-structural measures adopted to

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mitigate the damages, an attempt has been made to implement the IFAS for the flood forecasting of the Kabul River. The precise and timely flood forecast and warning play vital role in saving the lives and movable properties of the communities. The specific objective of the study is to make the Integrated Flood Analysis System (IFAS) applicable for the flood forecasting of the Kabul River. The structural countermeasures have been taken time and again but due to destabilized economic condition of the country it is not possible to invest bulk amount of money for the flood control. Therefore, in this scenario non-structural countermeasures are the only solution of this problem.

Study Area

The Kabul River basin has a catchment area of 92,605 square kilometers. Kabul is the tributary river of Indus River System. It drains the two countries including Afghanistan and Pakistan and its trans-boundary catchment area spans over the same two countries. The river originates in the central Afghanistan and snakes through the central Kabul, province of Afghanistan. It enters Pakistan via northwestern areas flowing through the north in a southerly direction joins Indus River near the city of Attock and finally merges into the Arabian Sea near the port city, Karachi. The river has a number of tributaries including the important ones are Swat and Konar Rivers. A number of barrages have been constructed on the river which provides the backbone for the irrigation system of the country.

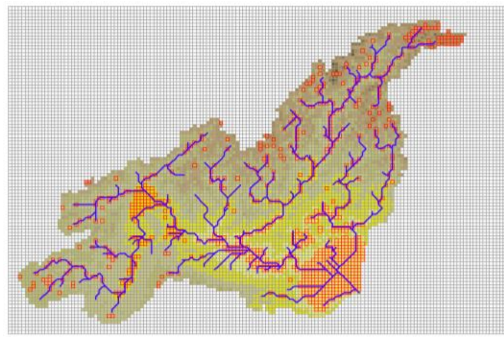

Figure 1: Study area depicts Kabul River Catchment

Data

The GSMaP_NRT hourly rainfall data is used for the period from July 01 to Aug 30, 2010 for the same catchment. The hourly GSMaP_NRT data then converted into two hourly by using the IFAS function (Project time interval). The specifications of the both satellite data are shown in the table1 (IFAS manual, 2009

Table 1: Specifications of the Satellite data

Product Name	**GSMaP_NRT**
Resolution	0.1^0 (L=11km, A=120km^2)
Resolution Time	1 (hour)
Coverage	60^0N-60^0S
Time Lag	4 (hours)
Coordinate System	WGS
Historical Data	Availibility period be mentioned
Developer and Provider	JAXA/EORC
Sensors	TRMM/TMIAqua/AMSR-EADEOSII/AMSRSSM/ IIRAMSU-B

Configuration of PWRI Distributed Model

The PWRI Distributed Model (version 2) contains the configuration of two tanks on vertical direction; the surface tank and the underground water tank and the third one is the river channel tank as shown in the figure 2 and 3.

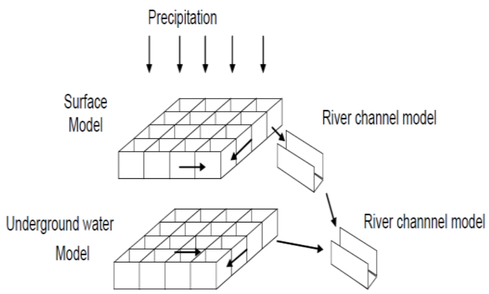

Figure 2: Scheme image of the model.

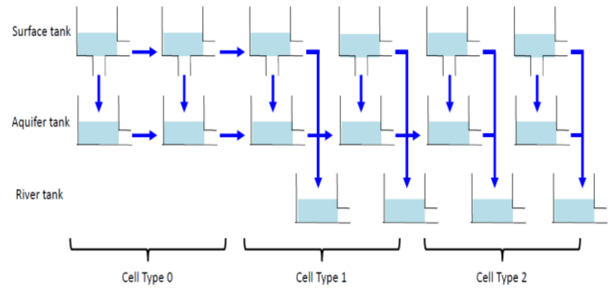

Figure 3: Cell type outline chart

Surface Parameters

The surface parameters used in this study have been shown in the table 2.

Table 2: Surface parameters used for Kabul River

Tunned Parameters	Final infiltration capacity fo(cm/s)	Maximum storage height S_{f2}(m)	Rapid intermediate flow S_{f1}(m)	Height where ground infiltration occurs $S_{f0(m)}$	Surface roughness coefficient N(m-1/3)	Rapid intermediate flow regulation coefficient α_n	Initial storage height (m)
1	0.00001	0.06	0.01	0.002	1	0.15	0
2	0.00002	0.08	0.01	0.002	3	0.2	0
3	0.00001	0.09	0.01	0.005	3.5	0.3	0
4	0.000001	0.05	0.0005	0.0001	2.1	0.25	0
5	0.000001	0.09	0.01	0.005	4.5	0.3	0

Aquifer Parameters

The aquifer parameters used in this study have been shown in the table 3.

Table 3: Aquifer parameters used for Kabul River

Tuned Parameters	AUD $(1/mm/day)^{1/2}$	AGD (1/day)	HCGD (m)	HIGD (m)
	0.2	0.0003	2	2

River Tank Parameters

The river parameters used in this study are shown in the table 4.

Table 4: River tank parameters used for Kabul River

Tunned Parameters	Constant of the Resume Law (c)	Constant of the Resume Law (s)	Manning roughness coefficient	Initial water table of river channel	Infiltration of Aquifer tank	Coefficient of cross shape (RHW)	Coefficient of cross shape (RHS)	Coefficient of cross shape (RBH)	Coefficient of cross shape (RBET)	Coefficient of cross shape (RLCOF)
1	7	0.5	0.038	0.2	0	9999	1	0.5	0.05	1.4
2	7	0.5	0.037	0.2	0	9999	1	0.5	0.05	1.4
3	7	0.5	0.036	0.2	0	9999	1	0.5	0.05	1.4

Error Analysis of IFAS

Efficiency criteria (objective function) are defined as mathematical measures of how well a model simulation fits the available observations (Beven, 1999). The performance of the IFAS model can be evaluated by three indices like wave shape error, volume error and peak discharge error which are defined by the Japan Institute of Construction Engineering (JICE). The each and every indicator can be described as shown in the table 5.

Table 5: Indicators for the error analysis of IFAS

Wave Shape Error	Volume Error	Peak Discharge Error
$E_w = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Q_{O(i)} - Q_{C(i)}}{Q_{O(i)}}\right)^2$	$E_v = \frac{\sum_{i=1}^{n} Q_{O(i)} - \sum_{i=1}^{n} Q_{C(i)}}{\sum_{i=1}^{n} Q_{O(i)}}$	$E_P = \frac{Q_{OP} - Q_{CP}}{Q_{OP}}$

Where, E , E_w , E_v and E_P represent Error, Wave Shape Error, Volume Error and Peak Discharge Error respectively; n : The number of calculating time ; Q_{OP} : Measured maximum run-off

$Q_{O(i)}$: Measured run-off at time I; $Q_{C(i)}$: Calculated run-off at time I

Q_{CP} : Calculated maximum run-off

Results and Discussion

The IFAS with default parameters showed no synchronization with the measured discharge values, therefore, it cannot be reliably applied for the flood forecasting of the Kabul River. The surface parameters like surface roughness coefficient (N)-to slow the surface outflow, and height where rapid intermediate outflow occurs (Sf1)-to slow the peak flow, are increased while rapid intermediate flow regulation coefficient (α n)-to decrease the rising limb of wave form, and final infiltration capacity (f o)-to increase the storage height of groundwater tank, are decreased in the tuning of IFAS. The aquifer parameter, slow intermediate flow regulation coefficient (Au)-to enlarge the set part of wave form, is increased in the tuned IFAS. The river parameter, surface roughness coefficient (n), is increased in the tuned IFAS.

The observed discharge data of Kabul River from 29.7.2010 to 7.8.2010 is missing therefore there is disruption in the hydrograph. The flood peak exists in the missing data period. The estimated value of peak discharge is more than 9800 m^3/s (Flood Report, 2010). The upstream rainfall and corresponding discharge data of Kabul River have been analyzed for the period from July 01 to Aug 30, 2010. The project time interval of IFAS is selected as two hours, therefore, the discharge data for the same period is linearly interpolated from six hourly to two hourly. The IFAS by using the data of Satellite GSMaP_NRT (corrected) calculated the peak discharge of magnitude 10471 m^3/s on 30.7.2010 at 10 hours. The duration and magnitude of the peak calculated by the IFAS is well synchronized with the estimated one. The flow in the Kabul River below the medium flood level is not a matter of concern for the authorities related to flood disaster management in the country. Therefore, to study the behavior of flood 2010, the threshold value has been selected at the medium level of flood. The various flood limits for the Kabul River at discharge gauging point Nowshera, have been shown in the table 6.

Table 6: Flood limits for the Kabul River

Station Name	Low-flood (m^3/s)	Medium-flood (m^3/s)	High-flood (m^3/s)	Very-high flood (m^3/s)	Extremely-high flood (m^3/s)
Kabul (Nowshera)	1260	1316	2800	5600	11200

The IFAS has been used, firstly, with the default parameters. The IFAS showed higher base flow discharge with default parameters in each and every case. The Satellite GSMaP_NRT with corrected rainfall, by using the Internationl Center for Water Hazards & Risk Management (ICHARM's) method for correction of rainfall data, shows the best results for each and every case. The discharge calculated by the Satellite GSMaP_NRT (corrected) is well synchronized with the measured discharge. The flood duration and flood peak calculated by the Satellite GSMaP_NRT (corrected) have the best agreement with the observed one.

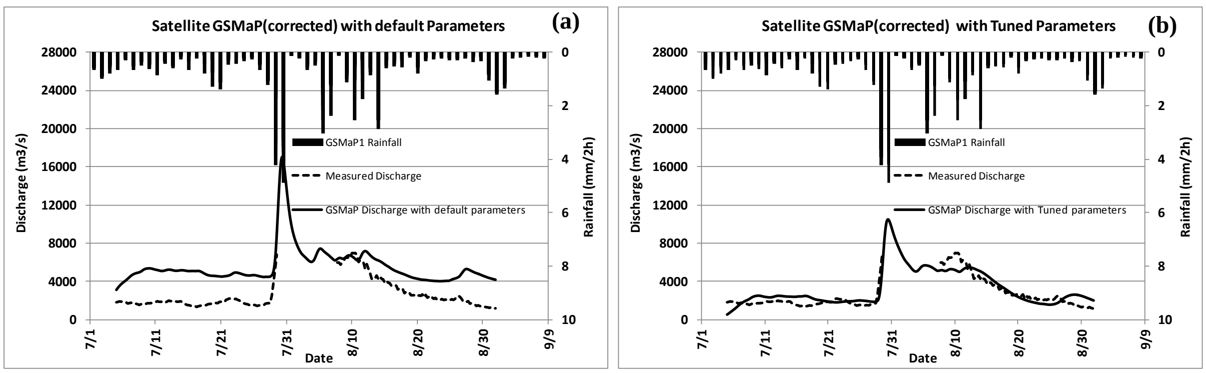

Figure 4: Results of GSMaP (corrected) **(a)** with default parameters & **(b)** with tuned parameters.

The GSMaP_NRT (original) provides almost no information for flood duration and peak. It is, therefore, obvious that the IFAS with default parameters cannot be applied for the flood forecasting of Kabul River.

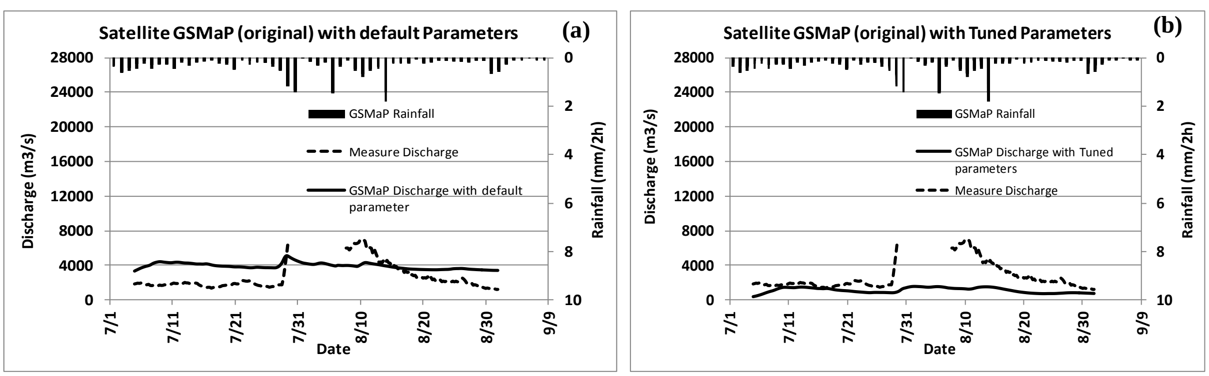

Figure 5: Results of GSMaP (original) **(a)** with default parameters & **(b)** with tuned parameters.

Error Analysis for Kabul Flood 2010

The wave shape error, volume error and peak discharge error have been calculated for Kabul 2010. The Satellite GSMaP (corrected) shows the peak discharge error of -6.8%. The negative sign indicates that the calculated peak is lower than the observed one. The results of Satellite GSMaP original and corrected for Kabul at Nowshera are shown in the table 7.

Table 7: Error analysis for Kabul 2010

Product	Wave Shape Error (Ew)	Volume Error (Ev)	Peak Discharge Error (Ep)
Satellite GSMaP (corrected)	3.705	-1.565	-0.068
Satellite GSMaP (original)	1.327	-0.695	0.87

Conclusion

This study focused on the province Khyber Pakhtunkhwa (KP), where as many as 1156 people died due to overflows from the Kabul River, as well as flash flooding in many tributaries within the river basin. In this study, IFAS with tuned parameters was applied to simulate rainfall–runoff. The objective here was to discuss whether or not the simulation model could provide useful information for evacuation and emergency response during or immediately after a disaster. The main focus was that how well the simulated flood peak agrees with the observed one. It was found that the model simulation performed can provide additional information to help identify where flood damage may occur during emergency situations based on limited local information. The Satellite GSMaP_NRT with corrected rainfall, by using the ICHARM's method for correction of rainfall data, showed the best calculation results. The discharge calculated by the Satellite GSMaP_NRT (corrected) is well synchronized with the measured discharge. This satellite showed the best results while calculating the huge and colossal Pakistan flood 2010. The flood duration and flood peak calculated by the Satellite GSMaP_NRT (corrected) have the best agreement with the observed one. The calculation results of the Satellite GSMaP_NRT (original) have low signals. The Satellite GSMaP-NRT (original) neither captured the flood duration nor did the flood peak.

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