DEVELOPMENT OF A FLOOD FORECASTING SYSTEM ON UPPER INDUS CATCHMENT USING IFAS

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ABSTRACT:

A flood forecasting system based on hydrological modeling is already covering main Indus but the upper reaches and Kabul river basin where most of the 2010 flood victims were located are not. This is the target for this research, providing a calibrated hydrological model to be the base of a flood forecasting model for Upper Indus river basin. Upper Indus river basin up to Taunsa, covering 577,000 km^2 has been modeled with IFAS (Integrated Flood Analysis System) based on a 5 km gridded, spatially distributed 3 layered tank model. The model building was performed in order to account as much as possible for local data available. In particular, soil hydraulic data newly surveyed by Pakistan Council of Research in Water Resources have been integrated in this model. However, a part from the great area to be covered, the lack of sufficient local hydrometeorological data had also to be overcome. Indeed for the upper reaches of the basin, there are only 24 rain gauges covering 133,300km^2 and only nine discharges measurements points at river stations, barrages and dams are available along the 1,650 km of Upper and Mid Indus. The model was calibrated on three flood events including 2010 floods and validated on three other events including 2012 recent floods. The simulation results suggested the uncertainty of rainfall data was great. For this reason, upstream discharges were input as boundary conditions and as a result, Nash-Sutcliff efficiencies reached a satisfactory average. Moreover, as an alternative to raingauges data, GSMaP-NRT (Global Satellite Mapping of Precipitation, Near-Real Time product) was calibrated and considered in runoff analysis. Input rainfall slightly improved but not enough to explain all runoff and therefore, in order to achieve acceptable performance, it is recommended to rely on upstream discharges as boundary conditions.

Key Words: hydrological modeling, large river basin, Indus, IFAS, GSMaP-NRT.

1. INTRODUCTION

During monsoon season (mid-June to end of September), floods usually occur in Indus river basin with more or less devastating impacts essentially due to runoff resulting from heavy rainfall accompanied sometimes with increased snowmelt (FFC, 2013). Efforts have been made to model Indus river basin from Tarbela to downstream in the 90's with FEWS (Flood Early Warning System) based on Sacramento rainfall runoff model and SOBEK 1D routing model. Hence, Upper Indus and Kabul river basin have not been covered (Afsar et al, 2013). This research is part of the "Strategic Strengthening of Flood Warning and Management Capacity of Pakistan" implemented by UNESCO from January 2012 to June 2014. The subject of this paper is the development of IFAS model for Upper Indus as part of a comprehensive flood forecasting system.

Figure 1 shows the target area (orange), Upper Indus, covering the very upstream of Indus river basin to Taunsa and the locations of river stations along main Indus River. It was modeled based on GlobalMap elevation data from ISCGM with PWRI-DHM with the 3-layer tank model configuration in Sugiura et al

(2013). For each grid representing the river basin model, the three layers are 1) a surface layer parameterized according to land use, 2) an unsaturated layer and 3) an aquifer tank, both parameterized according to soil textural class.

In this paper, the PWRI-DHM Upper-Indus model, run in IFAS, was improved by taking in account local soil hydraulics data surveyed by PCRWR (Pakistan Council of Research in Water Resources) during 2012-2013. Figure 3 shows observed rainfall data are not available in a satisfactory manner because of the rain gauges network density less than 10 times WMO standard, (2008), GSMaP-NRT (Global Satellite Mapping of Precipitation, Near-Real Time product from JAXA) satellite-based rainfall estimates were considered as input data and a correction method proposed and evaluated. Then simulated discharges using both observed rainfall, GSMaP-NRT corrected rainfall with or without input boundary conditions were compared to observed discharges and the modeling efficiencies appreciated through Nash-Sutcliff efficiency for 6 monsoon periods including 2010 mega-flood and 2012 recent flood.

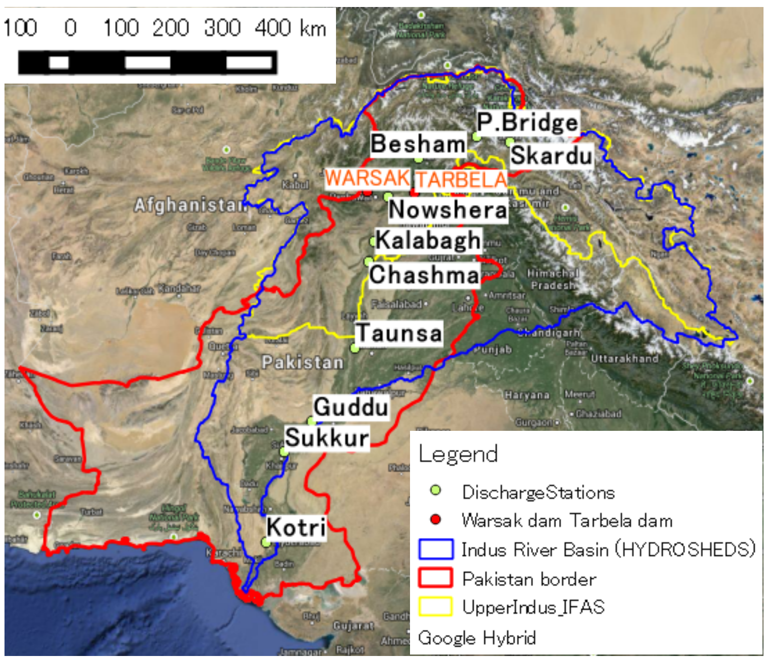

Figure 1 River stations locations and target area.

2. DATA AVAILABILITY IN UPPER INDUS

The performances of rainfall runoff analysis highly depend on the availability and quality of rainfall data, discharges data and other local data. Therefore this section analyzes the availability and the quality of daily rain gauges data, GSMaP-NRT rainfall estimates, discharges data at nine stations, and the relationship between rainfall and discharges as runoff rates. Finally soil hydraulic properties collected from a 112 sites survey by PCRWR will be presented. However, other local datasets such as river cross-sections or detailed barrages and dam operation rules for Tarbela or Warsak, Kalabagh and Chashma were not available and could not be taken in account.

2.1 Rainfall data in Upper Indus

2.1.1 PMD rain gauges data

Figure 2 presents the 92 rain gauge observation points data spatial distribution covering Pakistan in 2012 and Thiessen polygons (Thiessen, 1911) areas they represent in order to investigate Pakistan rain gauges network density. While comparing Indus Thiessen polygons areas with WMO recommendation for minimum rain gauges density network (WMO, 2008), there is almost no area in Pakistan complying with WMO requirements. Figure 2 shows the 26 rain gauges available in Upper Indus simulated by IFAS, to cover more than 400,000 km^2. It corresponds to an average density of 15,000 km^2 well above the recommendation of one station every 250km^2 for mountains or 575 km^2 for hilly and plain areas (WMO, 2008). However, due to the geography of Upper Indus culminating at elevation over 7,000m, there is a proper challenge to access, install and maintain rain gauges. Moreover, the transboudary character of Indus river basin also makes difficult the collection of hydrometorological data from other countries. Therefore, the potential contribution of satellite based rainfall estimates is considered in the next section.

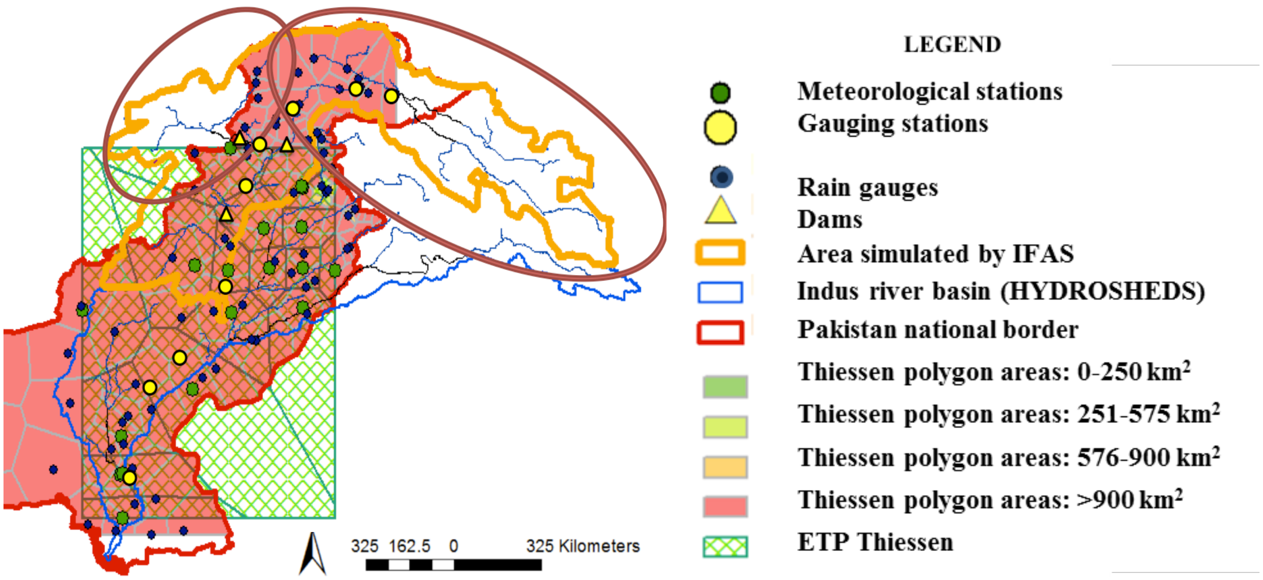

Figure 2 Hydrometeorological data stations and Thiessen polygons area for rainfall and Evapotranspiration. (Sugiura et al, 2013)

2.1.2 GSMaP-NRT Satellite rainfall estimates characteristics for Indus river basin

GSMaP-NRT is provided as a 0.1 by 0.1 degree resolution gridded hourly rainfall data (Kubota et al, 2007).But due to GSMaP algorithm limitations and consequent uncertainty, there are areas reported with no data, in particular for snow covered area as the algorithm cannot differentiate between depositing snow and deposited snow through brightness temperature (Aonashi et al, 2009). GSMaP-NRT Missing values were interpolated by inverse distance weighted with surrounding data. However GSMaP-NRT rainfall estimates cannot be used directly either and need to be calibrated or corrected even for uses at daily time step and especially in mountainous area (Fu, Ruan, & Liu, 2011).

Figure 3 a) b and c) show accumulated rain gauge rainfall in mm, the accumulated interpolated GSMaP-NRT distribution in mm for the target period 01/07/2010 to 31/08/2010 and the distribution of the ratio between accumulated rain gauge rainfall and interpolated GSMaP-NRT rainfall estimates in order to investigate GSMaP-NRT error rates distribution. In general, the ratio is over 1 with green to red color showing GSMaP-NRT estimates are smaller than rain gauges data. However, GSMaP-NRT estimates are particularly underestimated compared to rain gauges data in the zone between P.Bridge and Taunsa (in the red circle) with color ranging from orange to purple accounting for ratio between 2 and 100 and GSMaP-NRT rainfall estimates will need to be greatly augmented before any use as input rainfall data.

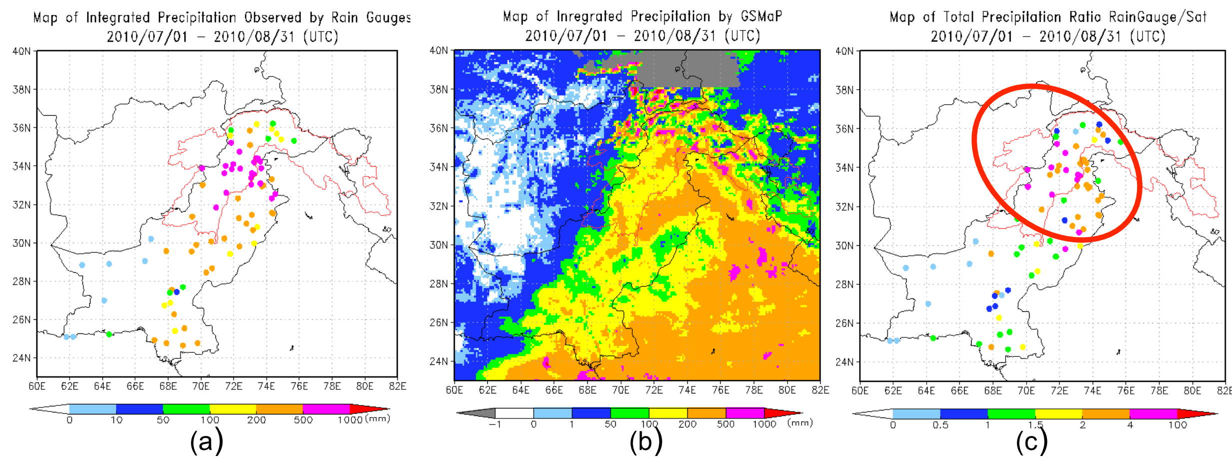

Figure 3 Accumulated rainfall a) Rain gauge b) interpolated GSMaP-NRT), c) Ratio of total rainfall (Rain gauge / interpolated GSMaP-NRT) for the period 01/07/2010 to 31/08/2010.

2.2 Discharge data

Measured discharges data are needed to runoff analysis results during the calibration and validation process. Figure 1 shows the location of the river discharge/heights measuring points currently also used for the current flood routing method installed in Pakistan. FFD reports the average travel time in hours between the different river stations. The shortest average travel time is between Besham and Tarbela (6h) and the longest between Chashma and Taunsa (51-72h). For the area modeled with IFAS, the average travel time between Skardu and Taunsa is between 111h and 132h. The previous 3 layer tank model based on global dataset in Sugiura et al 2013, relied on upstream discharges input as boundary conditions. Because of the travel time between stations, this model can be used efficiently as part of a flood forecasting system relying on discharges measured 6 hourly.

Figure 4 shows discharges time-series at the different stations in 1997, 2010 and 2012, their relationships to appreciate a posteriori dam and barrages operations as their rules are unknown. For 1997 and 2012, which were not mega floods, Kalabagh, Chashma and Taunsa barrages operations result in upstream discharges higher than downstream ones. Without knowing the operation rules in advance, this cannot be modeled with IFAS. While comparing 1997, 2010 and 2012 dams and barrages operations, it appears that Tarbela dam stored most of the peak discharges in 2010. Indeed, TARBELA_OUT is seven times smaller than TARBELA_IN for 2010, but only 1.9 to 1.4 for 1997 and 2012 respectively. However in Kalabagh and Chashma, in 2010, inflow discharges were very comparable to outflow discharges and diverted amounts for Thal canal in Kalabah stayed comparable to the ones in 1997 and 2012. Without the knowledge of the dams and barrages operation rules to be input into the model, the model cannot simulate discharges properly and the modeling exercise will again rely on the input of upstream discharges boundary condition.

2.3 Runoff rates at different stations from Skardu to Taunsa

Figure 5 reports runoff rates defined as ratio of observed discharges volumes to Thiessen distributed observed rainfall volumes were calculated over the monsoon period of the 6 years considered for each sub-basins between two discharge stations. Runoff rate up to Tarbela, discharges are mainly due to snowmelt (Inman et al, 2007) and therefore runoff rates were not calculated for Skardu and Partab Bridge. However, ratios over 100% are unlikely for downstream of Tarbela as observed discharges volumes would be less than rainfall volumes which are the main contributors to discharges and would reflect the lack of observed rainfall. This is especially the case for Kabul river basin for which runoff rates are always over 100% for all years. Indeed, there is only one rain gauge to cover over 53,000km^2. For Tarbela, runoff rates should be over 100% as snowmelt is contributing mainly to its discharges, however, for 2010 and 2012, runoff rates are around 70%. For 2010, the great inundation might have contributed in decreasing discharges recorded in Tarbela. However, for 2012, as there was no significant flooding, this reflects again the uncertainty around rainfall volumes because of the scarcity of rain gauges, the rainfall volumes are difficult to assess. Runoff rates for Kalabagh and Taunsa fluctuate between positive and negative values reflecting barrages operations and volumes diverted between upstream dand downstream stations making difficult the interpretation of runoff rate values. For Chashma, which lies between Kalabagh and Taunsa, runoff rates are also reflecting unaccounted rainfall volumes until 1997 but then, runoff rates stabilize around 50% meaning rainfall volumes might be accounted for properly from then.

From this runoff rates analysis, uncertainties on rainfall volumes are significant for most of the modeled area so that it is unlikely runoff analysis run only with rainfall will provide satisfactory results.

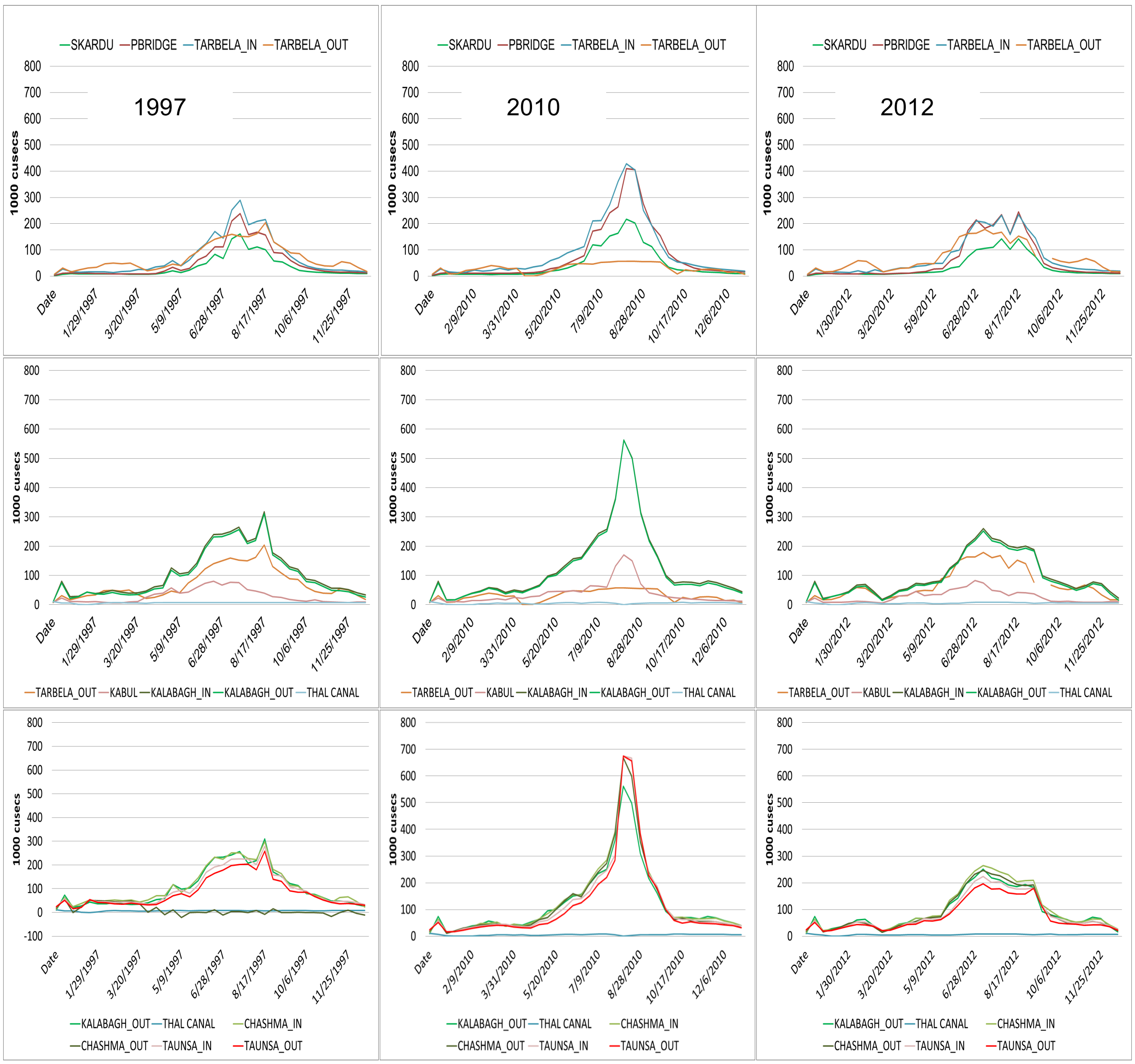

Figure 4 10 days averaged discharges for yearlong 1997, 2010 and 2012 at Skardu, P.Bridge, Tarbela, Kalabagh, Chashma and Taunsa.

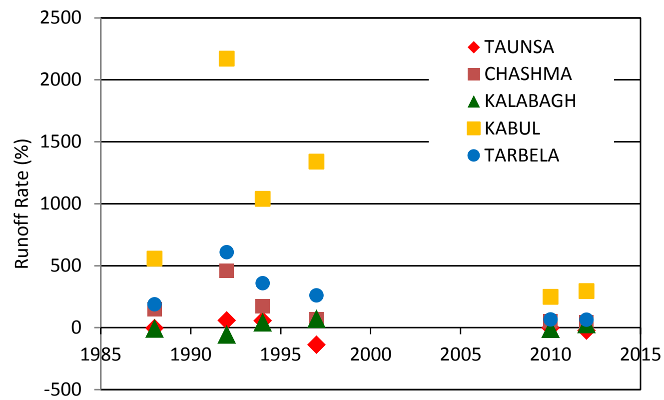

Figure 5 Runoff rates at Tarbela, Kabul, Kalabagh, Chashma and Taunsa sub-basins for 1988, 1992, 1994, 1997, 2010 and 2012.

2.4 Soil Hydraulic properties data

The parameters of the unsaturated tank, the second tank of the PWRI-DHM 3 layer tank model depend on soil physical properties (Fujita et al, 2006). In IFAS, the parameterization of the unsaturated tank is performed according to soil texture and depth distribution available from the Harmonized World Soil Database v1.2 (FAO et al, 2012). Figure 6 shows the distribution of FAO et al (2012) soil types classified into soil textural classes according to USDA (Maidment, 1993, Chapter 5). Eight soil textural classes were identified for Upper Indus with Sandy Clay Loam (lighter green) covering more than 52% of the upper catchment.

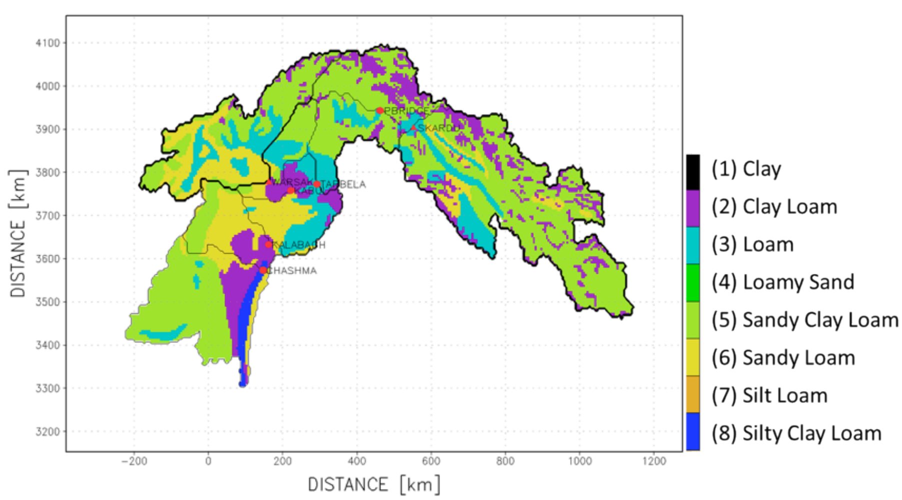

Figure 6 Soil textures distribution in the upper catchment of Indus

The previous Upper Indus model was improved by taking into account soil hydraulic properties obtained after a 112 sites field surveys conducted in 2012-2013 by PCRWR. So far only limited information was available on Pakistani soil (Kelleners et al, 1999). Table 1 compares saturated hydraulic conductivity, residual water content and saturated water content for the different soil textural types encountered in Upper Indus with ASCE standard values (Maiment, 1993). Soils in Pakistan present in average less much less retention capacity and are much more drainable than average soil of the same textural class derived from the literature (Maidment, 1993). For Sandy Clay Loam, the deficit in retention capacity is over 35% compared to ASCE standard, as infiltration rate is over 6 times higher.

Moreover, in this river basin, infiltration happens mainly in the floodplain and it can be described as an "alluvial corridor" where infiltration happens lying inside a wider less infiltrating material closer to bedrock and the surface tank was also parameterized according to the position of the river course by attributing the infiltration rate from the corresponding subjacent textural class.

Table 1: Comparison of Parameters for the unsaturated tank. –Global values (ASCE, Maidment, 1993) and field survey values – Kv: saturated hydraulic conductivity, θ_r: residual water content, θ_s: saturated water content.

Soil textural type	θs		θr		Kv (mm/h)	
	112 sites	Ref.80 ASCE	112 sites	Ref.80 ASCE	112 sites	Ref.81 ASCE
Sand	0.366	0.437	0.089	0.020	81.62	235.60
Loamy sandy	0.363	0.437	0.114	0.035	80.05	59.80
Sandy loam	0.371	0.453	0.125	0.041	41.93	21.80
Loam	0.382	0.463	0.145	0.027	16.77	13.20
Silty loam	0.379	0.501	0.157	0.015	55.94	6.80
Sandy clay loam	0.380	0.398	0.167	0.068	18.27	3.00
Clay loam	0.391	0.464	0.189	0.075	4.75	2.00
Silty Clay Loam	0.350	0.471	0.110	0.040	11.00	2.00
Clay	0.398	0.475	0.207	0.09	8.60	0.60

3. METHODOLOGY

3.1 PWRI-DHM – 3 tank layer configuration

The 5-km distributed PWRI-DHM 3 layer tank model, main analysis model of IFAS, was build based on GlobalMap elevation data from ISCGM and river courses path corrected to match Google Earth image for mainstream Indus. The calibration and validation processes are the same as detailed in Sugiura et al (2013) based on trial and error for each of the parameters. The river routing is based on kinematic wave. Because Indus and in particular Upper Indus is a large basin with scarce data, it was divided into six sub-basins and calibration done on sub-basins with less uncertainty on water balance. Then the parameter values identified were feedback to the remaining sub-basins. But snowmelt modeling remained out of the scope of this research and therefore, the model performance strongly relies on the quality of measured discharges input as upstream boundary conditions all along Upper Indus from Skardu to Taunsa.

3.2 GSMaP-NRT correction method

Shiraishi et al (2009) GSMaP-NRT correction method based on rainfall area movement was considered and its coefficient adjusted for 2010 monsoon. Equation [1] explains the relation between Mj, the correction factor for satellite rainfall estimates and Sn, the motion of rainfall distribution estimated from GSMaP data. The different steps are explained from Equation [2] to Equation [5].

Figure 7 shows the partition of Pakistan into four regions to take into account the spatial heterogeneity of GSMaP inaccuracy. The partition considered both the elevation and GSMaP-NRT data degree of inaccuracy compared to PMD rain gauges data resulting in four regions: Region1 corresponding to the area with elevation higher than 3,000m, Region 2, the area where large amount of total rainfall were observed by PMD rain gauges, Region 3, where the accuracy of satellite rainfall estimates is good and Region 4, the low elevation area between 0-100m.

Coefficients α and β were adjusted for each region identified for 01/07/2010 to 31/08/2010.

$$\mathrm{Mj} = -\alpha \times \ln(Sn) + \beta \quad [1]$$

Sn is calculated for every 3 hours and daily averaged Sn in each region. The averaged Sn and daily rainfall averaged among the region are considered for the analysis, also very low intensity rainfalls are not considered as their uncertainties are higher. Table 2 presents the calibrated coefficients per region.

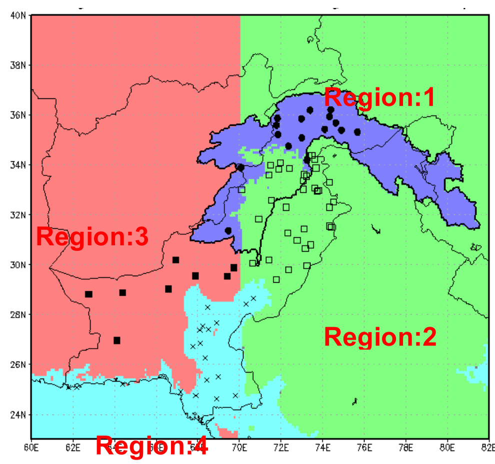

Figure 7 Upper Indus regionalization (●:Region 1, purple □:Region 2 green ■:Region 3 red ×:Region 4 light blue)

$X_{i,j} = \frac{1}{k}\sum_{t=1}^{k} X_{i,j}(t)$ [2]

$Sn^2 = \frac{1}{4}\sum_{x=0}^{1}(X_{i,j} - x_{i+6x-3,j+6y-3})^2$ [3]

$\overline{\mathrm{Sn}}(\mathrm{n}) = \frac{1}{f}\sum_{r=1}^{f} Sn(f)$ [4]

$R_{obs}(\mathrm{n}) = M_j \times R_{sat}(n)$ [5]

$X_{i,j}(\mathrm{t})$: Rainfall intensity of GSMaP_NRT

$R_{obs}(\mathrm{n})$: Rain gauge rainfall

$R_{sat}(\mathrm{n})$: Satellite rainfall

M_j : Correction factor

$\overline{\mathrm{Sn}}(\mathrm{n})$: Index of movement of rainfall distribution

Table 2 Coefficients fitted for ICHARM self-correction for each region.

Region No.	α	β	Remarks
1	2.871	4.6574	Only data over 10mm/day are considered.
2	1.835	2.9612	Only data over 5mm/day are considered.
3	3.067	1.7030	Only data over 5mm/day are considered.
4	1.143	1.9600	Only data over 4mm/day are considered.

4. RESULTS AND DISCUSSION

4.1 Application and evaluation of GSMaP correction method

The corrected values are compared to rain gauge rainfall data to evaluate their accuracy. Table 3 reports average error ratio, correlation coefficient, and bias scoring to evaluate daily averaged rainfall data correction accuracy for each region. GSMaP correction is especially efficient for region 4 (coastal area and low altitude area covering Sindh) for 2010 and region 3 (Balochistan) and for 2012. For region 3, ICHARM corrected GSMaP-NRT data are still underestimating the amounts of precipitation (average error rate and bias are negative) but the bias are the lowest, which is in accordance with the fact region 3 was identified with the greater accuracy. For both 2010 and 2012, ICHARM correction performances are limited on point based but the distribution effect (volume wise) is evaluated by using corrected GSMaP rainfall estimates as input data into the model.

Table 3 Scores for correction efficiencies (best performance in bold).

		2010		2012	
		(Interpolated only)	（ICHARM Correction）	(Interpolated only)	（ICHARM Correction）
Region:1	Average error rate (%)	**30.75**	53.14	**13.73**	24.13
	Correlation coefficient	0.67	**0.7**	**0.79**	0.67
	Bias (mm)	1	**0.88**	**0.23**	0.79
Region:2	Average error rate (%)	59.05	**40.34**	**28.59**	55.41
	Correlation coefficient	**0.79**	0.68	**0.7**	0.8
	Bias (mm)	3.23	**1.57**	1.11	3.03
Region:3	Average error rate (%)	**11.09**	-22.32	-39.55	**-1.57**
	Correlation coefficient	0.43	**0.63**	**0.66**	0.44
	Bias (mm)	**0.12**	-0.19	-0.33	**-0.02**
Region:4	Average error rate (%)	20.2	**-15.5**	-21.3	**17.59**
	Correlation coefficient	0.8	**0.88**	**0.88**	0.8
	Bias (mm)	0.37	**-0.23**	**-0.32**	0.33

4.2 Evaluation of hydrological modeling efficiency with PMD rainfall and corrected GSMaP_NRT rainfall estimates with or without discharges given as boundary condition.

The simulated discharges at the different stations (Taunsa, Chashma, Kalabagh, Kabul, Tarbela, P.Bridge and Skardu, from upstream to downstream respectively) were compared with measured discharges. Their performances were evaluated using Nash-Sutcliff efficiency, E_{NS}, (Nash and Sutcliff, 1970) and results are presented in Table 4 and 5.

Table 4 Scores for discharges simulations for different years without boundary conditions, in red, score under 0.50, blank when no data available, PMD stand for ground rainfall and GSMaP for corrected GSMaP-NRT rainfall estimates.

Nash-Sutcliffe: E (without input discharges)

No	Name/Year /case	1988 PMD	1992 PMD	1994 PMD	1997 PMD	2010 PMD	2010 GSMaP	2012 PMD	2012 GSMaP
1	TAUNSA	-0.42	-2.00	-1.04	0.00	0.07	-0.28	-0.62	-0.39
2	CHASMA	-0.81	-2.15	-1.36	-0.65	0.39	-0.47	-0.78	-0.94
3	KALABAGH	-0.76	-2.29	-1.90	-1.41	0.25	-0.59	-1.09	-1.42
4	KABUL	-0.30		-0.39	-0.25	-3.17	-0.28	-0.15	-0.31
5	TARBELA	-2.95	-4.17	-3.17	-2.94	-0.96	-1.45	-3.86	-4.70
6	P.BRIDGE	-3.34	-3.48	-2.77	-2.22	-1.47	-1.99	-2.50	-2.88
7	SKARDU	-2.96	-2.90		-1.54	-1.08	-1.39	-1.61	-2.60

Table 5 Scores for discharges simulations for different years with boundary conditions, in red, score under 0.50, blank when no data available, PMD stand for ground rainfall and GSMaP for corrected GSMaP-NRT rainfall estimates.

Nash-Sutcliffe: E (with input discharges)

No	Name/Year /case	1988 PMD	1992 PMD	1994 PMD	1997 PMD	2010 PMD	2010 GSMaP	2012 PMD	2012 GSMaP
1	TAUNSA	0.88	0.61	0.94	0.51	0.72	0.88	-1.13	-1.11
2	CHASMA	0.94	0.91	0.93	0.82	0.97	0.94	0.89	0.91
3	KALABAGH	0.73	0.55	0.89	0.78	0.85	0.94	0.76	0.79
4	KABUL	0.29		0.80	0.89	0.56	0.49	0.85	0.83
5	TARBELA	0.30	0.46	0.86	0.62	0.73	0.73	0.84	0.84
6	P.BRIDGE	0.71	0.04	-4.34	0.52	0.16	0.16	-0.05	-0.05
7	SKARDU	-2.94	-3.04		-1.66	-1.17	-1.39	-2.24	-2.60

E_{NS} average value when all stations are considered for all events with PMD rainfall is -1.62 (-1.34 if from Tarbela to Taunsa as snowmelt is significantly contributing to runoff up to Tarbela, Inam et al, 2007) if no discharge is considered and 0.14 (0.68 if from Tarbela to Taunsa) if discharges are input as boundary conditions. As snowmelt is significantly contributing to runoff until Tarbela (Inam et al, 2007), water balances are in deficit for Skardu, PBridge, and in a lesser extent Tarbela and Kabul which correspond to the negative or low E_{NS} in both Table 4 and 5. The low performance of the model for Taunsa in 2012, even considering input boundary condition can be explained by the fact measured discharges are very low compared to recorded rainfall. Indeed, for similar runoff rate in Figure 5 between 2010 and 2012, in Figure 4 recorded TAUNSA_IN discharges are much lower in 2012 than in 2010. Moreover, runoff rates for Taunsa are 4 times smaller in 2012 than in 1997 but comparable discharges are measured in Figure 4. This means 2012 discharges volumes are unexpectedly low for the volume of rainfall recorded. In Sugiura et al 2013, it was also reported that 2012 Taunsa discharges are lower by over 50% the discharges in 1992 and 1994. Hence this bad scoring for 2012 Taunsa does not discard the model. Therefore, in overall, the performances while inputting boundary conditions as satisfactory.

While comparing only 2010 and 2012 for evaluating the difference in rainfall input, without discharges as input condition, neither PMD nor GSMaP-NRT corrected with ICHARM method are sufficient to reproduce runoffs at any stations. However, while inputting discharges as boundary conditions, simulations with GSMaP-NRT corrected with ICHARM method performs slightly better than with PMD rainfall (0.62 against 0.60 while considering stations from Tarbela to Taunsa).

Taking in account soil hydraulic properties only slightly improved the model compared to the one built only on global data. The global dataset based model averaged Nash-Sutcliff efficiency was E_{NS} = 0.67 (Sugiura et al, 2013) against E_{NS} =0.68 in the local data updated model. Moreover, input of upstream discharges boundary condition increases all values for E_{NS} , bringing them from negative values when not considered to values over 0.50 when considered. On the other hand, this makes the model performance very dependent from the quality of input boundary conditions but acceptable discharges are simulated in a context of great uncertainty on hydrometeorological data. Considering GSMaP-NRT data did not solve the problem on rainfall volumes uncertainty even though E_{NS} slightly improved. In the context of Indus, it is not clear if the poor performance of GSMaP with no boundary condition is due to GSMaP-NRT itself or if the correction is not enough due to the lack of rain gauges data.

Upper Indus river basin is very challenging to model: it is a very large river basin, it is difficult to collect hydrometeorological data such as snowmelt measurements or data to measure it, insufficient rain gauges network density, limited number of river discharges measurement points, no shared data on cross-sections, no shared data available on dams and barrages operation rules. However, it was possible to build a hydrological model with acceptable performance. Moreover, the model taking in account more local data only slightly outperformed the model only based on global data. Hence, by inputting upstream discharges as boundary conditions, it was possible to reduce the uncertainty on water balances at sub-basins level. Thus, this Upper Indus model is a successful example of large river basin modeling based on global dataset and with scare local data.

5. CONCLUSION

In Pakistan, the upper reaches of Indus as well as Kabul river basin have not been modeled yet as part of an effective flood forecasting system. The purpose of this study was to improve a first modeling attempt of Upper Indus based on global data sets and a 5km mesh PWRI-DHM 3 layer tank model in IFAS comprising a surface tank parameterized according to land use, an unsaturated tank and an aquifer tank parameterized according to soil hydraulic properties based on soil textural classes, and a river tank in which routing is based on kinematic wave. It was possible to calibrate and validate Upper Indus improved PWRI-DHM 3 layer tank model by considering surveyed soil hydraulic properties. However, because of the uncertainty on rainfall volumes bigger than the uncertainty of the model even considering GSMaP_NRT rainfall estimates, uncertainty on barrages and dams operations and lack of knowledge on river cross sections, the model had to rely heavily on upstream discharges as boundary conditions to simulate satisfactory discharges. However this should not impede the model to perform in a flood forecasting system as long as sufficiently recent discharges data are available. Moreover, comparing the performance of Upper Indus model only built based on global data and Upper Indus model accounting for more local data, the improvement was little. Nevertheless, this Upper Indus model is a successful example of large trans-boundary river basin modeling with scare local data. It illustrates how it was possible to overcome the lack of hydrometeorological data like snowmelt, insufficient rain gauges and discharge data, the lack of knowledge of cross-sections and dams and barrages operation rules by considering input of upstream discharges as boundary conditions. And also the results suggested global datasets based model does not perform significantly less than a local dataset based model and therefore, this raise the possibility to consider more the use of large basins with scare local data in flood forecasting.

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6. APPENDIX

ASCE: American Society of Civil Engineering

PMD: Pakistan Meteorological Department

PWRI-DHM: Public Work Research Institute- Distributed Hydrological Model

7. REFERENCES

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