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Performance Evolution of a Satellite Rainfall Product as a Possible Input Data Choice for Hazard Assessment Models: A Case Study of Pakistan

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SUMMARY: Rainfall is considered to be a prime driver in triggering of climate extremes (flooding and droughts) throughout the globe. For the management of economic, social and environmental impacts of these extremes, various Hazard Assessment Models (HAMs) available and proposed. Major barrier in the use of such HAMs lies in the preparation of their input data sets at fine spatial and temporal resolutions, which is usually not possible and practiced in the case of developing countries like Pakistan. This study is an attempt to provide an alternative choice for the preparation of rainfall estimates for the HAMs. In this study PERSIANN-RT satellite rainfall product is tested over Pakistan for year 2008-2010 and results of monthly time scale rainfall are compared with in situ data. Data comparison is done by continuous verification methods like statistical Bias varies from < -40 to > 30 and Correlation Coefficient (CC). The Cumulative Frequency Distribution (CFD) function gives us under and over estimation of SRE at different rainfall intensities. From this study it is concluded that PERSIANN-RT Satellite product accuracy in rainfall estimation is influenced by snow cover and topographic effects which should be taken under consideration beforeits application in different Hazard Assessment Models (HAM).

KEYWORDS: Droughts, Flooding, Hazard Assessment, PERSIANN-RT, Pakistan

1 INTRODUCTION

Rainfall is considered as an impetuous in triggering of Landsliding flooding and droughts, which in turn cast damages tohuman population, infrastructures and economic losses.Rainfall over high mountains is linked to flooding and agriculture in low land areas of Pakistan. Accurate, spatial and temporal estimations of rainfall especially, over mountainous regions are hampered by the tough terrains and extreme climatic constrains. Pakistan has agricultural economy which is dependent on water. Major portion of Gross Domestic Product (GDP) and employment is provided by the agriculture sector. The major source of water is provided by rainfall and snow melting over northern parts of country.Correct estimation of rainfall has very strong relationship with rainfall related natural hazards like flooding, droughts and landsliding(Guo et al 2015).

Flooding in Pakistan is one of the most commonly occurring and devastating natural hazards (Tariq and Giesen, 2012).Pakistan'shistory is full of occupancy of natural disasters episodes like flooding and droughts. The phenomena of climate change has proved a catalyst in increasing both frequency and magnitude of flooding in Pakistan over the last 25 or 30 years (Khan, et al, 2014).Massive flooding in 2010 which affected Pakistan's economy badly is one of the most recent example of such disasters. Almost, 20 million population was affected and country suffered an estimate loss of about 5.8 percent of its GDP (NDMA, Annual Report 2010). A major factor in this damage was the lack of proper flood forecasting systems which are based on proper and timely rainfall estimation over mountainous regions.There are large number of hydrological models used for efficient management of natural resources including water at global as well as at local scales.A bench of hydrological applications are developed to manage the all aspects of past, present and future of water cycle.In words of Thiemig et al., 2013, results from these models are used to, issue flood warnings (Cloke and Pappenberger, 2009), estimate drinking water availability (Soboll et al., 2011), determine ecological flows required to maintain a healthy environment (e.g. Dyson et al., 2008), or to optimize water allocation schemes (de Condappa et al., 2009) or landsliding hazard assessment model SHIA-Landsliding (Aristizábal et al., 2015). The benefits from these applications for decision making are solely depending on the accuracy and reliability of inputs parameters used for the analysis. Hazard assessment modelsare dependent on the input rainfall data along with other data sets.Unfortunately, rain gauges of Pakistan Metrological Department(PMD) are very rare and they are also installed near towns. The stations recovery is even low in high mountains (Nair et al., 2008). This scarce availability of traditional rainfall measuring instruments can be overcome by the utilization of Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Real Time(PERSIANN-RT) product. Its spatial resolution is 0.25° × 0.25°, which is very attractive for hydrologists than thecoarser spatial scale of Rain gauges network in Pakistan.

We apply a technique for estimating the rainfall by using PERSIANN-RT satellite product and results are compared with actual rainfall data. In this study, monthly precipitation data obtained from the PMD (Pakistan Metrological Department) is used as standard quality check.

2 MATERIAL AND METHODS

2.1 Study area

Pakistan lies in South Asian region having geographical coordinates 61–77^0 E longitude and 23.5–37^0 N latitude, it is bounded at north by China, westernboundary is shared with India, on eastern side it is bounded by Afghanistan and Indian Ocean lies at south (Figure 1).Major portionof Indus Basin lies in Pakistan. It is irrigated by the world's best irrigation system called Indus Basin Irrigation Canal System (IBICS). Major source of water for irrigation is the Indus River along with its tributaries like Chenab, Jhelum and Sutluj, thatall merge into Indus River, before falling into Arabian Sea.Elevation decreases from north to south. Monsoon rains which starts in June and end in August are the major sources of surface and groundwater. Climatologically, study area is very diverse in space and timeand is divided into different climatic zones. At extreme north there is humidclimate zone, but as we move from north to south the aridity goes on increase and climate becomes extreme arid at southern end. Flooding and droughts in low land areas of Indus Basin and landsliding in northern Himalayas Mountains are the hazards which occur almost every year.

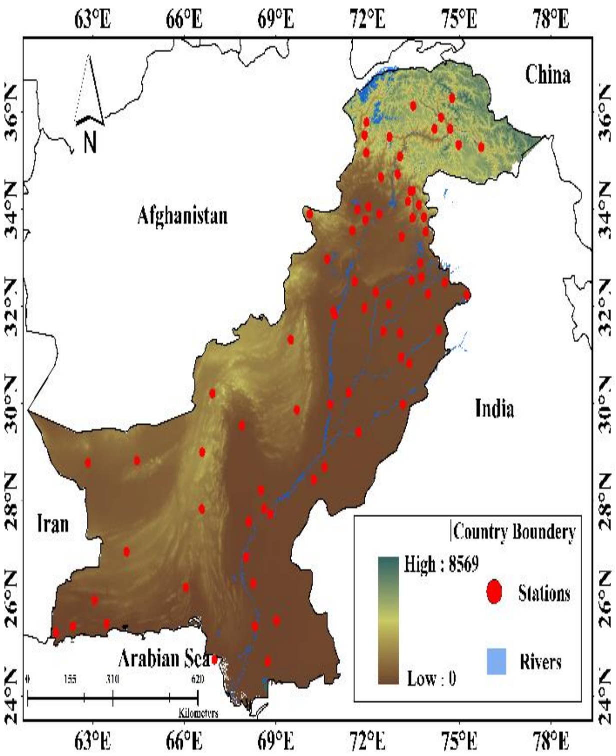

Figure 1. Regional location of Pakistan along with Pakistan Metrological Department rain stations and Digital Elevation Model

2.2 Rain gauge data

A total of 76 areavailablefor the 2008-2010 period(Figure 1). These stations are distributed on 76SRE resolution (0.25°) pixels. Data interpolation techniques are not recommendedin this case because of spare distribution of data points, which may generate some unrealistic estimation.(Scheel et al., 2011, Satgé et al., 2016).

2.3 Satellite dataacquisition and processing

PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) is a product of the Center for Hydrometeorology and Remote Sensing (CHRS). Rainfall rates are estimated at 0.25° × 0.25 pixel of the infrared brightness temperature image provided by satellite using a neural network technique described by (Hsu et al., (1997) and (Sorooshian et al., 2000). Rainfall computed through PMWs (TMI, AMSU-B and SSM/I) is used in a second step to adjust the neural network parameters and increase the accuracy of the rainfall estimates. There is a near real- time version (PERSIANN-RT) based on satellite only and an adjusted version (PERSIANN-Adj) using the Global Precipitation Climatology Project data (version 2.1) from GPCC at a 2.5° monthly scale(Satgé et al., 2016). This technique provides rainfall data at temporal resolution of 3 h and spatial resolution of 0.25° × 0.25°. The data are available from March 2000 until now in binary file format and can be easily downloaded from (http://chrs.web.uci.edu/persiann/ data.html).

2.4 Comparison of satellite with insitu data

Rain gauges have limited spatial resolution and high accuracy while, satellite products have high resolution, but with limited accuracy.
The aim of this study is the performance evolution of PERSIANN-RT satellite product at monthly scaleby computingCorrelation Coefficient (CC) andbias or mean error (ME) (Equation 1).Comparisons between insitu and satellite rainfall are done at the monthly time step on pixelsincluding one rain gauge(0.25° × 0.25°) (Figure 3-4). Mean annual rainfall map for the 2008-2010 period is also represented to observe PERSIANN-RT ability in regional rainfall pattern representation (Figure 2).

$$\text{Bias} = \frac{\sum_{i=1}^{n}(P_{SRE_i} - P_{G_i})}{\sum_{i=1}^{n} P_{G_i}} \times 100 \quad (1)$$

where, N is the length of the monthly series; P_{Gi} is the gauge precipitation for the considered monthi; and P_{SREi} is the SRE precipitation for the considered month(Satgé et al., 2016).

Bias and CC provide comparative accuracy of precipitation estimation from satelliteand in situ rainfall measurementover study area. Bias between these two data sets may be positive or negative representing over and underestimation, respectively. CC varies from less than 0.1 to greater than 0.7.

3 RESULTS AND DISCUSSION

3.1 Annual scale

Mean annualPERSIANN-RT rainfall over the 2008-2010period is shown in figure 2. Thetypical north south regional gradient of rainfall is well captured by PERSIANN-RT with decreasing and increasing aridity which is in agreementwith in situ dataobservation.

3.2 Monthly scale

The monthly rainfalls estimated from satellite data are compared with insitu data by calculating bias and CCat each pixel location including rain-gauges (Figure 3 and 4). A traffic color scheme is used to presents the bias results. Red and blue color show negative and positive bias, respectively while green color shows best match between PERSIANN-RT and insitu rainfall estimation.Thebias is acceptable when $-10\% \leq$ bias $\leq 10\%$. Negative value of bias indicates an under estimation of rainfall measured by PERSIANN-RT, while a positive bias is an indicator of overestimation. The pixels which fall in centralplainareas have relatively acceptable bias values whichmight be because of less humidity in air and relatively flat terrain. Northern pixel indicates a rainfall overestimation tendencywith Bias>50% (figure 3). It may be related to the predominance of snow and glacial cover which can be misidentified as rainy cloud by SREs due to the low superficial temperature and high emissivity. CC is considered as significant when CC $\geq$ 0.7 (Satgé, et al., 2016).CC values distribution confirms Bias observation with higher CC value in the central plain Pakistan region (Figure 4).

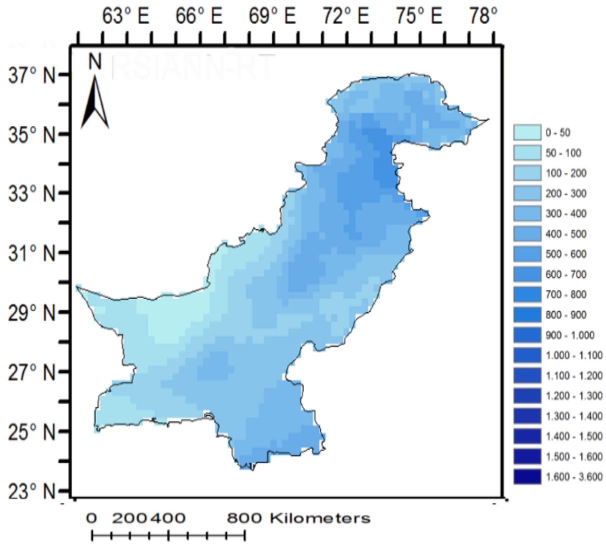

Figure 2. Annual rainfall pattern for PERSIANN-RT measurements.

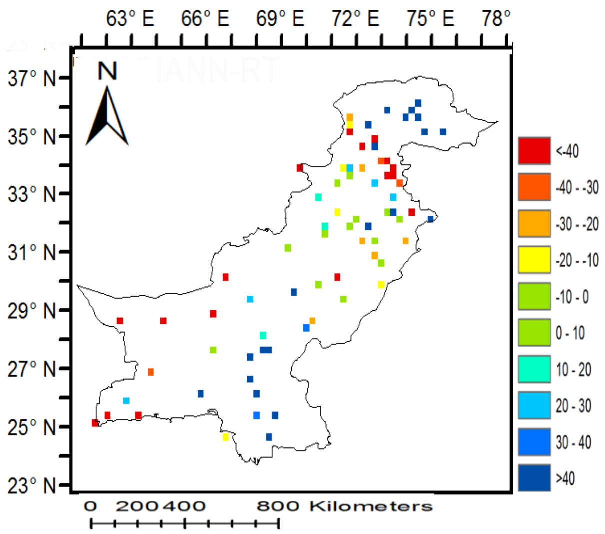

Figure 3. Spatial distribution of mean monthly Bias for 2008 – 2010 period

Thus contrast in soil/airhumidity and land superficial temperature/emissivity contrast could bethe major factorof observed PERTSIANN-RT uncertainty.

Cumulated frequency is plotted to see at which rainfall intensity PERSIANN-RT over estimatesand under estimates rainfall. Figure 5 shows that below and above 50 mm/month the PERSIANN-RT underestimates and over estimates the rainfall occurrences, respectively.

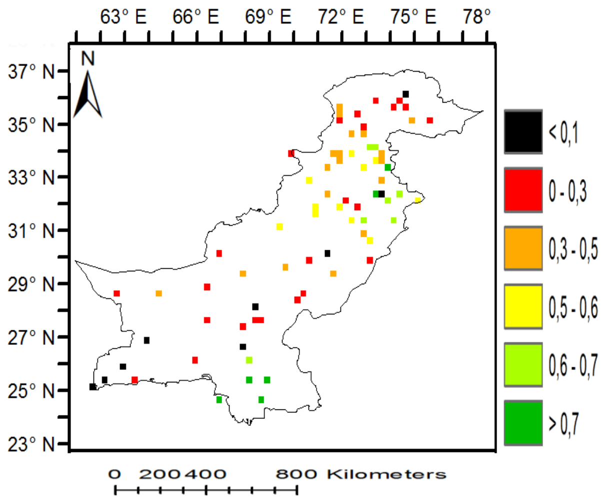

Figure 4. Spatial pattern of CC between rain gauges and PERSIANN-RT monthly precipitation for the 2008 – 2010 period.

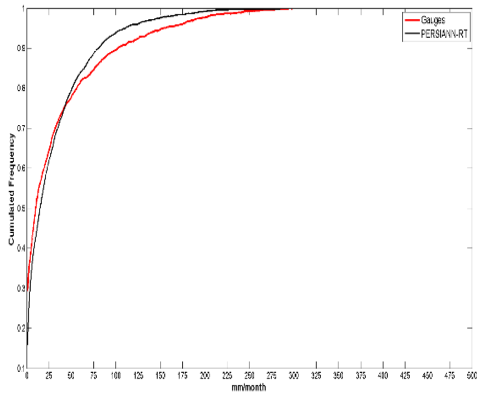

Figure 5. Cumulative frequency distribution

CONCLUSIONS

Pakistan lies in tropical climatic zone where there are sporadic climate change events which greatly affects the country in the form of extreme flooding and droughts. In these scenarios the need of proper rainfall estimation is very important. Unfortunately, Pakistan has very limited number of rain gauges throughout the country. Because of theselimitations the satellite rainfall estimation has become an attractive alternative choice for hazardous impact mitigation through application of proper Hazards Assessment Models..PERSIANN-RT accuracy seems to be related to land surface temperature and emissivity contrast. With relativefine spatial resolution and easy availability PERSIANN-RT isa possible choice for Hazard Assessment Modeling (HAM) over Pakistan and other regions having similar climatic conditions. However, adjustment of rainfall estimates are recommended to decrease high bias value observed over the region.

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