# Evaluation of hydrological modeling using climatic station and gridded precipitation dataset

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**सार** – क्षेत्र के कुछ भागों के वर्षा के आँकड़ों के पारंपरिक आकलन अपेक्षाकृत सटीक होते है। इस प्रकार के आँकड़ों के अंतर्वेशन से वास्तविक वर्षण क्षेत्र का अनुमान लगाया जाता है। हालाँकि जिन क्षेत्रों के आँकड़े उपलब्ध नहीं हैं, परिणामी वर्षण क्षेत्र उन क्षेत्रों में वास्तविक वर्षा का मोटा आकलन होता है। इंडस बेसिन पाकिस्तान जैसे अनुपलब्ध आँकड़ों वाले क्षेत्रों में सुदूर संवेदन के माध्यम से प्राप्त आँकड़े बहुत उपयोगी सिद्ध हो सकते हैं। प्रस्तुत शोध में पाकिस्तान में तीन छोटे बांधों के लिए जलवायु स्टेशन के आँकड़ों के साथ-साथ दो प्रकार के ग्रिड किए गए आँकड़े अर्थात यूरोपीय पुनर्विश्लेषण (ERA) अंतरिम और 55 वर्ष के जापानी पुनर्विश्लेषण (JRA-55) का मूल्यांकन किया गया। चूंकि इन बांधों में प्रवाह के मापे गए आँकड़े उपलब्ध नहीं हैं, इसलिए निकटतम संभावित जल ग्रहण क्षेत्रों, जहाँ प्रवाह के आँकड़े उपलब्ध हैं, का अंशांकन किया गया और फिर इन जल ग्रहण क्षेत्रों के प्राचलों का उपयोग वास्तविक बांधों में मृदा और जल मूल्यांकन यंत्र (SWAT) के माध्यम से सभी तीन प्रकार के आँकड़ों से प्रवाह के अनुकरण हेतु किया जाता है। ग्रिडेड और वर्षामापी वर्षण की तुलना के परिणाम से पता चलता है कि ग्रिडेड आँकड़े जलवायु स्टेशन को बहुत अधिक बढ़ा कर दर्शाते देखे गए SWAT मॉडल द्वारा प्रवाह के अनुकरण की तुलना में भी इसी तरह के परिणाम देखे गए JRA-55 से सर्वाधिक बाढ़ की गणना अनुमान से अधिक होती है जबकि तीन में से दो जलग्रहण क्षेत्रों में ERA-अंतरिम सर्वाधिक बाढ़ की तुलना की जा सकती है।

**ABSTRACT**. The conventional rainfall data estimates are relatively accurate at some points of the region. The interpolation of such type of data approximates the actual rainfield however in data scarce regions; the resulted rainfield is the rough estimate of the actual rainfall events. In data scarce regions like Indus basin Pakistan, the data obtained through remote sensing can be very useful. This research evaluates two types of gridded data *i.e.*, European Reanalysis (ERA) interim and Japanese Reanalysis 55 years (JRA-55) along with the climatic station data for three small dams in Pakistan. Since no measured flow data is available at these dams, the nearest possible catchments where flow data is available are calibrated and the calibrated parameters of these catchments are then used in actual dams for simulating the flow from all the three types of data using Soil and Water Assessment Tool (SWAT). The results of the comparison of gridded and rainguage precipitation shows that gridded data highly overestimates the climatic station data. Similar results were observed in the comparison of flow simulated by SWAT model. The Peak flood calculated from JRA-55 overestimates while the Era-Interim peak floods are comparable to that of climatic stations in two of the three catchments.

**Key words** – Hydrological modeling, Gridded data, Accuracy assessment.

## 1. Introduction

The hydrological modeling in Pakistan is carried out using the rainfall data of conventional rain gauges. Due to the high cost of climatic stations and its monitoring the rain gauges are often limited in number. In order to estimate the spatial variability of rainfall a dense network of rainguages is required which is not possible in the developing countries due to its high cost. Even in the technologically advanced nations, the data collected from the rain gauges do not represent the actual precipitation and the situation is worse in the less developed nations

(Wilheit, 1986). The spatial variability of rainfall is better estimated by the radars which are limited in developing countries due to high cost of radars.

The satellite images are now used for estimating the rainfall events and various methods have been proposed for estimating the rainfall from different electromagnetic spectrum bands (Dingman, 2002) and the most important is obtained from the Tropical Rainfall Measuring Mission (TRMM) (Kummerow *et al.*, 2000). In this research ERA-Interim and JRA-55 estimates were evaluated through comparison with the precipitation data of raingauges and through the estimation of stream flow using the semi distributed model *i.e.*, Soil and Water Assessment Toll (SWAT). The main objective of this research is to examine whether the ERA-Interim and JRA-55 estimates are helpful to the rainfall-runoff models in the data scarce regions. The focus of the study is to use these estimates only for hydrological modelling rather than developing new rainfall estimates.

## 2.    Satellite based estimated rainfall

Information regarding the different components of the hydrological cycle can be obtained from the satellite images. Even before the launch of the first meteorological satellite *i.e.*, TIROS in April 1960, it was assumed that the occurrence of rainfall might be detected from the parent cloud system (Petty, 1995). With the development of the Micro-Wave Sensors, estimation of rainfall based on the Infrared and Visible wavelength of light were improved (Ramage *et al.*, 2003).

For the hydro-meteorological studies, many researchers suggest the use of gridded data (Lutz *et al.*, 2014). Around twelve widely used precipitation datasets were tested based on the basin wise mass balance equation for Upper Indus Basin (UIB) and all the datasets were underestimating the precipitation except European Reanalysis-40 (ERA-40) and the ERA-Interim for some parts of the UIB (Khan, 2015). TRMM data was evaluated for the tributary of Amazon through a large scale model and it was found that the hydrographs obtained from the TRMM data is comparable with the observed hydrographs (Collischonn *et al.*, 2008). The latest global atmospheric reanalysis product is ERA-Interim which is developed by the European Centre for Medium-Range Weather Forecasts (ECMWF). ERA-15 is the first reanalysis product for almost 15-years spanning 1978 to 1994. The second product is ERA-40 for almost 40-years spanning 1957 to 2002 and is replaced by Era-Interim data which ranges from 1979 till date (Dee *et al.*, 2011). The second reanalysis project carried out by the Japanese Meteorological Agency (JMA) is the Japanese 55-years reanalysis data known as JRA-55 which provides the high quality climatic data from 1958. Many of the deficiencies in the JRA-25, the first project of JMA, were alleviated by JRA-55 (Kobayashi *et al.*, 2015).

## 3.    Soil conservation curve number method

The rainfall runoff modelling in hydrology is as important as other modelling techniques in other fields (Donigian *et al.*, 1995). We model things because of the limitation of the procedures and techniques to record the various components of the hydrological modelling (Beven & Freer, 2001). Another use of hydrological modelling is to see the effect of one parameter on changing certain conditions (Donigian *et al.*, 1995). The documentation of the hydrological modelling started in the mid-19th century and the first model which is now known as rational formula was first described by T.J. Mulvaney in 1851 (McCuen, 1998). This is known as the marking point of documentation of hydrological modelling. In 1871, Saint Venant developed the surface water equation for flow of water in one dimension (Maidment, 1993). Manning developed the equation of open channel flow in 1891. One of the most popular model the field of hydrology is the Green and Ampt model which was developed in 1911. The Horton model was introduce in 1919. Sherman developed the concept of unit hydrograph in 1932 (Todini, 1988). Horton also described the theory of infiltration in 1933 which is known as the most important theory of infiltration. In 1939, McCarthy introduced the hydrological method which later on published as Muskingum Routing method. Cung in 1969, showed some improvements into the Muskingum method. The simplest model for calculating runoff from rainfall is the Soil Conservation Services (SCS) Curve Number (CN) model now known as the Natural Resources Conservations services (NRCS) Curve Number model. For small catchments hydrology, the engineers and hydrologists recommend this model (Mishra & Singh, 2013). For small catchments, the initial abstraction ratio ($\lambda$) in the NRCS-CN greatly affects the results (Baltas *et al.*, 2007). The value of the initial abstraction ratio must be selected by considering the climatic condition (Ponce & Hawkins, 1996). The value of $\lambda = 0.2$ in the original NRCS-CN model is ambiguous and this value must be determined for a given watershed. A value of 0.05 was confirmed by studying 307 U.S. watershed's rainfall runoff data (Woodward *et al.*, 2003). In the Three Gorges area of China, different watershed studies defined the range for the initial abstraction ratio as 0.010 to 0.154 (Shi *et al.*, 2009). Data from 237 U.S watershed showed a value of $\lambda = 0.01$ (Mishra *et al.*, 2004). Data from 186 Australian watersheds suggested a value of $\lambda = 0.05$ (Beck *et al.*, 2009). All the watershed characteristics and climatic factors are combined in one entity called the Curve Number (CN) in the SCS-CN model
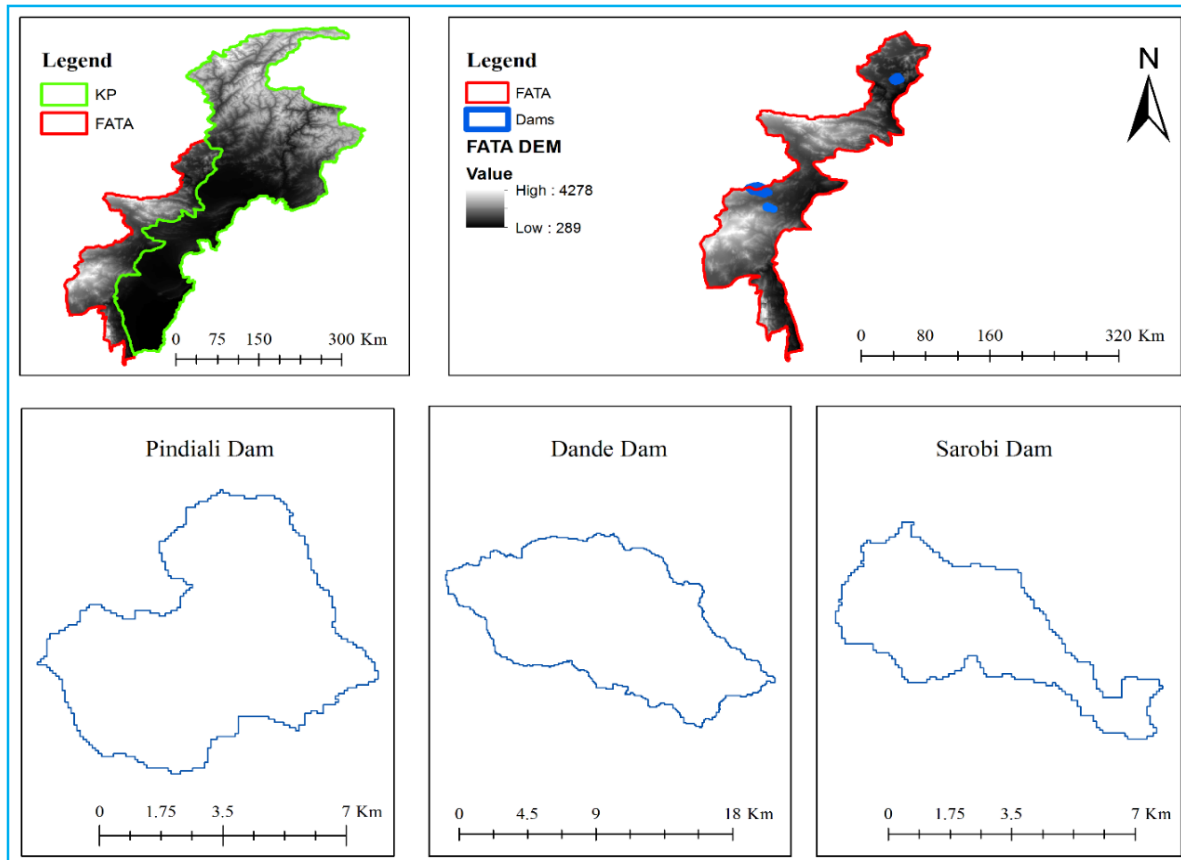
**Fig. 1.** Location of three small dams on the map of KP and FATA

(Ebrahimian *et al.*, 2012). The values of the curve number can be selected using the tables; however, this value can be better estimated base on the rainfall-runoff data of a watershed. Various procedures are available for estimating the curve number and there is no agreement on a single method of determining the curve number (Soulis & Valiantzas, 2012). SCS-CN model and the proposed models performance were checked based on the CN value selected from tables and CN value calculated using event based rainfall-runoff data. The result showed that model performance was good in case of CN calculated from the event based rainfall runoff data (Ajmal *et al.*, 2015). Fifteen watershed with eight different rainfall-runoff models including the SCS-CN model, SCS inspired models and proposed models for the watershed by the researcher with modified initial abstraction ratio was used and it was found that the proposed model performed well as compared to the other models (Ajmal and Kim, 2014).

**4. Methodology**

The quality of the ERA-Interim and JRA-55 estimates were assessed by comparing the daily data with the raingauge daily precipitation data over the three catchments. SWAT was used with daily time step with ERA-Interim, JRA-55 and rainguage data as inputs to simulate the flow.

The study area is briefly explained in the section "Watershed Description". The availability of data is described in the section "Data Collection". The SWAT model is described in "Soil and Water Assessment Tool". Calibration of the model and the stream flow comparison is mentioned in "Accuracy Assessment of Data and Stream Flow Comparison". The peak flood estimation is briefly explained in the "Estimation of Peak Flood".

**4.1. *Watershed description***

This study focuses on the hydrology of three small dams located in Federally Administered Tribal Are (FATA) now part the Khyber-Pakhtunkhwa (KP) province of Pakistan. Fig. 1. shows the location of dams on the topographic map based on digital elevation model (DEM) of KP and FATA.

**TABLE 1**

**Type and duration of data obtained from different departments in Pakistan**

| Station | Type of data | Time period | Source |
|---|---|---|---|
| Saidu Sharif | Precipitation, Temperature | 1974-1998 | PMD, Lahore |
| Kalam | Do | 2002-2011 | PMD, Lahore |
| Parachinar | Do | 1960-2009 | PMD, Lahore |
| Peshawar | Do | 1960-2016 | PMD, Lahore |
| Bannu | Do | 1991-2015 | WAPDA |
| Kurram at Thal | River Flow Data | 1991-1998 | WAPDA |
| Swat at Chakdara | Do | 1991-1998 | WAPDA |

Climate of Pakistan is dry with deficient precipitation during most of the year (Kottek *et al.*, 2006). Despite the fact that FATA has scarcity of both water resources and Land, the people are more dependent on the agriculture and livestock activities. In order to store the flood water in the streams and to bring more areas under irrigation command, the FATA Development Authority (FDA) has put forward to construct Small Dams. In this regards several small dams have been constructed while various projects are still under construction.

Pindiali Small Dam in Mohmand Agency-FATA is located on Pindiali Khawar (Stream) with a catchment area of 17.15 sq. Miles. The area falls in the rainfall zone of about 17.96 inches (456 mm). The annual inflow of the stream is about 2033 Acre-ft and 19.4 acre-ft of sediments per annum. The flood water will be stored in a reservoir and will be used to irrigate 300 acres of land at 109% intensity.

Sarobi Small Dam in North Waziristan Agency - FATA is located on Ping Algad (stream) with a catchment area of 8.9 sq. Miles. The area falls in the rainfall zone of about 12.96 inches (329 mm). The stream has perennial flow of about 0.5 cusecs and is estimated to bring 1035 AF inflow and 18 acre-ft of sediments per annum. The flood water will be stored in a reservoir and used to irrigate 450 acres of land at 100% intensity in command area.

Dande Small Dam in North Waziristan Agency - FATA is located on Dawagar Algad (Stream) with a catchment area of 59.12 sq. Miles. The area falls in the rainfall zone of about 14 inches (355.6 mm). The stream has no perennial flow is estimated to bring 88.68 acre-ft of sediments per annum.

4.2. *Data collection*

4.2.1. *Observed data*

Observed hydrological data and Gridded data was used in this study. Observed data (Rainfall and Temperatures) was provided by the Pakistan Meteorological department (PMD), Lahore and Water and Power Development Authority (WAPDA). The River Flow Data was obtained from WAPDA. Detail about the data for different stations obtained from PMD and WAPDA is given in Table 1.

4.2.2. *Gridded data*

Two types of Gridded precipitation and temperature data used are

(*i*)   ERA-Interim data for the period of 1979-2010 was download from http://apps.ecmwf.int/datasets/data/interim-full-daily/

(*ii*)   JRA-55 data for the period 1979-2010 was downloaded from https://rda.ucar.edu/datasets/

4.2.3. *Soil, land use and digital elevation model*

Apart from the precipitation and temperature data, some other types of data necessary for the preparation of SWAT model are :

(*i*)   Food and Agriculture Organization (FAO) of the United Nations global soil data was download from http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/

(*ii*)   The Glob Cover 2009 Land Use data was download from the link http://due.esrin.esa.int/page_globcover.php/

(*iii*) The digital elevation model (DEM) used in this research was accessed from the link http://srtm.csi.cgiar.org/

#### 4.2.4. *Data required for accuracy assessment*

The data required for accuracy assessment is :

(*i*) Actual Evapotranspiration ($ET_{act}$) Data of ERA-Interim available at http://apps.ecmwf.int/datasets/data/, FAO available at http://gaez.fao.org/Main.html#, Willmott and Matsuura (W&M) PET data available at http://climate.geog.udel.edu/ for the period 1999-2010 have been used in this research

(*ii*) Ground Water Recharge Data of World-wide Hydro-geological Mapping and Assessment Program (WHYMAP) available at http://www.whymap.org/whymap/EN/Downloads have been used in this research.

(*iii*) Potential Evapotranspiration (PET) Data of ERA-Interim available at http://spirits.jrc.ec.europa.eu/files/ ecmwf/int/asia/evpt/, Potential Evapotranspiration data of FAO available at http://gaez.fao.org/Main. html# for the period 1999-2010 have been used in this research.

#### 4.3. *Soil and water assessment tool*

Numerous computer models are present in order to evaluate the watershed hydrology. Among them, SWAT is most widely used semi-distributed physical model (Arnold *et al.*, 1998). A large input data is required for SWAT model which makes the parameterization and calibration of the model complicated. The SWAT model can be calibrated manually or a using a semi-automated procedure known as SWAT calibration and uncertainty procedure (CUP) (Arnold *et al.*, 2012). The hydrology of the Upper Illinois River Basin was simulated using two different models in order to check the suitability of the model and it was found that the SWAT Model best simulates the low flow as compared to the other model (Singh *et al.*, 2005). Another study compared the SWAT model with the Hydrologic Simulation Program-Fortran (HSPF) model and showed that for agriculture watershed SWAT showed an element of robustness as compared to the HSPF in estimating the stream flow (Van Liew *et al.*, 2003). In order to check the capabilities of the SWAT model, data from three nested watersheds was used and it was found that once the SWAT model is calibrated, it can be used to for providing adequate simulation in case of climate change on water resources (Van Liew & Garbrecht, 2003). Another study revealed that the calibration of the HSPF model as compared to the SWAT model was less user friendly and time consuming because

of the numerous parameters to adjust and greater data pre-processing (Saleh & Du, 2004). In this study the SWAT model has been used in order to evaluate the flow from different types of precipitation datasets.

#### 4.4. *Accuracy assessment of data and stream flow comparison*

SWAT model was calibrated using the conventional raingagues data. Since no flow data is available at these three small dams, therefore, nearest possible flow measuring stations were delineated. The flow measuring station near to Pindiali dam is Chakdara station at River Swat and that near to Sarobi and Dande dam is Thal station at River Kurram.

The accuracy assessment of the data is important for calibrating the nearest catchments. The accuracy assessment was carried out using the Basin-Wise Mass Balance Equation (Reggiani & Rientjes, 2015). The proposed equation is

$$Q + ET_{act} - P = \pm \Delta S \tag{1}$$

where,

$Q$ = average annual flow (mm/year)

$P$ = Total annual precipitation (mm/year)

$\Delta S$ = Change in storage

$ET_{act}$ = Actual Evapotranspiration

Three limits *i.e.*, $L_1$, $L_2$ and $L_3$ were defined for the accuracy assessment and they are given below:

$$L_1 = Q + (ET_{act} + nGWR)\text{min} \tag{2}$$

$$L_2 = Q + (ET_{act} + nGWR)\text{max} \tag{3}$$

$$L_3 = Q + (PET + nGWR)\text{avg} \tag{4}$$

where,

$$(ET_{act})\text{minimum} = (ET_{act})\text{average} - (ET_{act})\partial$$

$$(nGWR)\text{minimum} = (nGWR)\text{average} - (nGWR)\partial$$

$$(ET_{act})\text{maximum} = (ET_{act})\text{average} - (ET_{act})\partial$$

$$(nGWR)\text{maximum} = (nGWR)\text{average} - (nGWR)\partial$$

*nGWR* = Net ground water recharge

*PET* = Potential evapotranspiration

$\partial$ = Standard deviation of the relative parameter

The data that lie in between the limit 1 and limit 2 is considered of good quality while the data that lie above the limit 2 and limit 3 is overestimation and the data that lie below limit 1 is underestimation (Khan, 2015). In our case, the climatic station data is considered of good quality as compared to the gridded dataset and hence this data is used for calibrating the models. The calibrated parameters of River Kurram at Thal station were used for Sarobi and Dande dam while that of River Swat at chakdara were used for Pindiali dam and the flow was then simulated using ERA-Interim, JRA-55 and conventional rain gauges data as inputs to the SWAT model.

### 4.5. *Peak flood estimation*

Design flood was estimated using Hydrologic Engineering Center (HEC) Hydrologic model system (HMS). HEC-HEC is a software that calculates the flood hydrograph at different junctions of the stream by entering the catchment area, the loss rate in terms of curve number, the lag time and the time distribution of rainfall as input. The time of concentration ($T_c$) for the catchment was calculated using the Kirpich's equation.

$$T_c (\text{minutes}) = \left( \frac{11.9 \times L^3}{H} \right)^{0.385} \qquad (5)$$

where,

*L*  =  length of longest flow path (miles)

*H*  =  the difference between the highest and lowest point (feet)

The Synthetic unit hydrograph (UH) has been developed using the parameters of the curvilinear dimensionless UH and the SCS triangular unit hydrograph through the HEC-HMS rainfall-runoff model. The peak storm is estimated using the Gumbel Extreme value-I distribution and SCS Type-II distribution has been used for hourly distribution of peak storm. To estimate the direct runoff, the most widely used model is the SCS-CN model. The slope adjusted curve number is calculated by the SWAT model using soil, land use and slope data. The SCS curves for initial abstraction ratio ($\lambda$) are obtained using the equation:

$$Q = \frac{(P - \lambda * S)^2}{[P + (1 - \lambda) * S]} \qquad (6)$$

where,

Q  =  runoff volume in inches

P  =  rainfall in inches

S  =  soil retention parameter in inches after runoff

$\lambda$  =  Initial abstraction ratio

## 5. Results and discussion

### 5.1. *Mean basin rainfall comparison*

Rainfall data was obtained for all the three dams from different sources as explained in the "Data Collection" section. Accumulated mean daily precipitation for gridded and climatic station data for all the three catchments is shown in Fig. 2.

Fig. 2 shows that both Era-Interim and JRA-55 estimates are very far from that of raingauge estimates, when the rainfall is averaged over the catchments. In terms of the total amounts of rain during the 32-years period, the results are very different.

In order to explore the seasonal variations, basin average rainfall was compared on monthly basis as shown in Fig. 3. Monthly averages were calculated for a period of 32 year from 1979-2010 and during this period, both the JRA-55 and Era-Interim data overestimates the climatic station data in the wet as well as the in the dry season. However, the seasonal variability is well distinguished both by JRA-55 and Era-Interim datasets.

### 5.2. *Comparison of mean inflow at dam site*

The accumulated mean daily inflow estimated from SWAT model for gridded and climatic station data for all the three catchments is shown in Fig. 4.

Fig. 4 shows that both Era-Interim and JRA-55 estimates of inflow are very far from the flow generated from the precipitation of raingauge, when the flow is averaged over the catchments. The results are also different in terms of the total amounts of flow for 32-years period.

In order to explore the seasonal variations based on the inflow in the streams, basin average inflow to the Dam site were compared on monthly basis as shown in Fig. 5.
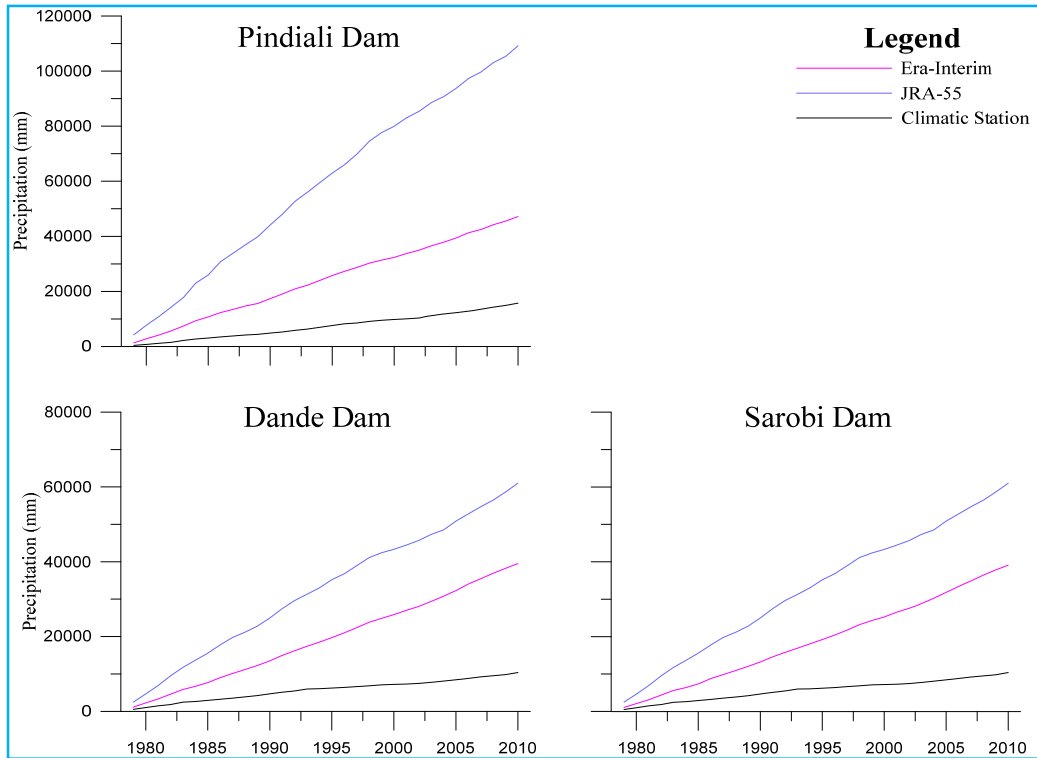
**Fig. 2.** Accumulated mean daily rainfall over the three different catchments for Era-Interim, JRA-55 and climatic station
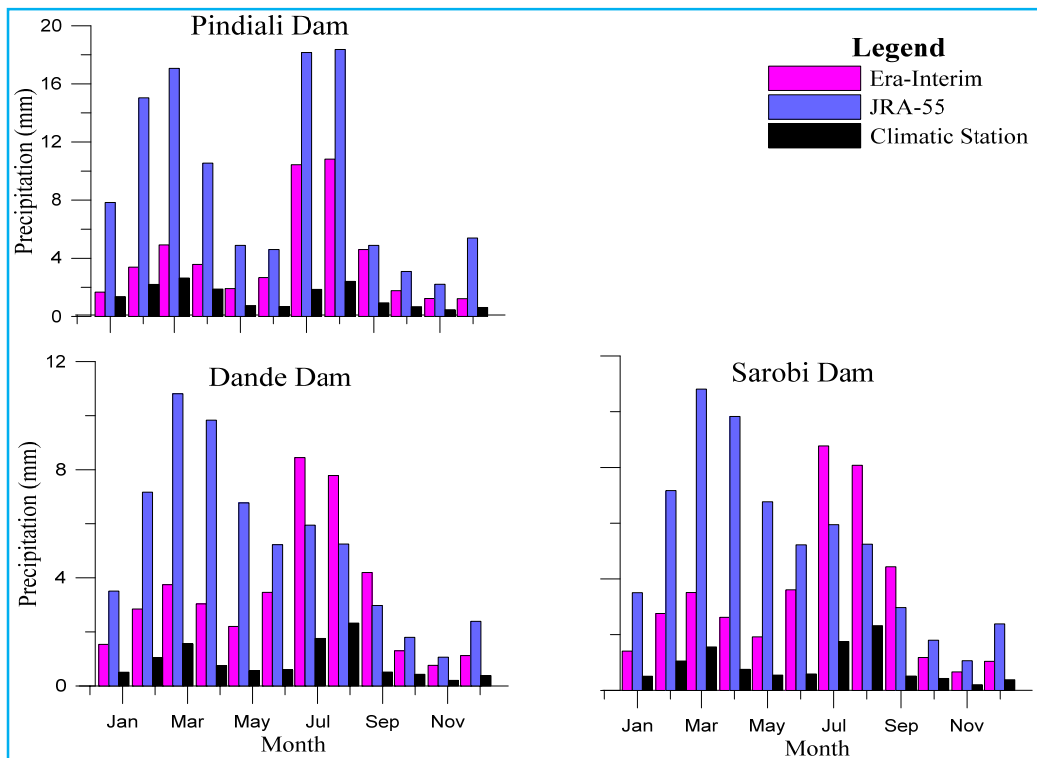


**Fig. 3.** Average monthly precipitation based on different types of datasets for all the three Dams
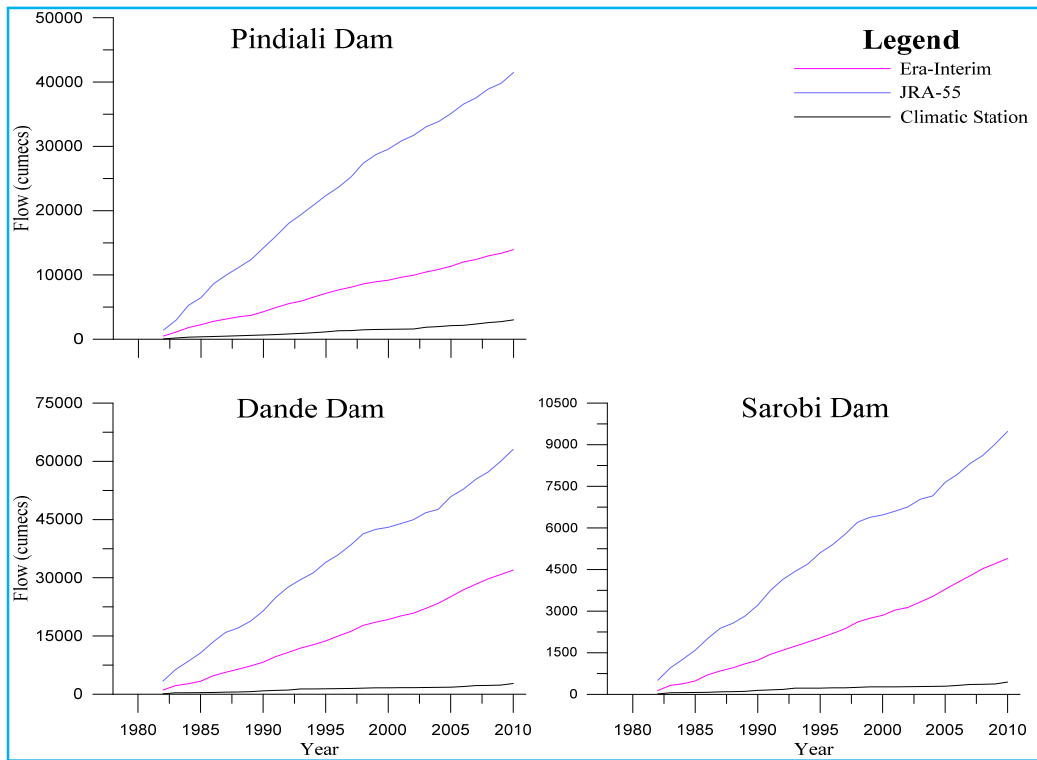
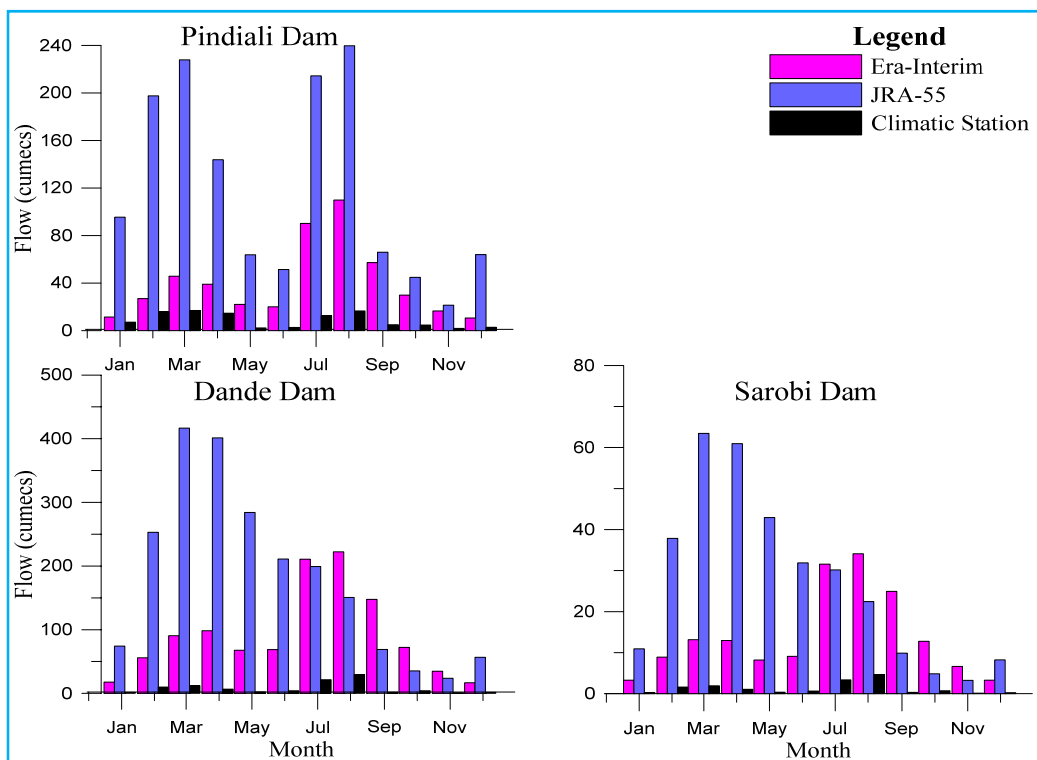**Fig. 4.** Accumulated mean daily inflow over the three different catchments for Era-Interim, JRA-55 and Climatic Station



**Fig. 5.** Average monthly precipitation based on different types of datasets for all the three Dams
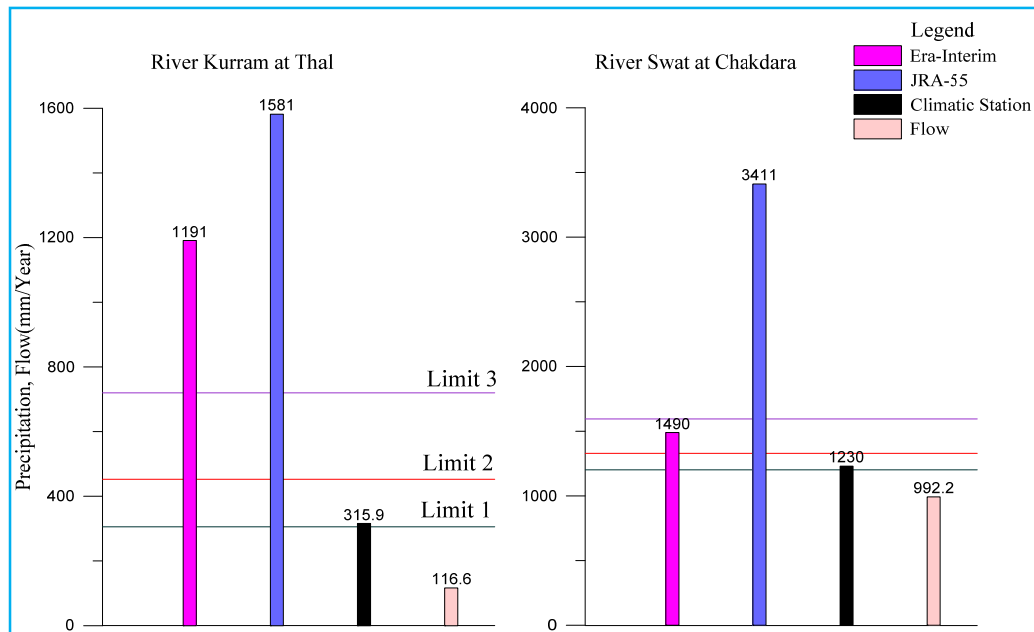
**Fig. 6.** Accuracy assessment of gridded and climatic station data for two different catchments

Monthly averages were calculated for a period of 32 year from 1979-2010 and during this period, both the inflow generated from JRA-55 and Era-Interim data overestimates the flow from climatic station data in the wet as well as the in the dry season. However, the seasonal variability is well distinguished both by JRA-55 and Era-Interim datasets.

### 5.3. *Accuracy assessment of data*

The accuracy assessment of the data helps in determining the precipitation data for calibration of SWAT models. As explained in the section "Accuracy Assessment of Data and Stream Flow Comparison", the basin wise mass balance equation was applied on the two catchments where flow data was available. The result of the accuracy assessment is shown in Fig. 6.

Fig. 6. shows that for both catchments, River Kurram at Thal and River Swat at Chakadara station, ERA-Interim and JRA-55 datasets show overestimation as the data lies above Limit 2 and Limit 3 while the climatic station data well represents these catchments' precipitation as it is in between the limit 1 and Limit 2.

### 5.4. *Calibration and validation*

The nearest possible catchments were calibrated where the flow data was available and the calibrated parameters were then used in actual study area and flow was estimated. The catchment near to Dande and Sarobi small dam was River Kurram at Thal station and the near to the Pindiali small dam was River Swat at Chakadara station. The calibration period for River Kurram at Thal station was taken from Jan-1991 to December-1998 as shown in Fig. 7.

The calibration was carried out on monthly basis and shows that model performed very well having Nash–Sutcliffe efficiency (NSE) = 0.72 and correlation coefficient ($R^2$) = 0.90. The validation period for the same model is from Jan-99 to Dec-03 on monthly basis. The validation results also show the model performance is in good range having NSE = 0.74 and $R^2$ = 0.66. The calibration period for River Swat at Chakadara station was taken from Jan-1991 to December-1995. The calibration was carried out on monthly basis and it shows that model performed very well having NSE = 0.91 and $R^2$ = 0.96. The validation period for the same model is from Jan-1996 to Dec-98 on monthly basis. The validation results also show the model performance is in very good range having NSE = 0.80 and $R^2$ = 0.91.

### 5.5. *Peak flood generation*

The peak floods from climatic station and gridded precipitation datasets were calculated for all the three catchments and is shown in Fig. 8.

The peak flood for Pindiali Dam was generated using HEC-HMS software. The time of concentration was calculated using the Kirpich's Equation (Fang *et al*., 2008).
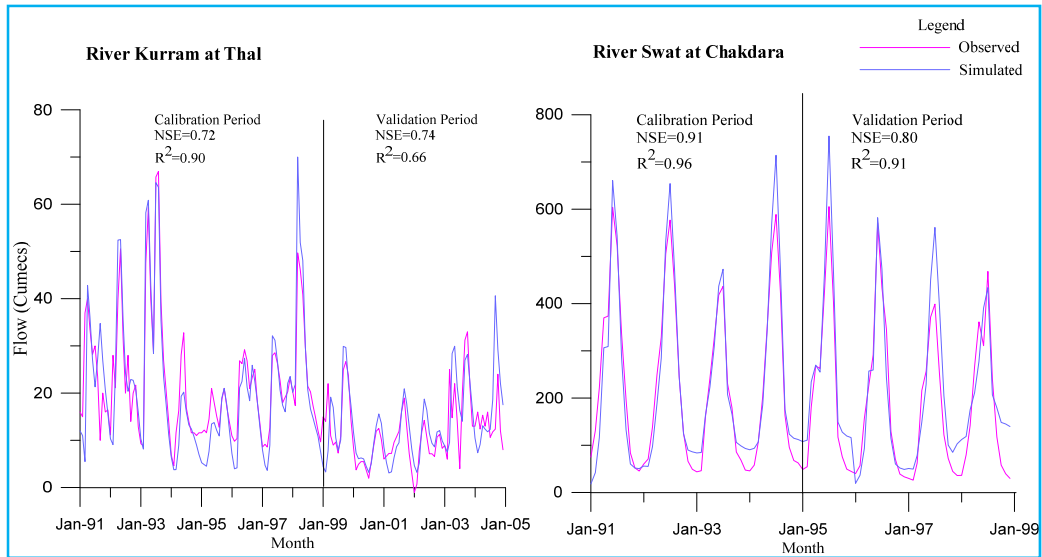
**Fig. 7.** Calibration and validation of River Kurram at Thal and River Swat at Chakdara catchments
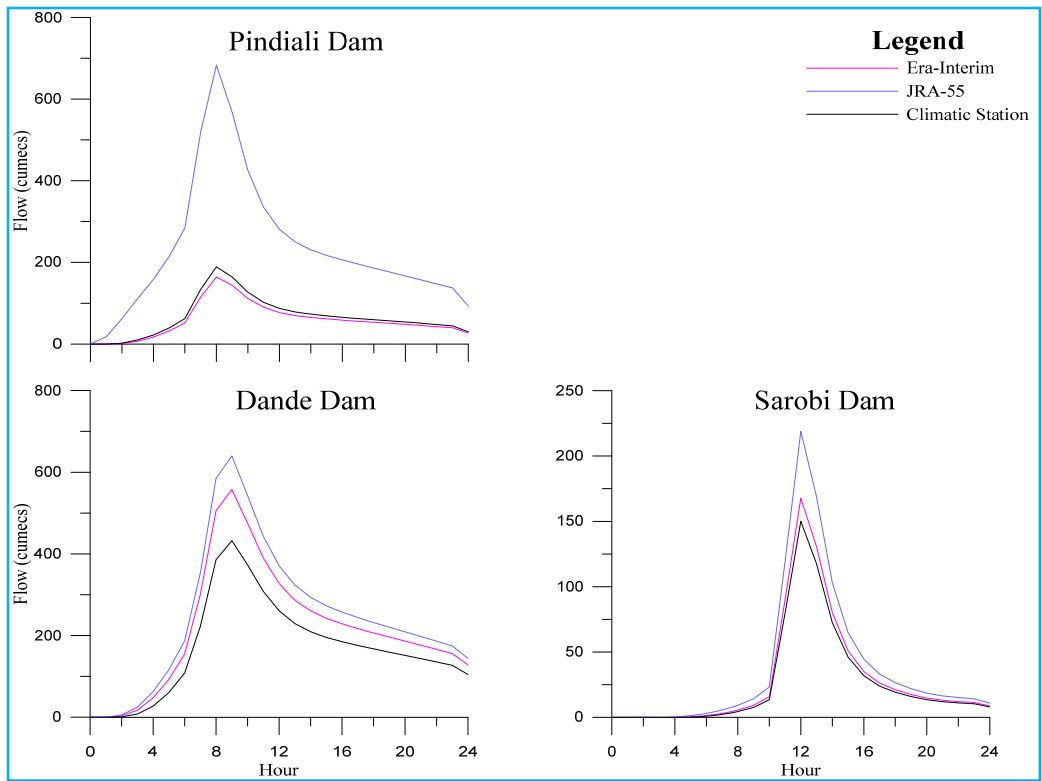


**Fig. 8.** Estimating the peak flood from gridded and climatic station datasets using HEC-HMS

The peak flood from ERA-Interim and Climatic station datasets are in good agreement for Sarobi and Pindiali catchments while in case of Dande dam the peak flood from Era-Interim data is also overestimating. Peak flood calculated from JRA-55 is overestimating for all three catchments of dams. For Pindiali dam the peaks of JRA-55 and Era-Interim are 3.0 and 0.9 times of climatic station peak respectively. For Sarobi dam the peaks of JRA-55 and Era-Interim are 1.5 and 1.1 times of climatic station peak respectively. For Dande dam

the peaks of JRA-55 and Era-Interim are 1.3 and 1.2 times of climatic station peak respectively.

It is clear that both JRA-55 and ERA-Interim overestimates the results in precipitation comparison as well as in flow comparison. Hence the use of these two types of gridded datasets in water scarce regions is recommended only after some bias correction. The peak flood estimated from era-interim is somehow comparable in two of the three catchments to that estimated from the rainguage data. This shows that daily maximum rainfall of each year for ERA-Interim matches with the daily maximum of rainguage data.

## 6. Conclusion and recommendation

In this study, we have compared the precipitation data from three sources *i.e.*, Era-Interim, JRA-55 and conventional rain gauge data over three small dams in Pakistan for the period of study (1979-2010). We also compared the flow from all these data using Soil and Water Assessment Tool (SWAT). Comparative assessment showed that both JRA-55 and ERA-Interim overestimates precipitation as well as flow both in the wet and dry season. However, the seasonal variability is well distinguished by gridded datasets. Hence we conclude that the use of these two types of gridded datasets in these water scarce regions is recommended only after some bias corrections. The peak flood estimated from era-interim and rain gauge data is somewhat comparable in the two catchments. This means that daily maximum rainfall of each year for ERA-Interim matches with the daily maximums of rain-gauge data and hence frequency analysis based on both types of data produced similar results.

Since the two types of gridded data used in this research work overestimates the results, evaluation of some other types of gridded data for the said catchments is required. Moreover we conclude that the calibrated parameters of the nearest catchments may not represent the ungauged catchments, therefore, the same research work is recommended for the gauged watershed. Although SWAT model performed very well both in Calibration and Validation, however, evaluation of the performance of some other models with the SWAT model is recommended.

*Conflicts of Interest* : The authors declare no conflict of interest. The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

## References

Ajmal, M. and Kim, T. W., 2014, "Quantifying excess stormwater using SCS-CN – based rainfall runoff models and different curve number determination methods", *Journal of Irrigation and Drainage Engineering*, **141**, 3, 04014058-1_12.

Ajmal, M., Waseem, M., Ahn, J. H. and Kim, T. W., 2015, "Improved runoff estimation using event-based rainfall-runoff models", *Water Resources Management*, **29**, 6, 1995-2010.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R. D., Van Griensven, A., Van Liew, M. W., Kannan, N. and Jha, M. K., 2012, "SWAT : Model use, calibration and validation", *Transactions of the ASABE*, **55**, 4, 1491-1508.

Arnold, J. G., Srinivasan, R., Muttiah, R. S. and Williams, J. R., 1998, "Large area hydrologic modeling and assessment part I : model development", *JAWRA Journal of the American Water Resources Association*, **34**, 1, 73-89.

Baltas, E., Dervos, N. and Mimikou, M., 2007, "Determination of the SCS initial abstraction ratio in an experimental watershed in Greece", *Hydrology and Earth System Sciences Discussions*, **11**, 6, 1825-1829.

Beck, H. E., De Jeu, R. A., Schellekens, J., Van Dijk, A. I. and Bruijnzeel, L. A., 2009, "Improving curve number based storm runoff estimates using soil moisture proxies", *IEEE Journal of selected topics in applied earth observations and remote sensing*, **2**, 4, 250-259.

Beven, K. and Freer, J., 2001, "Equifinality, data assimilation and uncertainty estimation in mechanistic modelling of complex environmental systems using the GLUE methodology", *Journal of hydrology*, **249**, 1-4, 11-29.

Collischonn, B., Collischonn, W. and Tucci, C. E. M., 2008, "Daily hydrological modeling in the Amazon basin using TRMM rainfall estimates", *Journal of hydrology*, **360**, 1-4, 207-216.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., Van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge Sanz, B. M., Morcrette, J. J., Park, B. K., Peubey, C., de Rosnay, P., Tavolato, C., Thepaut, J. N. and Vitart, F., 2011, "The ERA-Interim reanalysis: Configuration and performance of the data assimilation system", *Quarterly Journal of the royal meteorological society*, **137**, 656, 553-597.

Dingman, S. L., 2002, "Bioclimate-Vegetation Interrelations along the Pacific Rim of North America", *Physical Hydrology*, 2ⁿᵈ Edition, Prentice Hall, Upper Saddle River, Manuel Peinado, Gustavo Díaz, José Delgadillo, Francisco Manuel Ocaña-Peinado, Miguel Ángel Macías, Juan Luis Aguirre, Alejandro Aparicio, *American Journal of Plant Sciences*, **3**, 1430-1450.

Donigian, A. S., Imhoff, J. C. and Ambrose, R. B., 1995, "Modeling watershed water quality", In: Singh V.P.(eds) *Environmental Hydrology*, *Springer*, **15**, 377-426.

Ebrahimian, M., Nuruddin, A. A. B., Soom, M. A. B. M., Sood, A. M. and Neng, L. J., 2012, "Runoff Estimation in Steep Slope Watershed with Standard and Slope-Adjusted Curve Number Methods", *Polish Journal of Environmental Studies*, **21**, 1191-1202.

Fang, X., Thompson, D. B., Cleveland, T. G., Pradhan, P. and Malla, R., 2008, "Time of concentration estimated using watershed parameters determined by automated and manual methods", *Journal of Irrigation and Drainage Engineering*, **134**, 202-211.

Khan, A., 2015, "Accuracy assessment of gridded precipitation datasets in the Himalayas", AGUFM, 2015, PA11B-2149.

Kobayashi, Shinya, Ota, Yukinari, Harada, Yayoi, Ebita, Ayataka, Moriya, Masami, Onoda, Hirokatsu, Onogi, Kazutoshi, Kamahori, Hirotaka, Kobayashi, Chiaki, Endo, Hirokazu, Miyaoka, Kengo and Takahashi, Kiyotoshi, 2015, "The JRA-55 reanalysis : General specifications and basic characteristics", *Journal of the Meteorological Society of Japan. Ser. II*, **93**, 5-48.

Kottek, M., Grieser, J., Beck, C., Rudolf, B. and Rubel, F., 2006, "World map of the Köppen-Geiger climate classification updated", *Meteorologische Zeitschrift*, **15**, 259-263.

Kummerow, C., Simpson, J., Thiele, O., Barnes, W., Chang, A. T. C., Stocker, E., Adler, R. F., Hou, A., Kakar, R., Wentz, F., Ashcroft, P., Kozu, T., Hong, Y., Okamoto, K., Iguchi, T., Kuroiwa, H., Im, E., Haddad, Z., Huffman, G., Ferrier, B., Olson, W. S., Zipser, E., Smith, E. A., Wilheit, T. T., North, G., Krishnamurti, T. and Nakamura, K., 2000, "The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit", *Journal of Applied meteorology*, **39**, 12, 1965-1982.

Lutz, A., Immerzeel, W., Shrestha, A. and Bierkens, M., 2014, "Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation", *Nature Climate Change*, **4**, 7, 587-592.

Maidment, D. R., 1993, "Handbook of hydrology" *McGraw-Hill New York*. 9780070, p397323.

McCuen, R., 1998, "Hydrologic design and analysis. Prince Hall, New Jersey, 814.

Mishra, S. K. and Singh, V. P., 2013, "Soil conservation service curve number (SCS-CN) methodology" *Springer Science & Business Media*, **42**, 1-514.

Mishra, S., Jain, M. and Singh, V., 2004, "Evaluation of the SCS-CN-based model incorporating antecedent moisture", *Water Resources Management*, **18**, 6, 567-589.

Petty, G. W., 1995, "The status of satellite-based rainfall estimation over land", *Remote Sensing of Environment*, **51**, 1, 125-137.

Ponce, V. M. and Hawkins, R. H., 1996, "Runoff curve number: Has it reached maturity?" *Journal of hydrologic engineering*, **1**, 1, 11-19.

Ramage, K., Jobard, I., Lebel, T., Desbois, M. and Ramage, K., 2003, "Satellite estimation of 1-day to 10-day cumulated precipitation: comparison and validation over tropical Africa of TRMM, METEOSAT and GPCP products", in the 2003 EUMETSAT Meteorological Satellite Conference, **29**.

Reggiani, P. and Rientjes, T., 2015, "A reflection on the long-term water balance of the Upper Indus Basin", *Hydrology research*, **46**, 3, 446-462.

Saleh, A. and Du, B., 2004, "Evaluation of SWAT and HSPF within BASINS program for the upper North Bosque River watershed in central Texas", *Transactions of the ASAE*, **47**, 4, 1039-1049.

Shi, Z. H., Chen, L. D., Fang, N. F., Qin, D. F. and Cai, C. F., 2009, "Research on the SCS-CN initial abstraction ratio using rainfall-runoff event analysis in the Three Gorges Area", *China. Catena*, **77**, 1, 1-7.

Singh, J., Knapp, H. V., Arnold, J. and Demissie, M., 2005, "Hydrological modeling of the iroquois river watershed using HSPF and SWAT", *JAWRA Journal of the American Water Resources Association*, **41**, 2, 343-360.

Soulis, K. and Valiantzas, J., 2012, "SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds-the two-CN system approach", *Hydrology and Earth System Sciences*, **16**, 3, 1001-1015.

Todini, E., 1988, "Rainfall-runoff modeling-Past, present and future", *Journal of hydrology*, **100**, 1-3, 341-352.

Van Liew, M. W. and Garbrecht, J., 2003, "Hydrologic simulation of the little Washita river experimental watershed using SWAT", *JAWRA Journal of the American Water Resources Association*, **39**, 2, 413-426.

Van Liew, M., Arnold, J. and Garbrecht, J., 2003, "Hydrologic simulation on agricultural watersheds : Choosing between two models", *Transactions of the ASAE*, **46**, 6, p1539.

Wilheit, T. T., 1986, "Some comments on passive microwave measurement of rain", *Bulletin of the American Meteorological Society*, **67**, 10, 1226-1232.

Woodward, D. E., Hawkins, R. H., Jiang, R., Hjelmfelt, J., Allen T, Van Mullem, J. A. and Quan, Q. D., 2003, "Runoff curve number method: examination of the initial abstraction ratio", *In World water & environmental resources congress 2003*, **308**, 1-10.