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Investigating Alternative Strategies for Streamflow Simulation in Data Sparse Watersheds

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ABSTRACT

Satellite based precipitation (SBPP's) have proved their significance as a main source of input data for various hydrological simulations in recent decades. These models are crucial, particularly in regions with complicated topography or ungauged basins where ground-based observatories are typically few or non-existent. SBPP's have the potential to overcome the issues of data scarcity caused by sparse rain gauges. However, significant uncertainties appear in these precipitation data, and especially in complex topographic regions. Before being used in practice, these precipitation products' accuracy must be assessed. The objective of this research is to evaluate semi distributed modelling of a data scarce watershed by using Arc swat model utilizing four different SBPPs (SM2RAIN, PERSIANN, PERSIANN-CDR and MEERA-2). Arc-SWAT model was analyzed with precipitation data from 2010 to 2022 for hydrological modelling and SWAT-CUP was used for Calibration and Validation. The time period of 2010 to 2014 as warm-up period and from 2015 to 2018 calibration time period and from 2019 to 2022 was time period of validation in SWAT-CUP by using SUFI-2 method. This study assessed the applicability and accuracy evaluation of notable SBPP's in sparsely gauged catchment. Harro river, which is a catchment of Khanpur Dam causes challenges for hydrological modelling and was selected as the study are for this research project. SBPP's were analyzed on the basis of statically matrices R^2, NS, SSQR, PBIAS, KGE, and RSR. The results

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revealed that (add the numbers of performance metrics like $R^{2\text{ of all SBPPS}}$ and than write that based upon all other metrics SM2RAIN pefromed better)
Conclude that on the bases this evaluation matrices the SM2RAIN well performance then other SBPP's under consideration.

Keywords: Remote Sensing; Hydrological Simulation; Arc Swat 3 (List Three To Ten Pertinent Keywords Specific To The Article Yet Reasonably Common Within The Subject Discipline.)

Introduction

Keeping in view the climate change scenario the developing countries are more prone to data scarcity issues than ever before and, Pakistan is under-developed country [5]. Precipitation is the most important variable for hydrological modelling [1-4].. Area is about 8 MKm^2 [6]. Pakistan metrological department install about 97 gauges in Pakistan for collecting precipitation data regularly [7]. Due to high and sparse gauge density global researcher moves toward satellite base precipitation products (SBPP's) for hydrological modelling [2, 3]. Satellite-Based Precipitation Products provide high spatial and temporal resolution as compared with gauge data[8]. The demand of precipitation estimation through satellite-based precipitation product is further highlighted in areas with high gauge density. SBPP's can play vital role in flash flooding monitoring, efficient water resources management and drought management in area with sparse ground based metrological observations[9]. Number of studies explained different benefits like hydrological modeling [3],[10],[11], hydraulic Studies[12], environmental studies [13], [14] and climatic change studies[15] of SBPP's.

Use of SBPP's can improve water resources management in developing countries or even develpoepd countries with data scarce watersheds. To evaluate the developed methodology we seletdc a data scarce watershed in pothohar plateu of south Asia, namely Haro river basin. The outlet Haro river is located in Khanpur in Khyber Pakhtunkhwa it is also known as "Khanpur Dam", that supplies water for drinking, agriculture and industrial used. Pakistan Metrological department (PMD) gauges are very far away from khanpur catchment. The sparse ground-based gauge density causes difficulties in water management. Therefore, by the use of SBPP's can improve water resource management in throughout the Pakistan.

Researcher use two methods for comparison SBPP's, first one is direct comparison of satellite precipitation with ground rainfall gauges. Secondly, comparison of streamflow generated by hydrological modelling tools with ground measures run-off. Some researcher uses direct method[16 ,17, 18,19, 52], some of them use streamflow[20, 21, 22] and some of them used both methods[23, 24] in their research for different regions. Because of the variation in geography, climate, soil and land cover the assessment and validation of SBPP's give different result [20]. Therefore, needed separate evaluation and comparison of SBPP's on any region for check the reliability.

Several studies have evaluated the reliability of SBPP's for hydrological modelling for their regions[25, 26]. Soil Moisture to Rain (SM2RAIN) assessed on the Kali Gandaki River originates from the Nhubine Himal Glacier in the Mustang region of

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Nepal, in this research they use soil Water assessment tool for the simulation of stream flow and evaluated the SBPP's in Nepal[9]. Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANNs) assessed the SBPP's by both methods firstly precipitation and secondly streamflow comparison, in this study they comprehensively assess the SBPP's [23]. NASA Modern-Era Retrospective analysis for Research and Applications (MEERA-2) assessed on the Kuttiyadi river catchment lies in the Southern part of India, in this research they use Soil Water Assessment (SWAT) tool for hydrological modeling for streamflow simulation and evaluate only NASA MEERA-2 [21]. The Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record (PERSIANN-CDR) evaluate the hydrologic performance of gridded precipitation datasets for streamflow simulation in Ethiopia, the datasets from different SBPP's were compared statistically with the gauge observation dataset. Furthermore, the hydrologic performance of the products was evaluated using the Soil and Water Assessment Tool (SWAT) hydrologic model in two watersheds of the Lake Ziway basin[27].

The Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks- Climate Data Record (PERSIANN-CDR) assessed on two gauge-scarce river basins on the Tibetan Plateau, the source regions of the YellowRiver (UYE) and Yangtze River (UYA) basins, in this study they also comprehensively assess the SBPP's by the use of Hydro-Informatic Modeling System (HIMS) tool for hydrological modeling[9].

The Haro river watershed is modeled using the Geographic Information System-based semi-distributed model, Soil and Water Assessment Tool (SWAT), with the goals of simulating stream flow, establishing the water balance, and estimating the monthly volume inflow to the Khanpur dam at the basin outlet[28]. Pakistan's northern Punjab region, known as the Potohar plateau, is where the research takes place. The research region is located in western Pakistan, along the border with the Khyber Pakhtun Khwa (KPK) and Azad Kashmir provinces (AZK). Data from a variety of sources, including rain gauges (RGs), weather stations, and flow meters, provide the backbone of this approach. In addition, this research delves into the topic of combined satellite precipitation data sets. This research uses the Soil and Water Assessment Tool (SWAT) to compare the results of two MPDs (Merged Precipitation Datasets) in simulating daily streamflow on the Potohar Plateau in Pakistan[29].

Now researcher move towards the SBPP's Globally and also regionally for hydrological modeling [30 , 31 ,32, 33]. In Pakistan researcher mostly studied on direct comparison of SBPP's [34, 35 ,36,37] therefore minimum studies are available on stream-flow simulation using hydrological modeling tools [38]. Pakistan is underdeveloped country, in this region high gauge densities and scarcity of gauges cause difficulties in hydrological modeling. Therefore, need to move towards SBPP's for hydrological modeling and flood monitoring.

This study objective to compression four SBPP's for simulated streamflow in the data scarce region of Pakistan, where the only one ground gauges observatory available at outlet of dam and other ground observatories are not available nearby this catchment of listed PMD gauges. In this study the hydrological modeling of khanpur dam catchment using precipitation data of SBPP's, the Arc-SWAT (Soil and Water

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Assessment Tool) using for hydrological modeling of catchment. This research assesses the SBPP's, well-performing SBPPs will facilitate more advanced hydrological modelling, which in turn will improve water resource management in the regions with data scarcity issues globally.

Study Area

Harro River Watershed is located in Ayubia, Murree and Margallah Hills, Khyber Pakhtunkhwa (KPK) and capital of Pakistan was selected as the study area. The latitude and longitude of outlet of watershed is 33° 48' 06" N, 72° 55' 50" E. located near 40 km from north west of capital of Pakistan in Tehsil Khanpur, District Haripur. Watershed area is 800km2. The depth of 167 feet and reservoirs of 106,000 acre-feet of water in Khanpur dam.

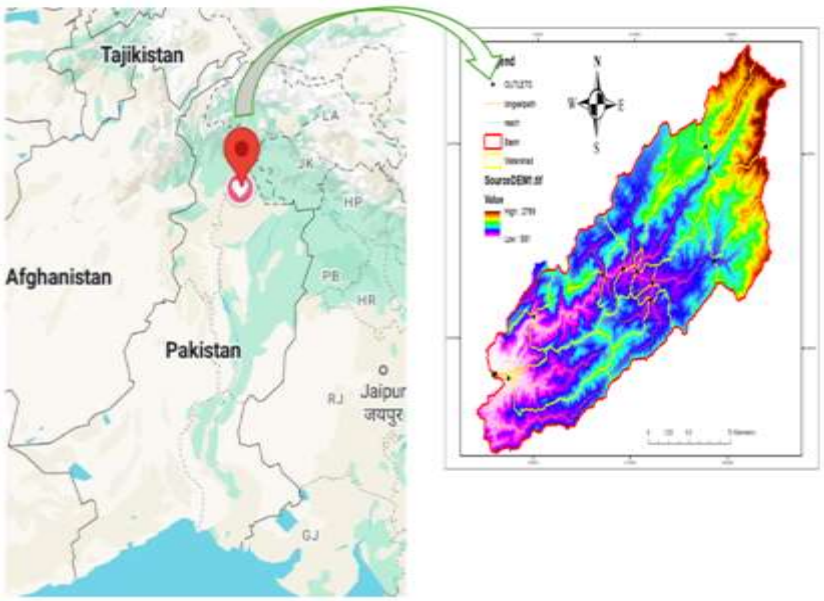

Figure 1. Map Showing the study area location of outlet of Khanpur Dam catchment of Harro River

Materials and Methods

The main objective of this study is to evaluate the performance of SBPP's in a data scarce watershed with complex topography by comparing the SBPP's simulated streamflow and ground observed stream flow. The flowchart of this study shown in figure.

The study of this methodology is divided into Six steps metrological data, satellite data, Geographical Information System (GIS) data, Ground Observed Data, SWAT modeling and Soil and Water Assessment Tool-Calibration and Uncertainty Programming (SWAT-CUP) Calibration and Validation.

First, Metrological Data (MD) is prepared according to formats of SWAT formatting, like temperature, humidity, sun radiation, temperature and wind speed which basic requirement SWAT model.

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Secondly Satellite Precipitation Data (SPD) acquire from particular different source individual SBPP's, prepare this according to the format SWAT model, precipitation data is important variable of hydrological models.
Third, Geographical Information System (GIS) data acquire from particular different source individual GIS Data, prepare these GIS Data according to the formats of SWAT model, GIS Data include Digital Elevation Model (DEM), Land Use Land Cover map (LULC) and Soil Map. These are important GIS Data for Hydrological Modeling.
Fourth, on Ground Observed Data it is important for the evolution of SBPP's while comparing, this data acquire from Water And Power Development Authority (WAPDA), the data used in this study is Ground Precipitation Data (GPD) and Ground Run-off Data (GRD). GPD is used for Hydrological Modeling and GRD for evolution.
Fifth, SWAT modeling in this all MD, SD, GIS Data and GPD use as inputs for hydrological modeling and simulate the streamflow for all SBPP's under consideration.
Sixth, SWAT-CUP calibration and validation, in this step we use different calibration parameter from previous studies[28], SWAT-CUP Calibration and Validation for SBPP's under consideration this compare on the bases of six Statically matrices.

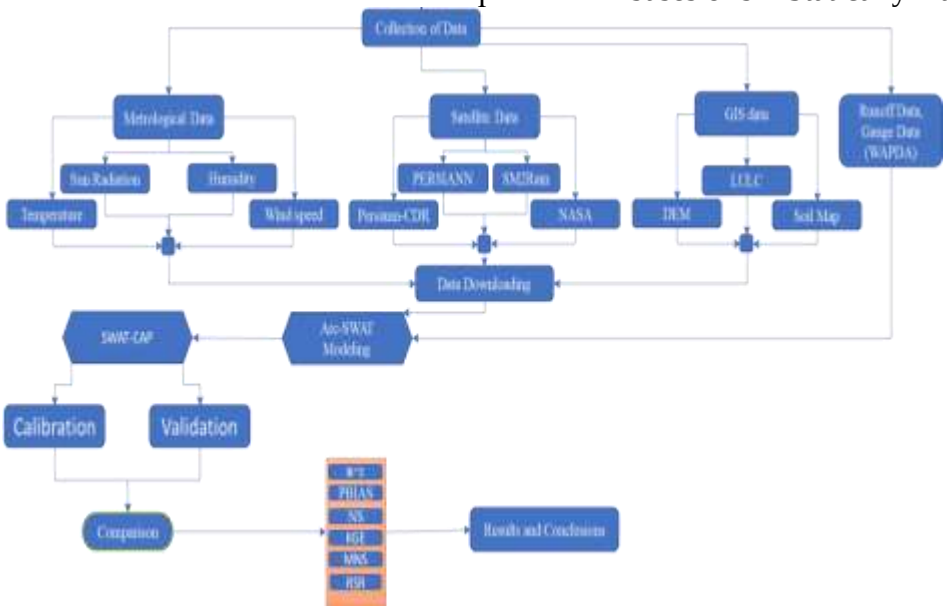

Figure 2. Flowchart showing the Research Methodology use in this study

Metrological data
Temperature, Sun Radiations, Wind speed, Humidity datasets from NASA website (https://power.larc.nasa.gov/) with resolution of 0.5°x0.5°. Data get from NASA and assigned data to SWAT for showing environmental condition for hydrological modelling. Data get from 1 January 2010 to 31 December 2022.

Satellite data
SM2RAIN-ASCAT

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Soil Moisture to Rain—Advanced SCAT terometer V1.5 (SM2RAIN-ASCAT) is a newer satellite-derived global precipitation product incorporating soil moisture conditions collected by the operational satellite MetOp from the European Meteorological Satellite (EUMETSAT) Organization (Darmstadt, Germany). This product utilizes an advanced algorithm called SM2RAIN using a bottom-up approach to obtain precipitation estimates using soil moisture data[39, 40]. It was generated using the soil WAter Retrieval Package (WARP) algorithm and ASCAT soil moisture data obtained from MetOp-A and MetOp-B satellites[9, 41]. The 0.125◦ spatial resolution SM2RAIN–ASCAT daily gridded data were extracted from luca brocca (luca.brocca@irpi.cnr.it) mail proeccess.

PERSIANN

The current operational PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) system developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI) uses neural network function classification/approximation procedures to compute an estimate of rainfall rate at each 0.25° x 0.25° pixel of the infrared brightness temperature image provided by geostationary satellites. An adaptive training feature facilitates updating of the network parameters whenever independent estimates of rainfall are available. The PERSIANN system was based on geostationary infrared imagery and later extended to include the use of both infrared and daytime visible imagery. The PERSIANN algorithm used here is based on the geostationary longwave infrared imagery to generate global rainfall. Rainfall product covers 60°S to 60°N globally.

PERSIANN-CDR

A near-global 37+ year high-resolution precipitation dataset for long-term studies is now available. PERSIANN-CDR (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks - Climate Data Record) developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI) provides daily rainfall estimates at 0.25 deg for the latitude band 60N-60S over the period of 01/01/1983 to 12/31/2015 (delayed present). PERSIANN-CDR is aimed at addressing the need for a consistent, long-term, high-resolution and global precipitation dataset for studying the changes and trends in daily precipitation, especially extreme precipitation events, due to climate change and natural variability. PERSIANN-CDR is generated from the PERSIANN algorithm using GridSat-B1 infrared data and adjusted using the Global Precipitation Climatology Project (GPCP) monthly product to maintain consistency of the two datasets at 2.5 deg monthly scale throughout the entire record. The PERSIANN-CDR product is available to the public as an operational climate data record via the NOAA NCDC CDR Program website under the Atmospheric CDRs category. (www.ncdc.noaa.gov/cdr/operationalcdrs.html)

This CDR was funded in part by NOAA's Climate Data Record (CDR) Program located in Asheville, NC at the National Centres for Environmental Information.

NASA MEERA-2

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The Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) provides data beginning in 1980. It was introduced to replace the original MERRA dataset because of the advances made in the assimilation system that enable assimilation of modern hyperspectral radiance and microwave observations, along with GPS-Radio Occultation datasets. It also uses NASA's ozone profile observations that began in late 2004. Additional advances in both the GEOS model and the GSI assimilation system are included in MERRA-2. Spatial resolution remains about the same (about 50 km in the latitudinal direction) as in MERRA.
Along with the enhancements in the meteorological assimilation, MERRA-2 takes some significant steps towards GMAO's target of an Earth System reanalysis. MERRA-2 is the first long-term global reanalysis to assimilate space-based observations of aerosols and represent their interactions with other physical processes in the climate system. MERRA-2 includes a representation of ice sheets over (say) Greenland and Antarctica.

Table 1. Description of Satellite-Based Precipitation Products.

Name	Spatial Resolution	Temporal Resolution	Source
PERSIAN	0.25° x 0.25°	2000-Present	(https://chrsdata.eng.uci.edu/)
SM2RAIN	0.125° x 0.125°	2007-2022	(luca.brocca@irpi.cnr.it)
MEERA-2	0.5° x 0.5°	1980-Present	(https://power.larc.nasa.gov)
PERSIAN-CDR	0.25° x 0.25°	1983-Present	(https://chrsdata.eng.uci.edu/)

Geographical Information System (GIS) data

DEM

Digital elevation model is taken from USGS Shuttle radar topography mission (SRTM) with special resolution is 30x30m, has been used in numerous studies[3, 21, 42, 43]. It is a digital representation of ground surface, topography and terrains in SWAT modelling, Figure 3.

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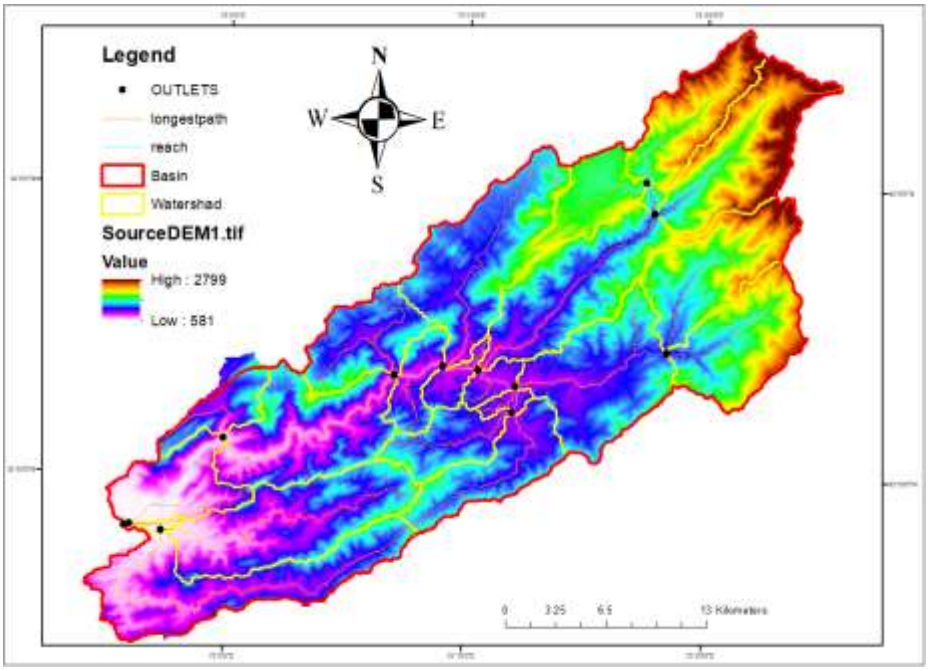

Figure 3. Digital elevation Model (DEM) catchment of Khanpur Dam

LULC

Land Use Land Cover of Sentinel-2 at resolution of 10x10 were obtain from ArcGIS. This map is available in Universal Transverse Mercator (UTM), it provides whole world LULC with 9 classes. Figure 4.

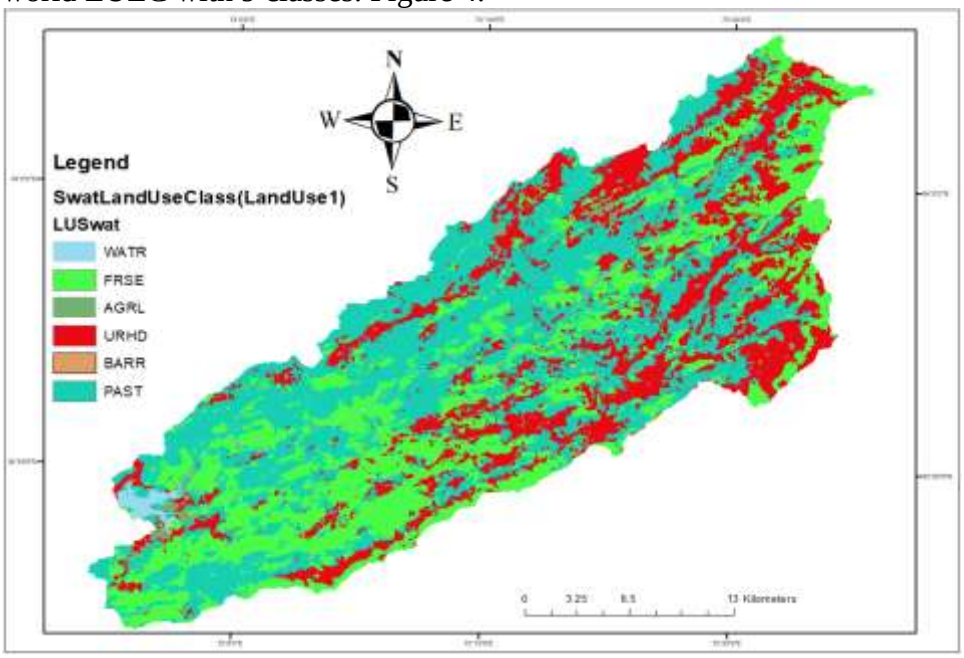

Figure 4. Land Use Land Cover (LULC) catchment of Khanpur Dam

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Soil map

The 30 m spatial resolution data related to soil information, which were resampled from the original spatial resolution of 30 arc-s (~1 km), were retrieved from the Food and Agriculture Organization of the United Nations (FAO) database called Harmonized World Soil Database (FAO, 2009)[9] figure

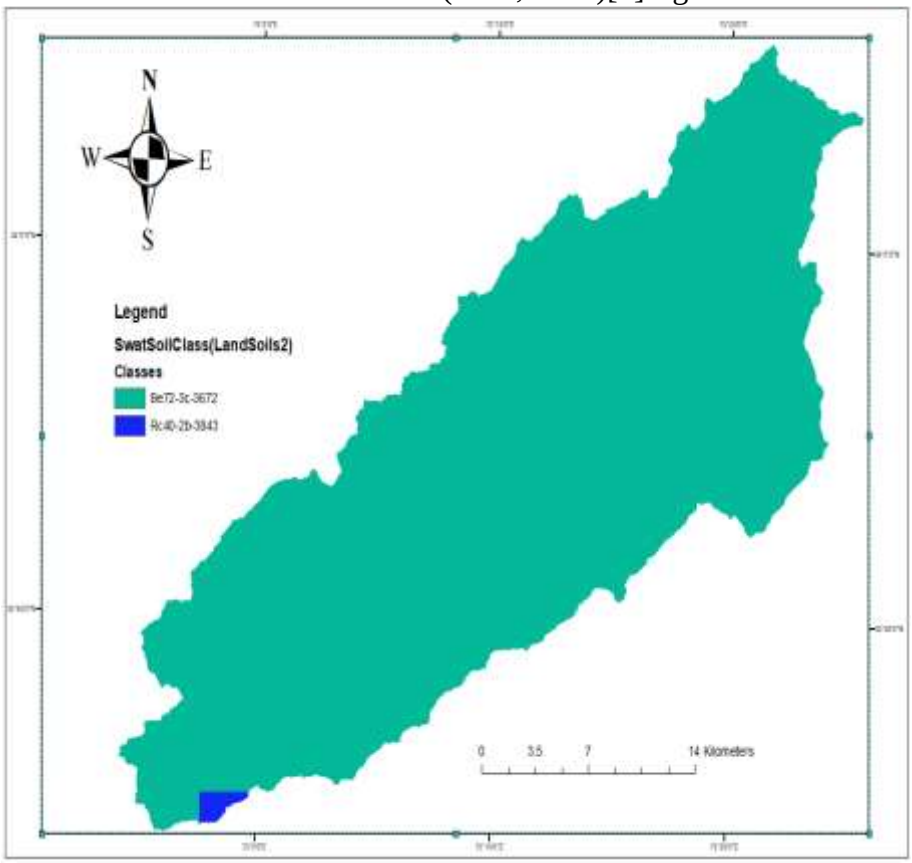

Figure 5. Soil Map catchment of Khanpur Dam

Table 2. Description of Geographical Information System (GIS) data

Name	Spatial Resolution	Source Name	Source
DEM	30m	SRTM	(https://earthexplorer.usgs.gov/)
LULC	10m	Sentinel-2	https://www.arcgis.com/home/item.html?id=fc92d38533d440078f17678ebc20e8e2
SOIL Map	30 arc-seconds	FAO	https://www.fao.org/

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Ground Observed Data

This study used Daily precipitation and daily Run-off data of one hydrological gauging station located at the outlet of the Khanpur Dam, Pakistan, from 1 January 2010 to 31 December 2022. The streamflow data were obtained from the Water And Power Development Athourity (WAPDA), a department under the Pakistan government responsible for gathering and disseminating official climate and hydrological data to the public.

SWAT modeling and SWAT-CUP

SWAT is a semi-distributed hydrological model that may be used to estimate streamflow using climatic data at daily, monthly, and annual time steps, analyze sediment movement, and evaluate the water quality of watersheds of any size or complexity[44]. The model was developed by the Agriculture Research Service (ARS) and the U.S. Department of Agriculture (USDA)[45]. The Hydrologic Response Unit (HRU) is the name of the tiny spatial unit used by SWAT. It is expected that All hydrological parameter evaporation, inflow, surface flow etc can estimate independently for every Hydrological Response Unit (HRU)[46]. In recent decades, the SWAT tool has become popular in modeling the watershed of the United States, Europe, and other regions of world[47].

In this research work on the daily time-step precipitation data of 13 years from 2010 to 2022, the time period of 5 years from 2010 to 2014 as warm-up period and 4 years from 2015 to 2018 calibration time period and from 4 years from 2019 to 2022 was time period of validation SWAT hydrological modeling. Based on the previous literature review findings on the parameters often used by other modelers to calibrate their SWAT models in similar regions, 14 parameters were selected for calibration and validation in table[29]. these are parameter remain same for all SBPP's under consideration.

Table 3. Description of Calibration Parameter and Ranges

Sr. No.	Symbols	Description	Min	Max
1	r__CN2.mgt	SCS runoff curve number	-0.2	0.2
2	v__ALPHA_BF.gw	Baseflow alpha factor	0	1
3	v__GW_DELAY.gw	Groundwater delay time	0	300
4	v__GW_REVAP.gw	Groundwater "revap" coefficient	0.02	0.2
5	v__ESCO.hru	Soil evaporation compensation factor	0	1
6	v__CH_N2.rte	Manning's "n" value for main channel	0	0.3
7	v__CH_K2.rte	Effective hydraulic conductivity	0	400
8	v__ALPHA_BNK.rte	Baseflow alpha factor	0	1
9	r__SOL_AWC().sol	Available water capacity of the soil layer	0	0.9
10	a__SOL_K().sol	Saturated hydraulic conductivity	-10	10
11	r__SOL_BD().sol	Moist bulk density	-0.5	0.5
12	v__SURLAG.bsn	Surface runoff lag time	0	12
13	r__CANMX.hru	Maximum canopy storage	-0.3	0.3
14	v__RCHRG_DP.gw	Deep aquifer percolation coefficient	0	1

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In this study, the calibration and validation were performed using the Sequential Uncertainty Fitting version 2 (SUFI-2) technique and an objective function Nash-Sutcliffe Efficiency (NSE) via SWAT-CUP software.

Table 4. Description Statically matrices, Ranges and Indication

Representation	Stand for	Ranges	Indication
R^2	Coefficient of Determination	0 to 1	Higher values indicate better model fit
NS	Nash-Sutcliffe Efficiency	0 to 1	Higher values indicate better model fit
KGE	Kling-Gupta Efficiency	-∞ to ∞	KGE<0 Poor performance, KGE>0 well performance, KGE=1 perfect match
SSQR	Sum of Squared Residuals	0 to ∞	Lower values indicate better model fit
RSR	Relative Squared Residual	0 to ∞	Lower values indicate better model fit
PBIAS	Percent Bias (%)	-100 to 100	Lower values indicate overestimate and Higher values indicate under estimate

Table shows the optimal value of the model performance metrics used. The performance of the model, driven by the selected Satellite-Based Precipitation Products (SBPP's) for accurate streamflow prediction, was assessed using NSE, PBIAS, SSQR, KGE, and R^2. The R^2 values indicate the correlation strength between observed and simulated streamflow values. NSE reflects how well the simulation aligns with the observations. PBIAS assesses the extent to which the simulated streamflow overestimates or underestimates the observations at the gauging station. Specifically, a positive PBIAS value indicates an overestimation relative to the gauging observations, while a negative PBIAS value indicates an underestimation. KGE is also performance measuring matric. SSQR quantifies how well a model predicts different levels of outcomes, helping to assess its accuracy across various scenarios.

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Results

Graphical Representation

Hydrograph

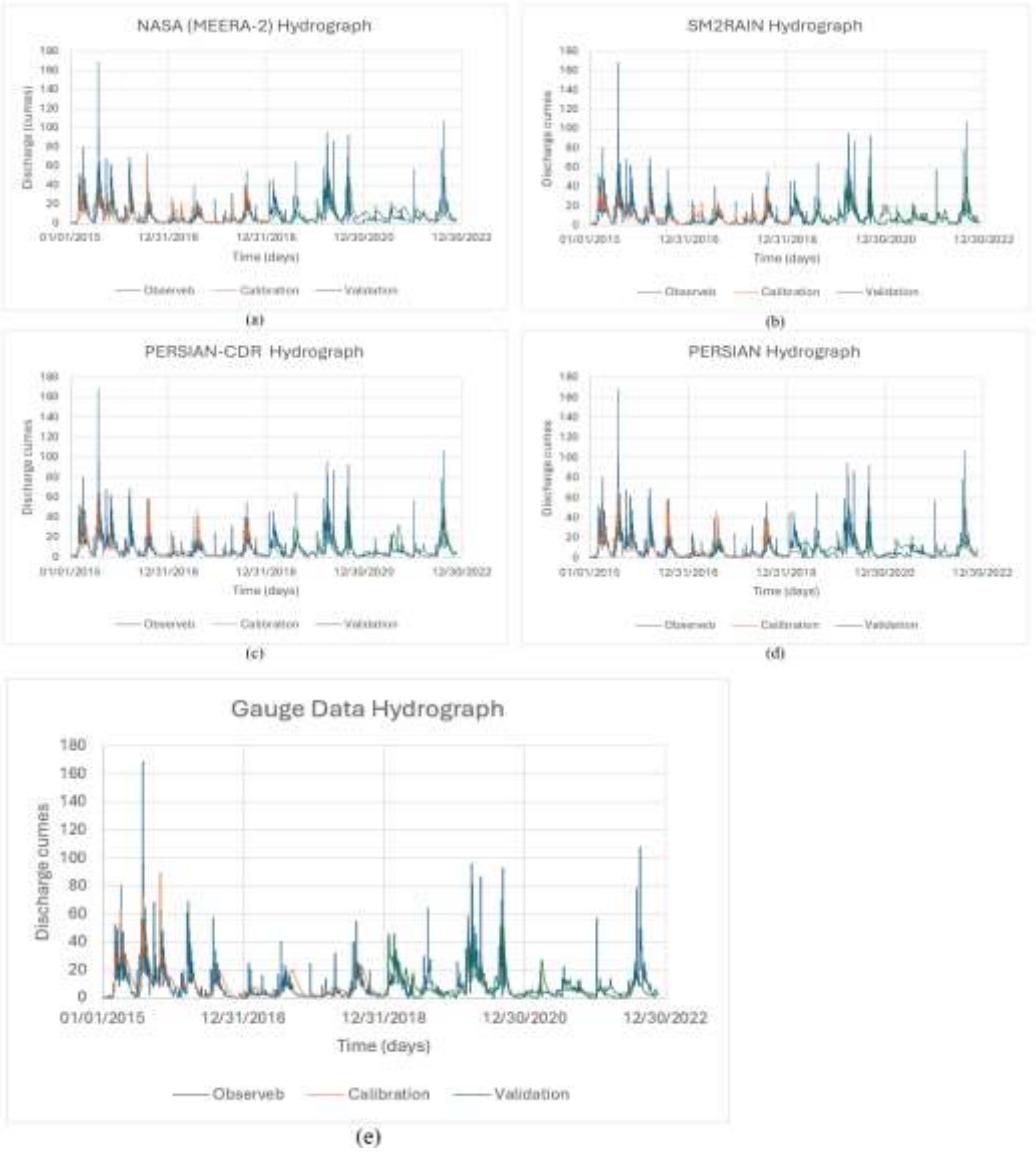

Figure 6. Comparison of hydrograph: Observe streamflow and simulated streamflow of four SBPP's and Ground-Based Observatories simulated streamflow

In the above hydrograph on the X-axis there is observed ground discharge data while on Y-axis there is simulated streamflow of individual SBPP's under consideration by using SWAT model. Blue line shows observed Ground discharge from 1 Jan 2014 to 24 Nov 2022, the orange line shows calibration period (1 Jan 2014 to 31 Dec 2018) of simulated streamflow of SBPP's and grey line shows simulated streamflow for validation period (1 Jan 2018 to 24 Nov 2022) of SBPP's.

As see in the graphical representation none of the SBPP's have estimate the peak 167 cumecs in observed data on 27 July 2015 and other peaks are near to the observed discharge.

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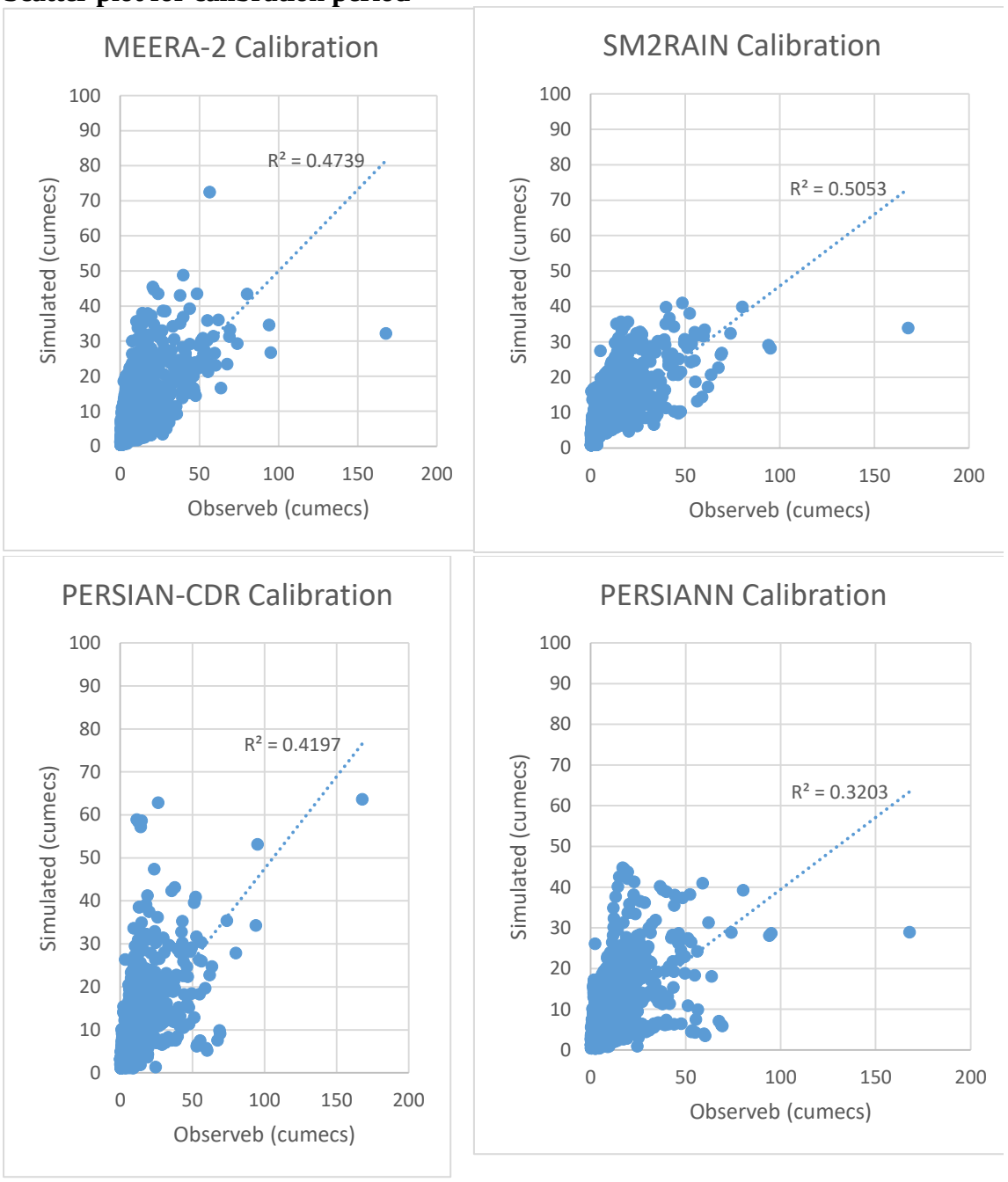
Furthermore, simulated streamflow all SBPP's nearby achieved the observed discharge in calibration period but in the validation period the PERSIANN and MEERA-2 not achieved the observed peaks and shows little peak where there no observed peaks are available.

Scatter plot for calibration period



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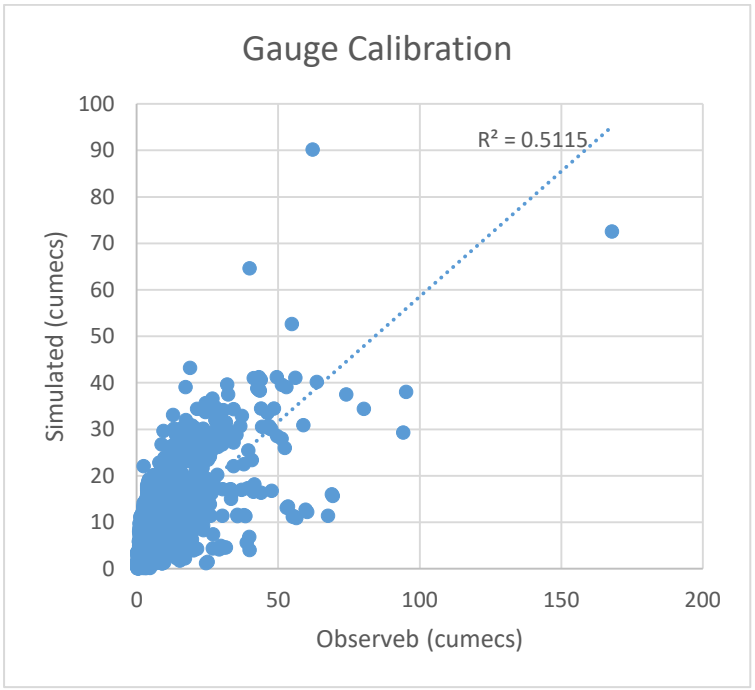
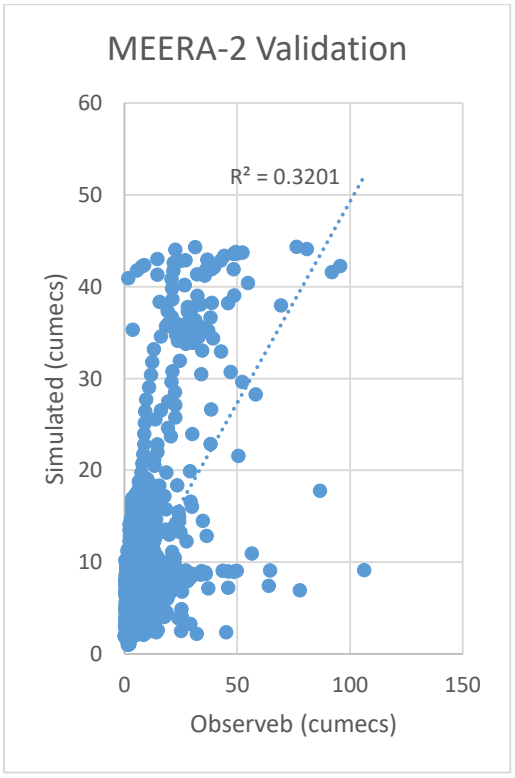
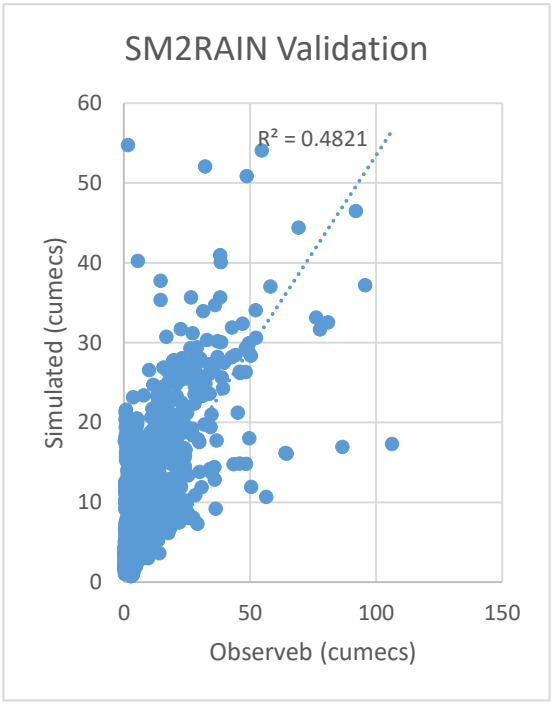


Figure 7. Daily simulated vs. observed streamflow scatter plot calibration period for 4 SBPPs and Ground Observatory with a trend line showing R2 values.

Scatter plot for Validation period





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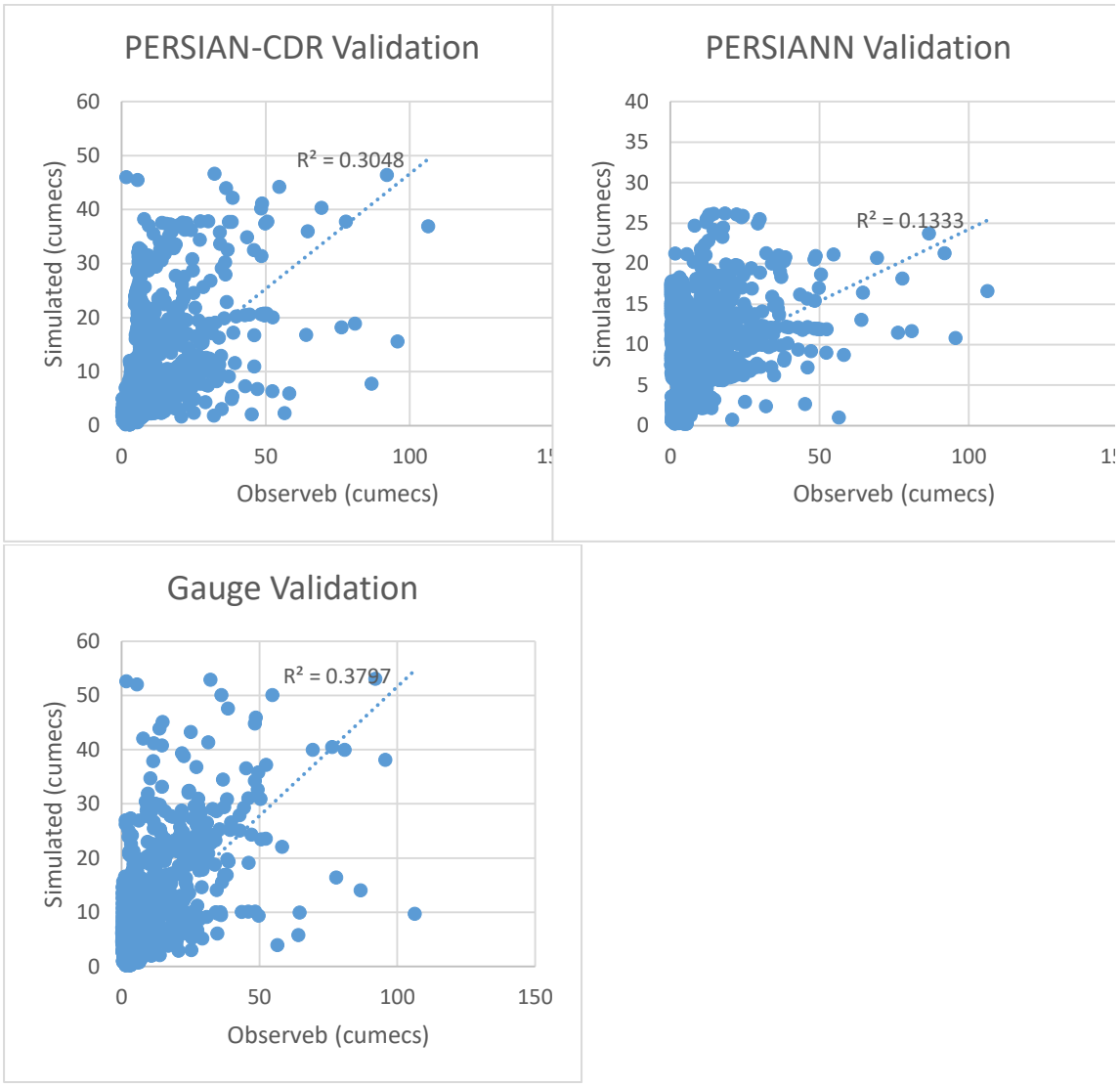

Figure 8. Daily simulated vs. observed streamflow scatter plot calibration period for 4 SBPPs and Ground Observatory with a trend line showing R2 values.

The correlation coefficient values are higher for calibration period as compared with validation period. SM2RAIN correlation coefficient value in calibration period is 0.5053 and validation period 0.4821 little decrease. Similarly, MEERA-2 in calibration period 0.4739 and validation period significantly decrease in value 0.3201. PERCIANN-CDR in calibration period is 0.4197 and validation period decrease to 0.3048. PERCIANN in calibration 0.3203 and in validation period significantly decrease to 0.1333. and the ground gauge in calibration 0.5115 and validation decrease to 0.3797. The values decreased for all SBPPs none of the SBPP's increase correlation coefficient values in validation period. Figure

In this study SM2RAIN perfume well in calibration and also validation then other SBPP's under consideration. But PERCIANN not well perform in calibration and in validation period poor performance.

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Evaluation matrices

Table 5. Model performance metrics Calibration and Validation for evaluating simulated daily streamflow for 4 SBPPs and Ground Data.

Products	Calibration						Validation					
	R^2	NS	PBIAS	KGE	SSQR	RSR	R^2	NS	PBIAS	KGE	SSQR	RSR
Gauge Data	0.51	0.51	18	-8.9	0.61	0.7	0.38	0.35	11	7.8	0.55	0.81
SM2RAIN	0.51	0.48	37	-2.5	0.48	0.72	0.48	0.48	18	-5.6	0.57	0.72
PERSIANN	0.32	0.3	30	16.1	0.4	0.83	0.13	0.11	48	8.6	0.18	0.94
PERSIANN-CDR	0.42	0.42	22	4.2	0.51	0.76	0.3	0.25	14	11.7	0.48	0.87
MEERA-2	0.47	0.47	22	11.8	0.53	0.73	0.32	0.27	15	-5	0.51	0.85

After graphical representation also notice in evolution matrices see that R^2 and NS values (0.51, 0.48 respectively in calibration and 0.48, 0.48 respectively in validation) of SM2RAIN are higher than the other SBPP's under consideration, NS value of SM2RAIN remain same in calibration and validation, but R^2 value decrease. Secondly PERSIANN-CDR and MEERA-2 well perform in calibration with R^2 and NS values (PERSIANN-CDR 0.42, 0.42 respectively, MEERA-2 0.47,0.47 respectively in calibration), in validation period the R^2 and NS (PERSIANN-CDR 0.3, 0.25 respectively, MEERA-2 0.32,0.27 respectively) decrease. PERSIANN not perform as compared to other SBPP's with R^2 and NS values (0.32, 0.3 respectively in calibration and 0.13, 0.11 respectively in validation), PERISIANN performance significantly reduce in validation. Furthermore, R^2 and NS values decrease in validation period of all SBPP's under consideration.

As PBIAS lower values show overestimation and higher values underestimation from table PBIAS values are greater than 0, PBIAS values show that all the SBPP's are underestimate the streamflow.

Other performance metrics, such as KGE, SSQR and RSR, could not provide definitive evidence and support for model performance evaluations in any given scenario and period. Thus, the quantitative assessment for the model performance evaluation using KGE, SSQR and RSR values was inconclusive. However, NSE and R2 metrics proved adequate for evaluating model performance and drawing reasonable conclusions for this study. But some the researcher uses these matric[48, 49].

Discussion

It is difficult to perform hydrological modeling in catchments with inadequate gauge densities. A network with a dense distribution of gauges and stations that can supply the models with realistic inputs is necessary for hydrological modeling. On the other hand, the actual gauge/station distribution is sparse and cannot adequately represent

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the temporal and spatial variability. In undeveloped nations like Pakistan, where data are either nonexistent or extremely rare, the situation is even worse. Furthermore, the lack of data for calibration and validation procedures of SBPP's adds a great deal of uncertainty to hydrological modeling in poorly or ungauged catchments[29]. As a result, a number of studies have lately concentrated on assessing the effectiveness of various SBPP's in hydrological modeling, especially the SWAT model use to simulate streamflow in catchments that are poorly or ungauged[3, 20, 21].

Temperature, Sunlight, humidity and windspeed are the key inputs for SWAT hydrological simulation that accessed from nasa.power larc these are also have uncertainties, and a reasonably dense network of RGs/stations is required to provide reliable input data. In poorly gauged watershed (mostly in developing countries like Pakistan), the distribution of RGs/stations is sparse and does not meet the scientific requirements. Therefore, to overcome the data scarcity issues, an alternative option must be investigated SBPP's.

The variability in Satellite Based Precipitation Products (SBPPs) poses significant limitations to studies relying on them. Each SBPP has its own set of characteristics, including spatial and temporal resolutions, which can vary widely between products. These differences affect how rainfall data is captured and processed, as well as how estimates are calibrated and validated using ground observations. As a result, simulating results and evaluating models based on these SBPPs can yield divergent outcomes.

Moreover, the complex topography of a region adds another layer of complexity. The high variability of precipitation patterns observed across different temporal and spatial scales within a watershed can further impact the accuracy of rainfall estimates derived from these products. This variability needs to be carefully considered and accounted for when utilizing SBPPs for research or practical applications, as it can introduce uncertainties and biases into the analysis.

This study shows that SM2RAIN is use with Spatial resolution 0.125° x 0.125° if finer than other SBPP's, perform will then other SBPP's under consideration. SM2RAIN is a method used to estimate rainfall from soil moisture data. It operates on the principle that soil moisture changes are related to rainfall, as precipitation affects soil moisture levels. The method uses empirical relationships between soil moisture variations and rainfall to infer rainfall amounts from soil moisture observations.

The basic idea behind SM2RAIN is to use soil moisture data, typically obtained from satellite observations or ground-based measurements, to indirectly estimate rainfall. This is particularly useful in regions where direct rainfall measurements might be sparse or unavailable.

The results highlight that setting up a hydrological model for a Khanpur Dam (Harro River) watershed Pakistan is complex. There was an underperformance and underestimate of modeled results with all four SBPPs used in this study. There were some notable limitations when carrying out this study, which contributed to the underperformance of the models. Our study area has observed rainfall data; that we also use for hydrological modelling and this also underperform. SBPPs may not be accurate due to cloud cover or missing data from equipment malfunctions.

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Additionally, the khanpur Dam watershed is regarded as poor gauge watershed, with the only one Rain-gauge and streamflow values available at the watershed's outlet. The watershed was assessed using selected SBPPs with limited observations.
Furthermore, utilizing observed climate data to calibrate and validate the satellite rainfall products before establishing a hydrological model to evaluate streamflow would likely have yielded more accurate results and definitive conclusions. Moreover, this study might have improved the simulation of streamflow results and higher accuracy in the model performance metrics if a larger watershed was considered for this kind of study, as carried out by [50, 51].
In this study we have not study direct comparisons SBPP's with observed data, sensitivity analysis also not a part of this study the calibration parameters are taken from previous Study for same watershed.

Conclusions

This section is not mandatory but can be added to the manuscript if the discussion is unusually long or complex.
Objective of study is to comparison of four different satellites on the bases of stream flow simulation using Arc-SWAT model with observed ground stream flow, following conclusion are drawn from this study.
By using the four SBPP's for hydrological modelling we conclude that the SM2RAIN show well performance Graphical representation and Evolution Matrices.
On the basis of PBIAS Evolution matrices all SBPP's underestimate the Streamflow in calibration period and validation period.
Evolution matrices demonstrate that all product well perform in calibration Period but not well perform in validation period because the performance Evolution matrices value decrease after calibration period.
Furthermore, simulated streamflow all SBPP's nearby achieved the observed discharge peaks in both periods, but in the validation period the PERSIANN and MEERA-2 not achieved the observed peaks and shows little peak where there no observed peaks are available.
Although the performance metrics did not show promising results as anticipated even after the extensive calibration process, they were within satisfactory performance levels.
Overall, we conclude from the results of this study SM2RAIN use for hydrological modeling and water resources management in data Scarce region of Pakistan with limitation. This study supports and highlights the use of SBPPs for hydrological studies in data scarce watersheds.

Author Contributions: Zakir Shahzad: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation. **Shakir Ali Haider**: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Muhammad Ehtsham**: Conceptualization, Methodology, Validation, Supervision, Project administration**. Muhammad Irfan**: Validation, Supervision, Project administration. **Saad Nisar**: Validation, Supervision.

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Data Availability Statement: We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required. Suggested Data Availability Statements are available in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics.

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Appendix A

The appendix is an optional section that can contain details and data supplemental to the main text—for example, explanations of experimental details that would disrupt the flow of the main text but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data is shown in the main text can be added here if brief, or as Supplementary data. Mathematical proofs of results not central to the paper can be added as an appendix.

Appendix B

All appendix sections must be cited in the main text. In the appendices, Figures, Tables, etc. should be labeled starting with "A"—e.g., Figure A1, Figure A2, etc.

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