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# The Evaluation of Satellite-Based Rainfall Estimates Comparison with Ground Rain Gauge Data for Selected Areas Over the Lower Indus Basin of Pakistan

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**Abstract**

The rainfall patterns in Pakistan are altered due to climate change, rainfall showers are for fewer periods with high intensity which results in successive floods and drought. Rainfall estimation is vital in non-farm water utilization and water resources management. Conventional methods for rainfall measurement are used in Pakistan i.e. ground rain gauge station, this method has several limitations as they are difficult to install and operate at high evaluation, the method requires continuation record-keeping, has chances of error due to human intervention, covers less area and floods affected them badly, etc. Satellite-based rainfall estimates are a better alternative to estimating rainfall depths with high accuracy. In this study, satellite rainfall estimates are geared from NASA satellite product Global Precipitation Mission (GPM) and rain gauge data for the study area for the period of twelve years from 2005 to 2017 collected from Pakistan Water and Power Development Authority (WAPDA) for eight numbers ground rain gauge stations. The collected rainfall data were evaluated using statistical tools. The scattered diagram was developed for each station using linear regression analysis. A regression line is a tool for checking the effect of the independent variable on the dependent variable. The coefficient of determination ($R^2$) lies between 0.7513 to 0.8625, indicating a significant result of 75.13% to 86.25%. GPM is an alternative for timely rainfall estimation, especially for remote areas with high elevations. It can potentially overcome scarcely rain-gauged catchments for hydrological modeling, used for irrigation scheduling. Its role can also be vital in calculating the climate change impact on rainfall patterns.

***Key Words: Climate Change, Regression Analysis, Rain Gauge, Rainfall Patterns***

# 1. Introduction

Water is the most important natural resource required for the survival of all living things. It is an important input to agricultural production and an essential requirement for domestic, municipal, and industrial activities. The impact of climate change has always been very important for water resources in the world. In countries like Pakistan where different weather conditions exist, the effects of climate change can be more crucial. Generally, climate changes are considered in terms of global warming i.e. increase in the average temperature of the earth's near-surface air. Global warming can have a strong impact on river flows in Pakistan (Shakir et al., 2010). Being one of the very sensitive parameters, climate change can cause significant impacts on water resources by resulting in changes in the hydrological cycle (Bates et al., 2008; Archer and Fowler, 2004; Abdo et al., 2009).
Climate change altered the global rainfall patterns. The extremes of rainfall are measured using historical rainfall events for the design of the water infrastructure system. (Das *et al.*, 2022). The extreme rainfall events due to the warming climate result in Sea-Level rise (SLR) and floods of high frequency (Panda *et al.*, 2023). It is reported that climate change would strengthen the Arabian Sea thermal contrast which will lead to conversion from a semi-humid to a humid zone and semi-arid to arid zone conversion would also increase due to the inflow of dry air from the Arabian region. (Panda *et al.*, 2023). According to the Intergovernmental Panel on Climate Change Assessment Report (IPCC, 2001), global climate change is expected to alter precipitation and run-off patterns, exerting significant pressure on water resources on a regional and global scale. Thus potential impacts of climate change on hydrologic extremes, like floods, in small and medium-sized watersheds, have not received significant attention. Consequently, there is a lack of sufficient development and application of suitable water resource design techniques in the context of climate change.
By affecting certain components of the hydrological cycle, especially precipitation and runoff, climate change can alter the spatial and temporal availability of water resources. For instance, reduced river runoff can concentrate the effects of pollutants or exacerbate the spread of water-borne diseases. On the other hand, climate change that increases overall water availability could either be beneficial or could increase the risk of flooding. A variety of climatic and non-climatic processes influence flood processes, resulting in river floods, flash floods, urban floods, sewer floods, glacial lake outburst floods, and coastal floods. The increase in precipitation intensity and other climate changes indicate that climate change has an impact on the intensity and frequency of floods. Climate change may also affect groundwater recharge rates (i.e., the renewable groundwater resources) and depths of groundwater tables (Milly et al, 2005).
Pakistan lies in South Asia with dry and cold areas and geography varies across the country, resulting in climate variation. Climate comprises of hot summer and mild winter. Recent studies indicated climate change can affect Pakistan's 22.8 percent area and 49.6 percent population (Mustafa, 2011). Floods on a large scale in the Indus River System of Pakistan caused massive damage to life, agriculture, and infrastructure are impacts of climate change. Heat waves and droughts are also

penalties for climate change (Qazlbash *et al.*, 2021). Pakistan's coastal areas were unprecedentedly destroyed in floods in 2022. The National Disaster Management Authority (NDMA) has reported millions of people to be affected by catastrophic floods (Iqbal *et al.*, 2022). Different departments of the country took different measures to minimize the losses but these measures are not sufficient to confirm the safety of people and areas that are prone to floods with a rapid onset (Khan *et al.*, 2021). Flood forecasting is the main pillar in the timely management of floods and the most challenging task in hydrology. It plays a vital role in reducing economic and life losses. (Jain *et al.*, 2018). Extreme rainfall events in Pakistan are resulting due to level low-level moisture flux and upward vertical moisture and these moisture events are not apparent during moderate events. (Chen *et al.*, 2023). Rainfall forecasting is a tool for farmers to avoid over- and under-irrigation in rain-fed and irrigated agricultural areas. (Bhatti and Anwar, 2022).

Temperature and rainfall are the main parameters for flood and drought management. Remote sensing techniques were used to calculate the impact of rainfall and temperature for selected areas of the Southern areas of Pakistan. (Ashraf *et al.*, 2022). It is essential to evaluate the performance of remotely sensed precipitation before using these products in different processes. Tropical Rainfall Measuring Mission (TRMM-3B42) and Global Precipitation Measurements from Integrated Multi-satellite Retrievals (GPM-IMERG) were evaluated concerning the rain gauge data for the period of 2004 to 2018 over Pakistan. The results showed that the performance of satellite-based remotely sensed precipitations was influenced by topography. (Arshad *et al.*, 2021).

## 2. Materials and Method

### 2.1. Study Area

The Indus River is a transboundary river of Pakistan, it has an annual flow of around 243 $Km^3$ with a drainage area of circa 1,120,000 $Km^2$. The lower Indus Basin from Tarbela Dam to Jinnah Barrage reach was the study area for this research study. Eight different points from the study area were selected to evaluate the remotely sensed rainfall estimates. The Water and Power Development Authority Pakistan already installed different ground rain gauge stations in the study area.

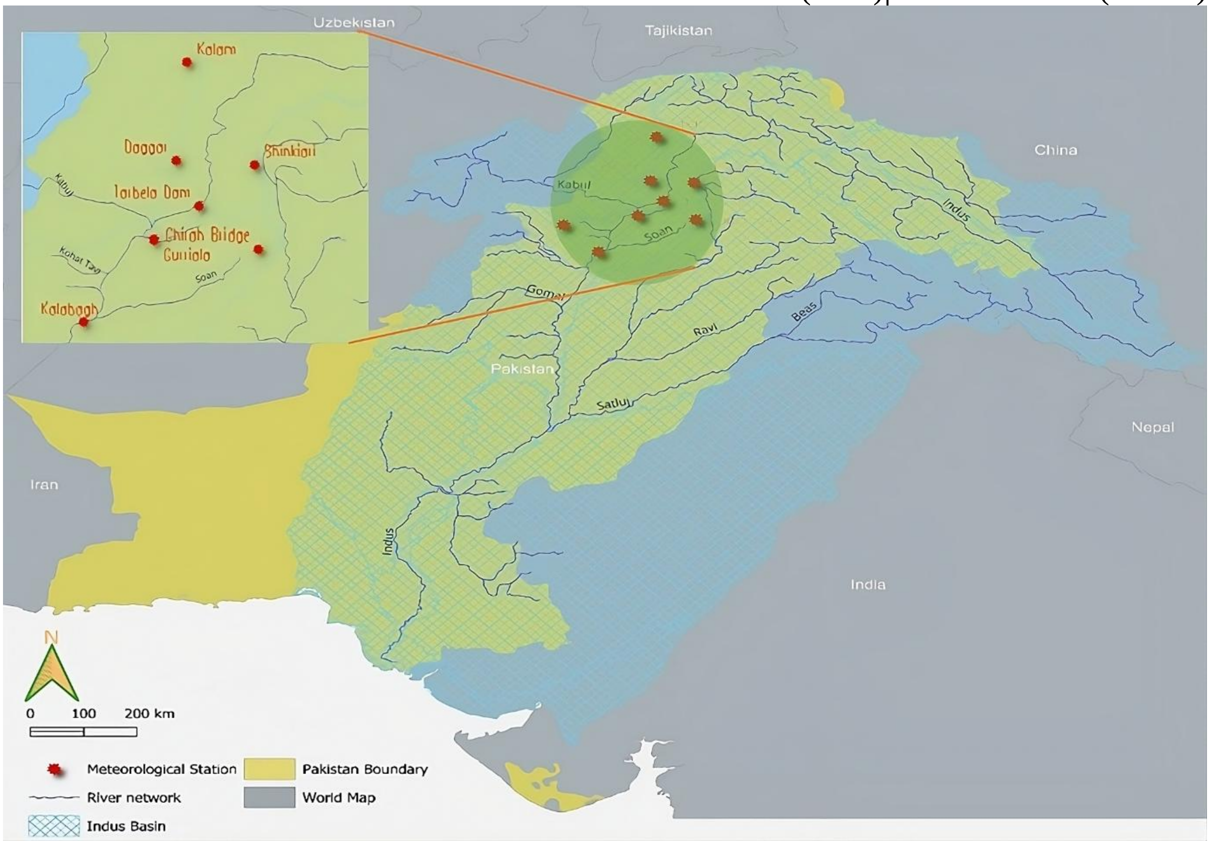

Figure 2.1 The illustration of the Study Area Map

## 2.2. Rainfall Data Collection from WAPDA

The Water and Power Development Authority Pakistan was founded in 1958 under the act of parliament for the rapid maintenance and development of power and water resources in Pakistan. WAPDA has already installed ground rain gauge stations at different eight points of study areas. The rainfall data of selected eight different rain gauge stations of more than ten years period was collected from WAPDA's Department Surface Water Hydrology (SWH) Department, Sunny View, Lahore, and that was used in this study. The summary of data collected from SWH is given in Table 2.1. Ground rain gauge data collected from WAPDA was used to evaluate the remotely sensed rainfall estimates of the study area. Global Prescription Measurement Mission (GPM) data product was downloaded, used in this study, and evaluated using statistical tools.

| Sr. No. | Station Name | River | Location | | Period of Data Collection |
|---|---|---|---|---|---|
| | | | Latitude | Longitude | |
| 1. | Chirah Bridge | Indus | 33° 39' 25" N | 73° 18' 15" E | 2005-2015 |
| 2. | Daggar | Indus | 34° 30' 36"N | 72° 29' 11"E | 2005-2017 |
| 3. | Fort Lockhart | Indus | 33° 32' 20"N | 70° 55' 10"E | 2005-2017 |
| 4. | Gurriala | Indus | 33° 44' 40"N | 72° 15' 45"E | 2005-2018 |
| 5. | Kalabagh | Indus | 32° 57' 00"N | 71° 33' 00"E | 2005-2018 |
| 6. | Kalam | Kabul | 35° 28' 10"N | 72° 35' 40"E | 2005-2018 |
| 7. | Shinkiari | Indus | 34° 28' 00" N | 73° 16' 00" E | 2005-2017 |
| 8. | Tarbela Dam | Indus | 34° 04' 00"N | 72° 43' 00"E | 2005-2017 |

Table 2.1: WAPDA Rainfall Data Summary.

### 2.3. GPM Data Downloading

GPM is the global precipitation measurement mission and consists of different international satellites that provide data on precipitation for the entire globe to improve the forecasting of extreme events. The rainfall data of the study area was downloaded by providing the coordinates of that area from https://giovanni.gsfc.nasa.gov/giovanni/.

For downloading the data, initially, a time series-area averaged plot was selected and then the required product was selected from the list. Moreover, coordinates of the respective study area were provided, and the plot data option was selected. After some time, rainfall data was downloaded in the CSV file and the graph image in the PNG file. The layout of Giovanni's website for downloading the rainfall data is shown in Figure 2.2.

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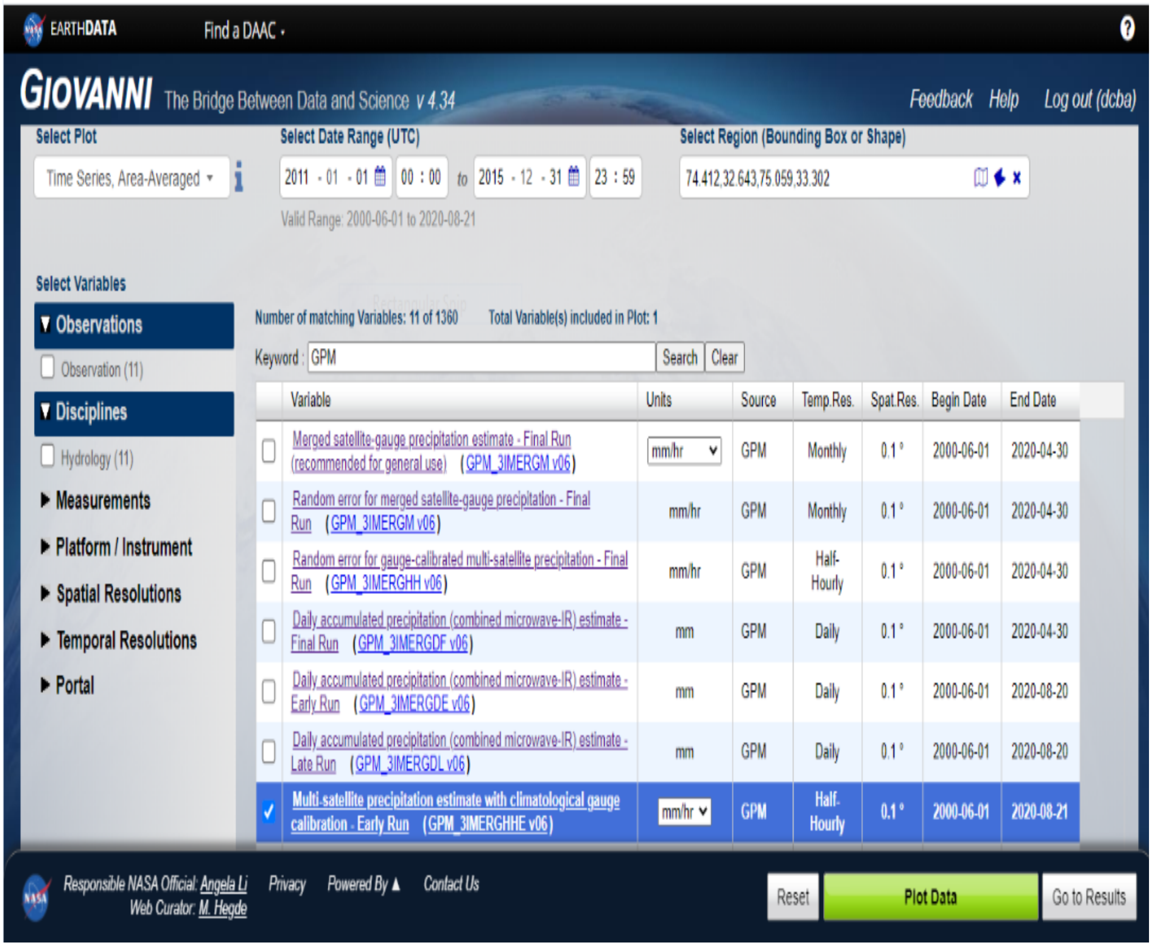


Figure 2.2 GPM Rainfall Data Downloading

## 2.4. Statistical Analysis

Rainfall data collected from WAPDA was used to evaluate the remotely sensed rainfall estimates of GPM data using statistical research tools. Regression analysis was performed and graphs of all the selected points of the study area were developed. Regression analysis was performed in MS Excel.

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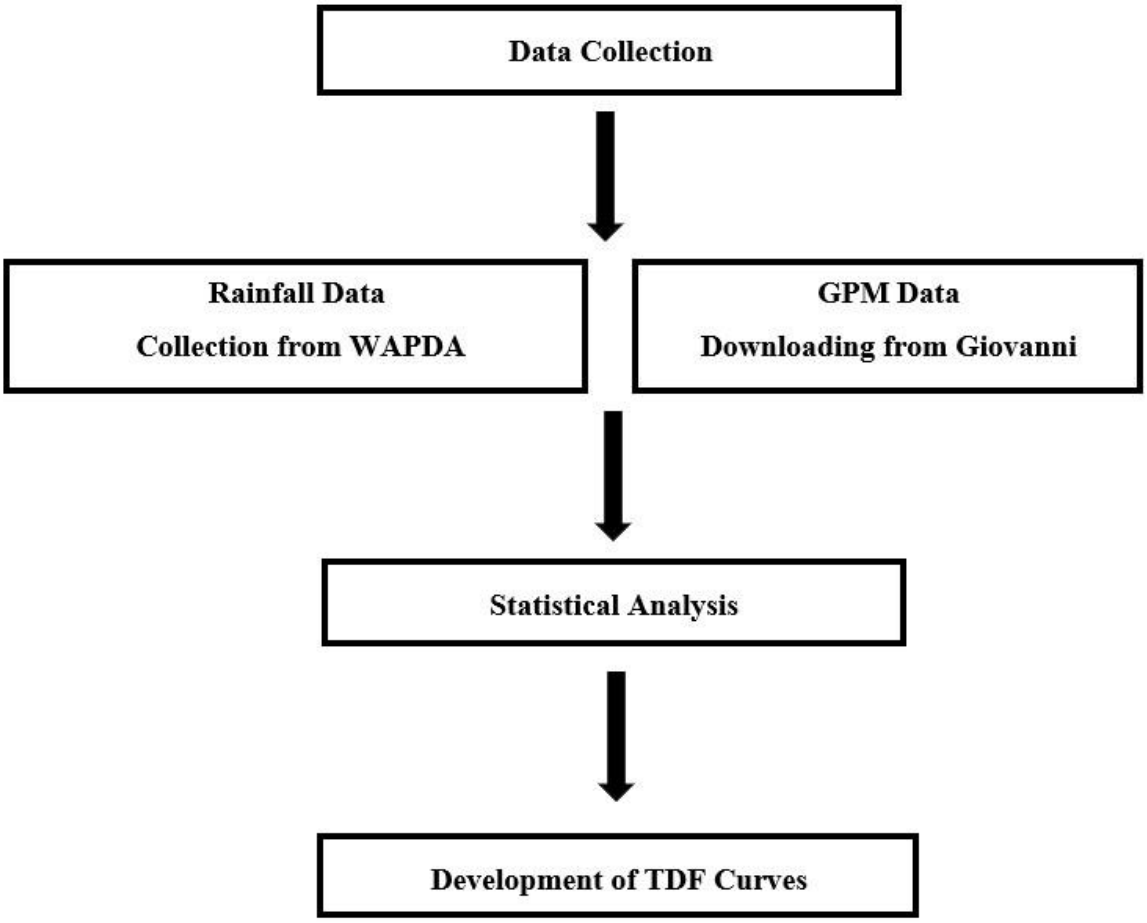


Figure 2.3 A flowchart representing the methodology of the study

## 3. Result and Discussion

### 3.1. Chirah Bridge Rain Gauge Data and GPM Data Testing

Chirah Bridge rain gauge station was installed on the Indus River in the province of Punjab by WAPDA at an elevation of 579 masl in 1976. The geographic location of the rain gauge is 33° 39' 25"N latitude and 73° 18' 15"E longitude. Rainfall data from 2005 to 2015 are used for statistical analysis of rain gauge data and GPM data. The scatter diagram using linear regression is shown in Figure 3.1.

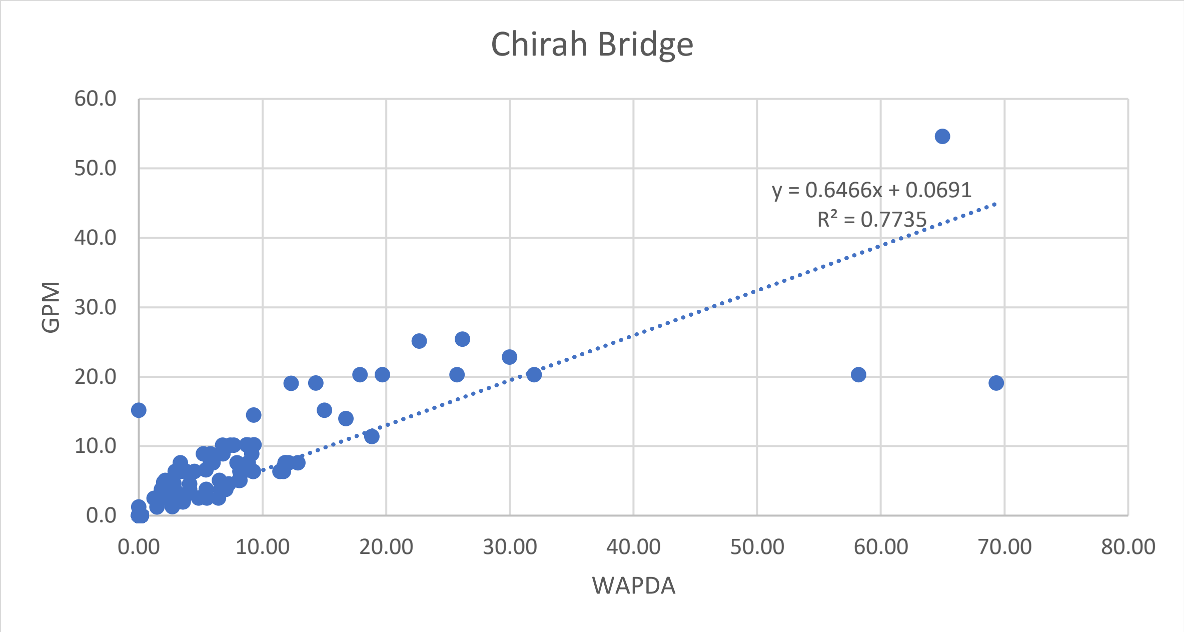


Figure 3.1: Regression analysis of GPM Vs WAPDA Chirah Bridge

### 3.2. Daggar Rain Gauge Data and GPM Data Testing

Daggar rain gauge station was installed on the Indus River in the province of Khyber Pakhtunkhwa by WAPDA at an elevation of 732 masl in 1963. The geographic location of the rain gauge is 34° 30' 36"N latitude and 72° 29' 11"E longitude. Rainfall data from 2005 to 2017 are used for statistical analysis of rain gauge data and GPM data. The scatter diagram using linear regression is shown in Figure 3.2.

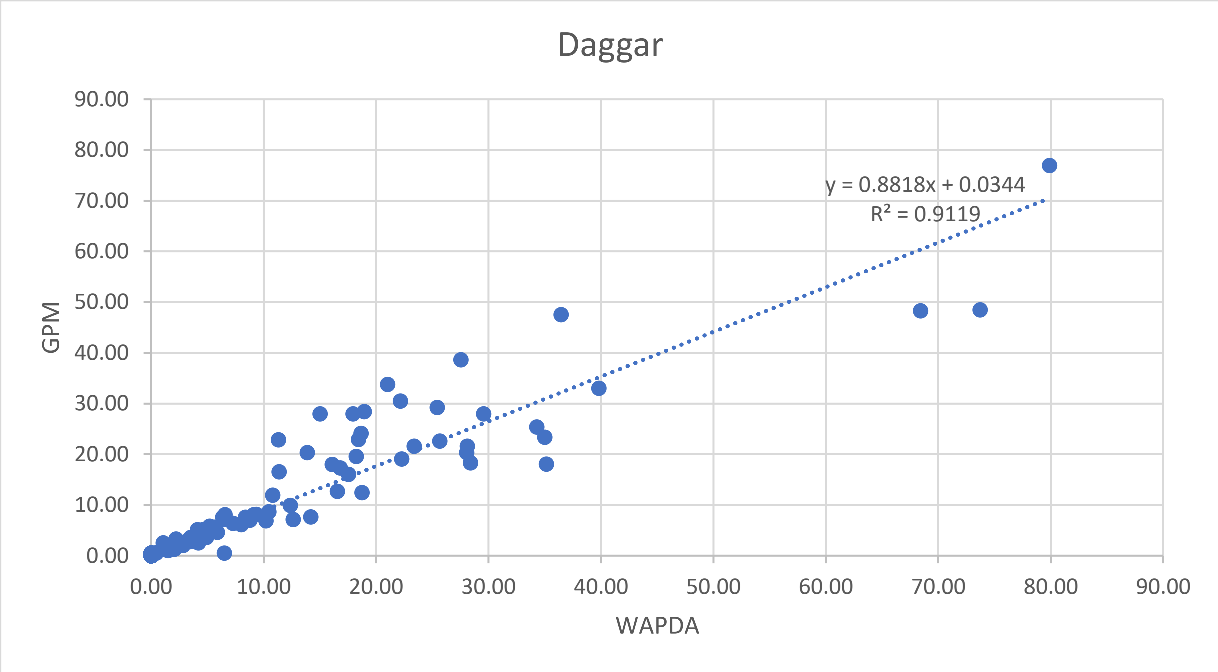


Figure 3.2: Regression analysis of GPM Vs WAPDA at Daggar

### 3.3. Fort Lockhart Rain Gauge Data and GPM Data Testing

Fort Lockhartrain gauge station was installed on the Indus River in the province of Khyber Pakhtunkhwa by WAPDA at an elevation of 6500 masl in 1962. The geographic location of the rain gauge is 33° 32' 20" N latitude and 70° 55' 10"E longitude. Rainfall data from 2005 to 2017 are used for statistical analysis of rain gauge data and GPM data. The scatter diagram using linear regression is shown in Figure 3.3.

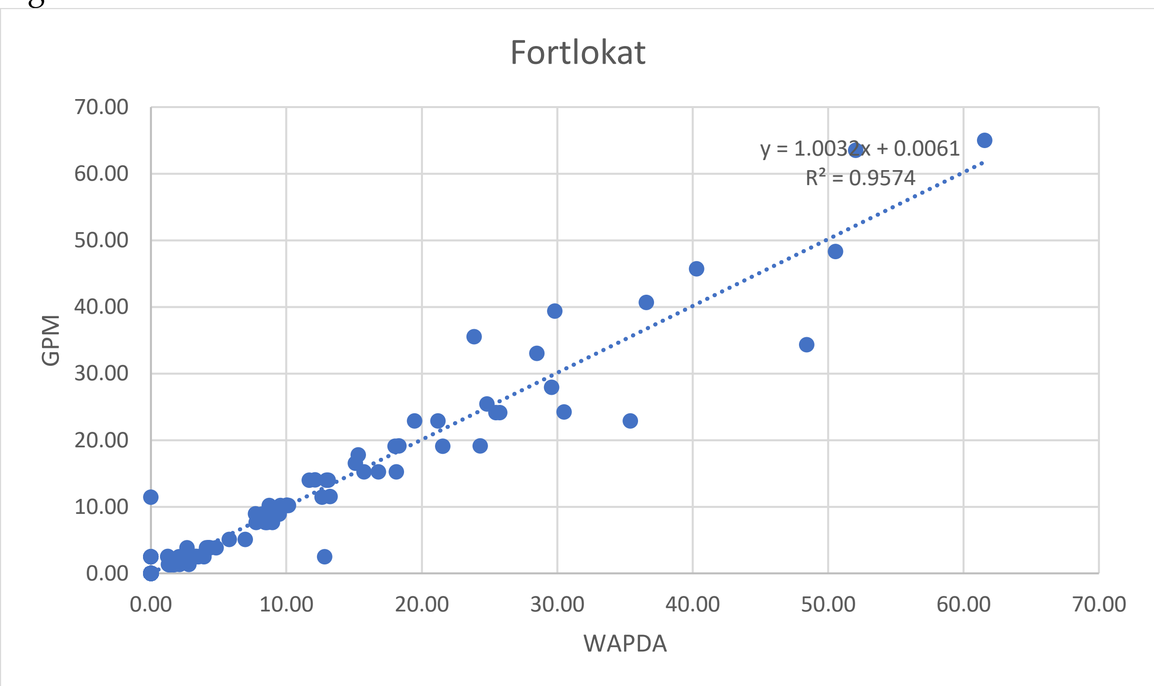


Figure 3.3: Regression analysis of GPM Vs WAPDA at Fort Lockart

**3.4 Gurriala Rain Gauge Data and GPM Data Testing**

Gurriala rain gauge station was installed on the Indus River in the province of Punjab by WAPDA at an elevation of 329 masl in 1976. The geographic location of the rain gauge is 33° 44' 40"N latitude and 72° 15' 45"E longitude. Rainfall data from 2005 to 2018 are used for statistical analysis of rain gauge data and GPM data. The scatter diagram using linear regression is shown in Figure 3.4.

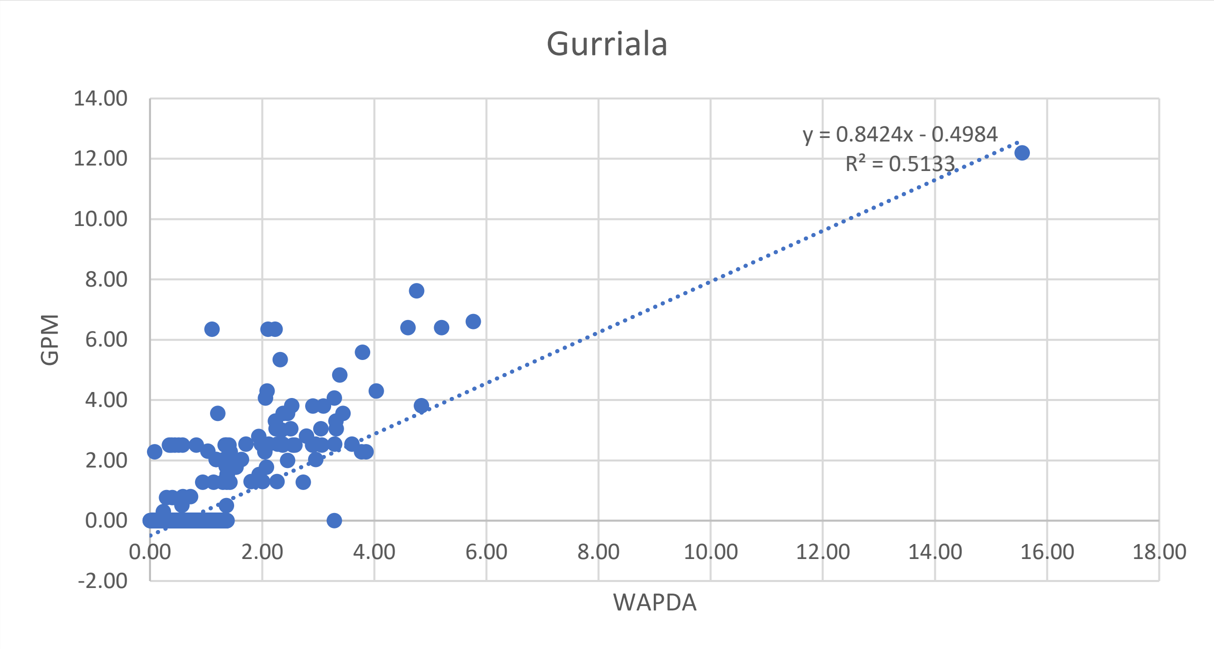


Figure 3.4: Regression analysis of GPM Vs WAPDA at Gurriala

**3.5 Kalabagh Rain Gauge Data and GPM Data Testing**

Kalabagh rain gauge station was installed on the Indus River in the province of Punjab by WAPDA at an elevation of 213 masl in 1987. The geographic location of the rain gauge is 32° 57' 00"N latitude and 71° 33' 00"E longitude. Rainfall data from 2005 to 2016 are used for statistical analysis of rain gauge data and GPM data. The scatter diagram using linear regression is shown in Figure 3.5.

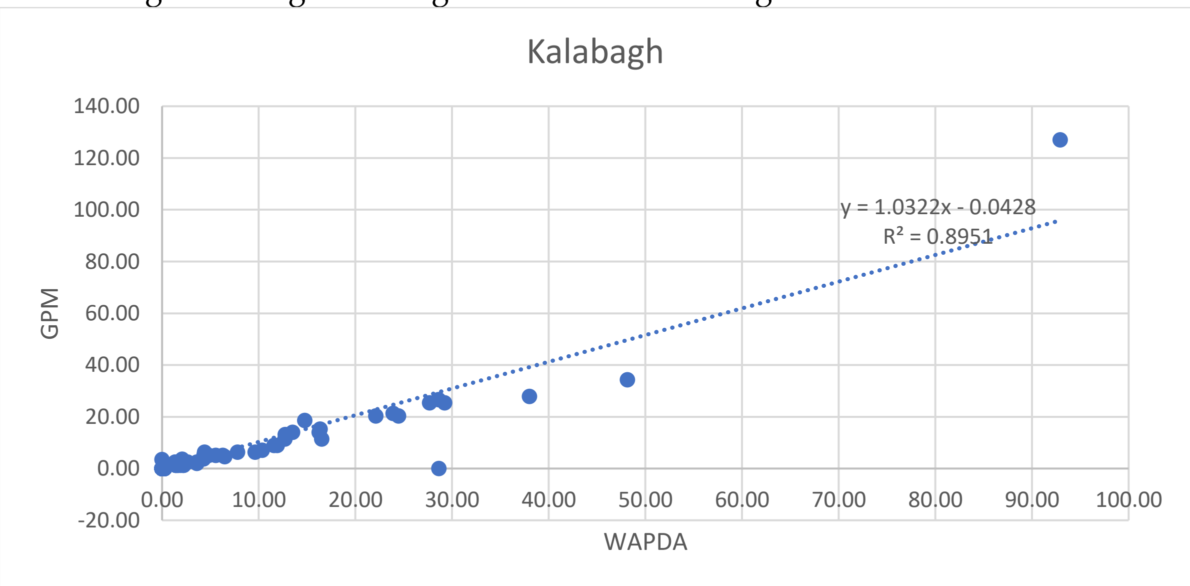


Figure 3.5: Regression analysis of GPM Vs WAPDA at Kalabagh

**3.6 Kalam Rain Gauge Data and GPM Data Testing**

Kalam rain gauge station was installed on the Kabul River in the province of Khyber Pakhtunkhwa by WAPDA at an elevation of 2744 masl in 1962. The geographic location of the rain gauge is 35° 28' 10"N latitude and 72° 35' 40"E longitude. Rainfall data from 2005 to 2018 are used for statistical analysis of rain gauge data and GPM data. The scatter diagram using linear regression is shown in Figure 3.6.

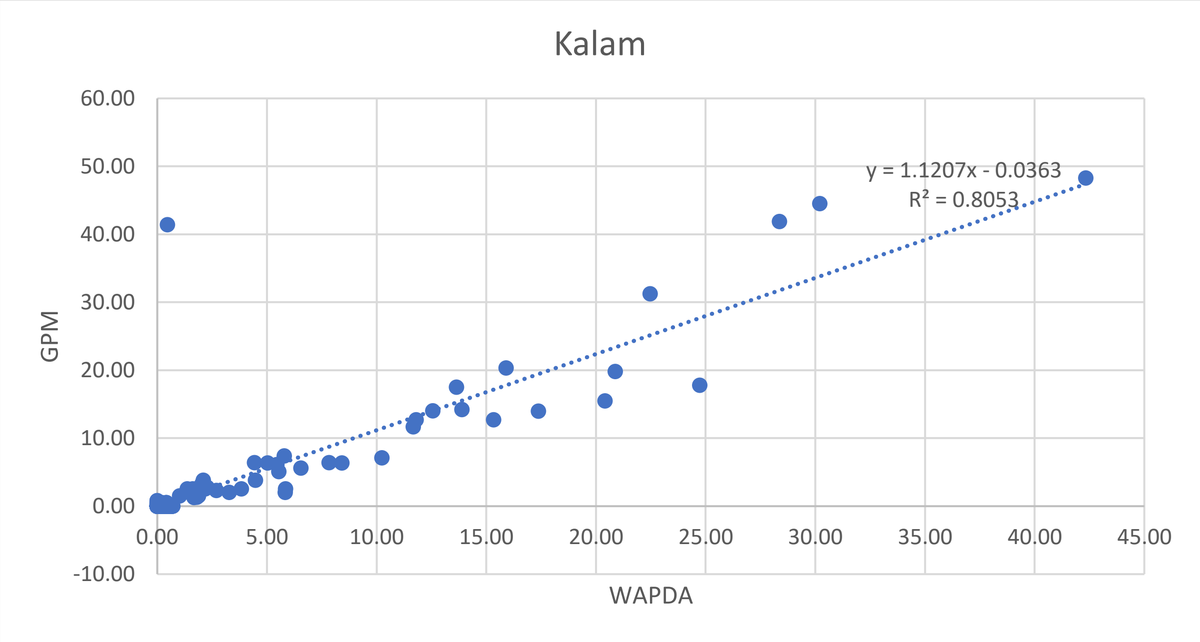


Figure 3.6 Regression analysis of GPM Vs WAPDA at Kalam

**3.7 Shinkiari Rain Gauge Data and GPM Data Testing**

Shinkiari rain gauge station was installed on the Indus River in the province of Khyber Pakhtunkhwa by WAPDA at an elevation of 991 masl in 1961. The geographic location of the rain gauge is 34° 28' 00"N latitude and 73° 16' 00"E longitude. Rainfall data from 2005 to 2017 are used for statistical analysis of rain gauge and GPM data. The scatter diagram using linear regression n is shown in Figure 3.7.

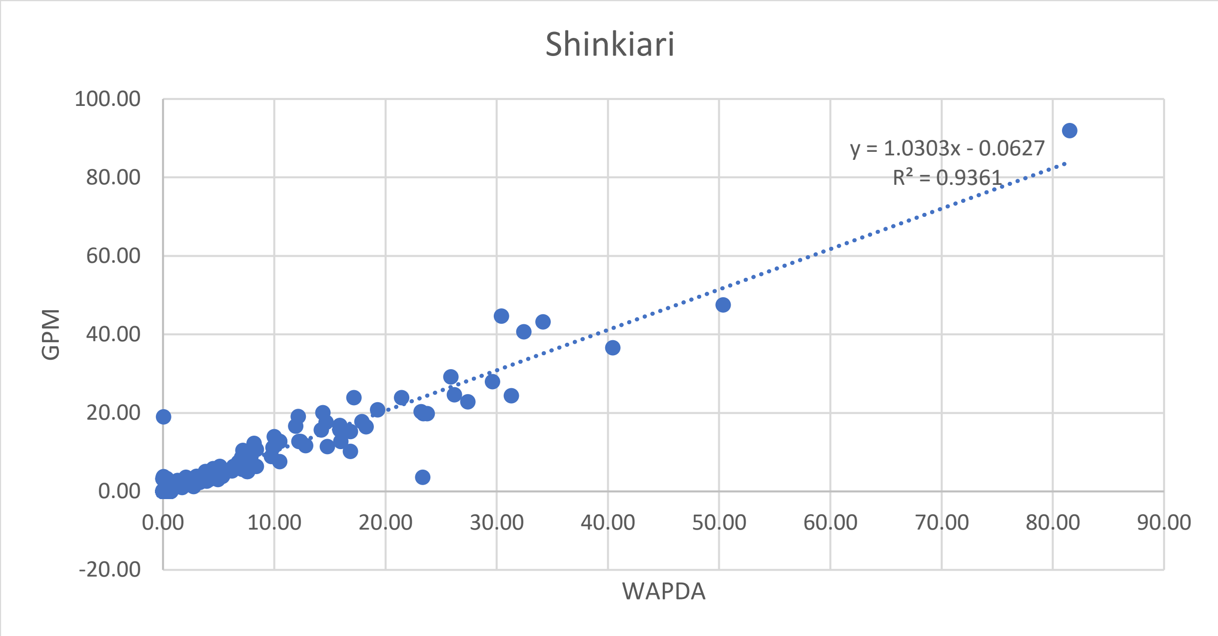


Figure 3.7 Regression analysis of GPM Vs WAPDA at Shinkiari

**3.8 Tarbela Dam Rain Gauge Data and GPM Data Testing**

Tarbela Damrain gauge station was installed on the Indus River in the province of Khyber Pakhtunkhwa by WAPDA at an elevation of 610 masl in 1961. The geographic location of the rain gauge is 34° 04' 00"N latitude and 72° 43' 00"E longitude. Rainfall data from 2005 to 2017 are used for statistical analysis of rain gauge data and GPM data. The scatter diagram using linear regression is shown in Figure 3.8.

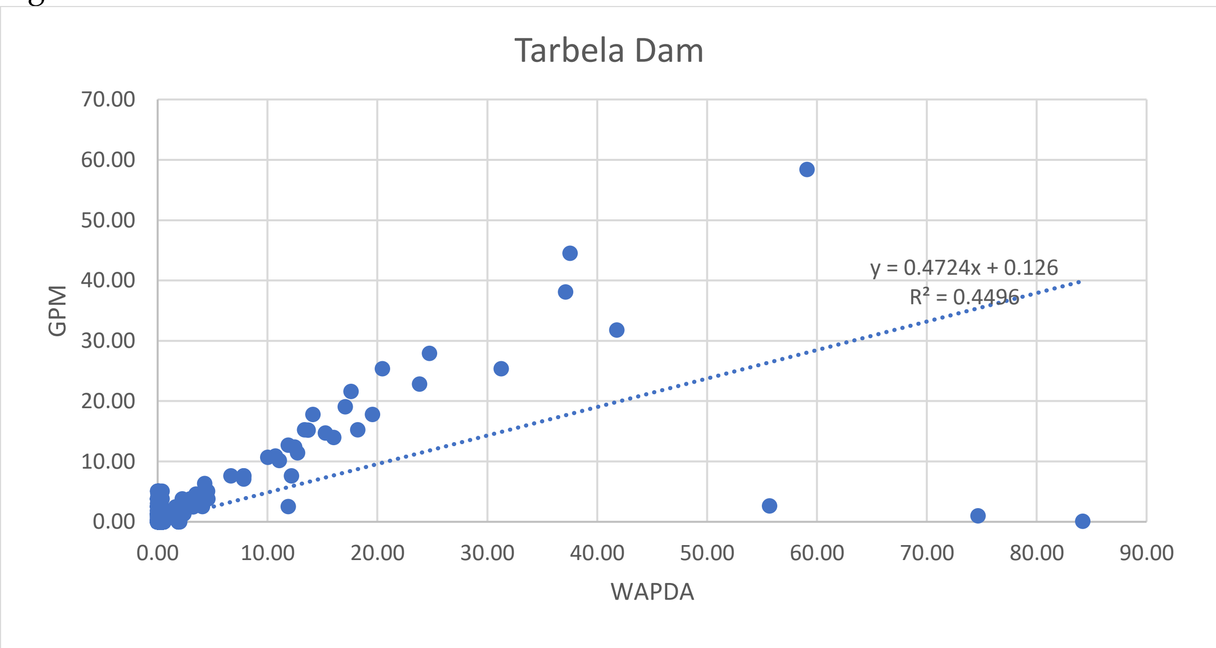


Figure 3.8 Regression analysis of GPM Vs WAPDA at Terbela

**Conclusion**

This study evaluated the performance of GPM data over the lower Indus Basin. The daily rainfall measurement data product of the GPM data was used and evaluated using statistical tools concerning data collected by WAPDA with the help of ground rain gauge stations already installed in the study area. GPM data show significant results, the coefficient of determination lies between 0.4 to 0.9. The elevation of the ground rain gauge was not incorporated in the study which may consider the limitation of this research. It is suggested that further studies may focus on this aspect.

**Conflict of Interest**
The Authors declare that there is no conflict of interest.

**Authors Contribution Statements:**
Remotely sensed rainfall estimates can play a vital role in Pakistan's on-farm water management, flood management systems, and water resources management. GPM data have significant potential to overcome the scarcity of rainfall measurement data with more accuracy and easy asses for Pakistan.

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