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# Assessing the Patterns and Dynamics of Balkh River flow Discharge in North River Basin of Afghanistan from 2006 to 2021

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## Abstract

*The current study offers a statistical assessment of the hydrology of the Balkh River which is in the Afghanistan North River Basin (NRB) for the period from 2006 to 2021. Therefore, this research aims to examine temporal characteristics of water flow in the Balkh River: temporal variations and trends and the factors that have contributed to them. The analysis is made using a complete set of data obtained on water flow in the course of its monitoring with the help of stations located along the Balkh River. Analytical tools used include time series analysis and trend analysis through which it is possible to identify the long-term trends and variations in the flow of water. The study results show that there were daily oscillations and changes in the water flow of the Balkh River during the observation period. These variations are also due to climate change and rainfall fluctuations, abstraction for irrigation purposes, and land-use changes amongst other factors. In addition, many parts of the research also establish the need for proper sustainable water management within the Afghanistan NRB. This paper underscores the importance of integrated water resources management approaches for the efficient management of water resources challenges occasioned by water availability variability in watersheds. These assertions help understand the dynamics of the water in the Balkh River and are essential information to the policymakers and the water resource managers that will aid in the formulation of the right strategies in the Afghanistan NRB when it comes to the management of water resources.*

**Keywords:** Afghanistan, Balkh, Climate Change, Water Flow, Water Resources Management.

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## 1. Introduction

The Afghanistan NRB comprises some of the country's extremely significant water source areas, developed for multipurpose uses to support ecosystem, agriculture, and human uses. Of all the rivers in this basin, the Balkh River sums up a reasonable average of water flow and its part in the water resources. Analyzing the characteristics and changing circumstances of water flow in the Balkh River plays an important role in an improved water management system and its utilization for development.

This research seeks to quantitative assessment of the discharge of water in the Balkh River in the Afghanistan NRB for the period of 2006 to 2021. Therefore, by analyzing the temporal characteristics of the water flow of the river, this research intends to contribute to understanding the temporal hydrological characteristics of the river and the conditions causing changes in water flow [7].

Quantitative analysis will be conducted by comparing the measurements of water flow which will be obtained from the different stations along the Balkh River basin. The cross-sectional research design will involve time series and trend analysis whereby the amount of water flow will be analyzed for the long-term trends and changes in the period of study.

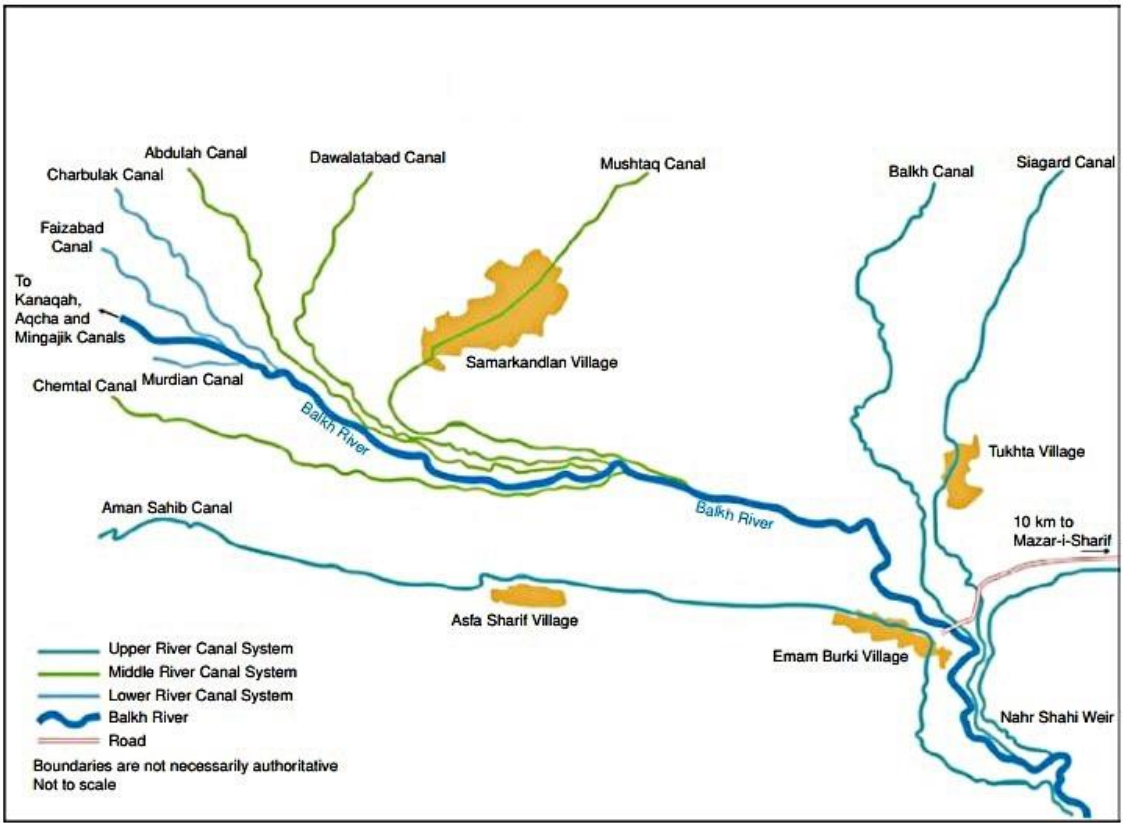



**Fig. 1.** Schematic of the Balkh River Canal System, AFG. Source: Modified from ADB (2004) [13].

The information to be generated in this study will add to an enhanced understanding of the existing water processes in the Balkh River and the likely implications in the formulation of water resource policies in the Afghanistan NRB. When the variables that affect changes in water flow are recognized, it will be easier for policymakers and water resource managers to devise appropriate action frameworks for efficient water use in the region taking into account human impact including water abstraction and land use changes as well as climate variability [7].

Besides, this research will offer novel findings on how the water resources in the Balkh River can withstand or be susceptible to change as new challenges in climate conditions and water demands rise in the region. From this extensive research, therefore, this study contributes to the scientific body of knowledge of the hydrological dynamics of the Balkh River and the water management dynamics by providing a detailed understanding of the situation. The acquired knowledge and understanding can be directly applied to the decision-making process at the regional and national levels thus guaranteeing sustainability and equitable allocation of water resources of the Balkh River for various sectors of development such as agriculture, industry, and domestic use.

The finding of this present research is therefore right and relevant to inform policymakers and stakeholders within the Balkh River basin about the guidelines required to adopt sound water resources management resulting into long standing appropriate measures. The more striking research elements from the comparative analysis of the present study with past works in the region relate to its tried and tested hydrological modeling supplemented by vigorous community involvement. This research presents a novel view and new approaches that have not been used previously in the Balkh basin. In conclusion, the findings made in this study will be a suitable tool for the protection of future water security for communities in the Balkh region.

Therefore, this study seeks to help clarify the water flow characteristics in the Balkh River and their repercussions for water availability in the Afghanistan NRB. Consequently, this research will be of great significance by providing a quantitative analysis of water flow patterns from 2006 to 2021 for sustainable development and water management policies by policymakers, water resource managers, and stakeholders in the region.

## 2. Water Resources Management in the Afghanistan North River Basin

Afghanistan has five general river basins, including four open; the general river basin of KBL, the general river basin of Harirud Marghab, the general river basin of Helmand, the general river basin of Kunduz, and one closed general river basin of North River basin. The NRB with an area of 70901 square kilometers is located in the north of the country and this basin constitutes 11 percent of Afghanistan's river basins, 15 percent of the agricultural area, and 13 percent of Afghanistan's population [7].

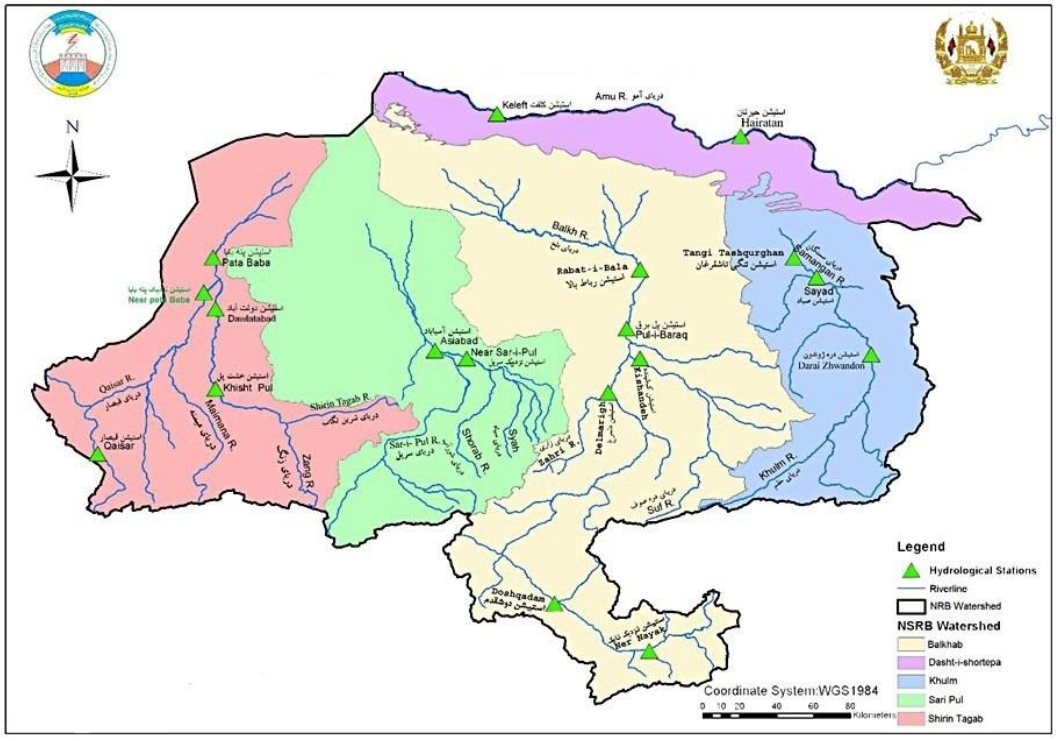



**Fig. 2.** North River Basin Hydrological Stations Map [7].

In addition, the water capacity of this river basin is 2.168 billion cubic meters and it provides the basis for agricultural prosperity in northern Afghanistan. Among the catchment areas, the northern part of Balkh province has the largest area of 28835 square kilometers. Northern AFG has 2,783,033 people and 39 people live in every square kilometer, about 44.36 square kilometers of this basin covered with snow. The standing water in the north river basin contains about 32.9 square meters of land; the amount of snow-covered land, standing water, and swamps only covers small parts of the Balkhab basin. 26-hydro-meteorological stations have been installed in the north river basin, of which 18 are hydrological stations, six are meteorological stations and two are snow gauges, and the north river basin includes the provinces of Balkh, Samangan, Sar-e-pul, Jawzjan, Faryab, and a part of Bamyan.

The average annual rainfall of the NRB is 246.97 millimeters, the maximum temperature is 45.70 degrees Celsius and the minimum temperature of this basin is -27.40 degrees Celsius, the average temperature is 15.81 degrees Celsius, the NRB is a closed basin whose water does not flow to any other country. 26-hydro-meteorological stations have been installed in this area.

### 2.1. Water Management Strategies for Sustainable Development in the AFG NRB

Therefore, adopting better water management measures is significant to revolutionize the Afghanistan North River Basin sustainable development [3]. Such strategies should include; efficient ways of distributing water, measures to enhance the efficient use of water especially for irrigation, and measures put in place for water conservation. IWRM approaches should therefore take both surface water and groundwater sources into consideration to foster sustainable development [15].

Additionally, investing in modern infrastructure, such as efficient irrigation systems and storage facilities, can enhance water efficiency and reduce losses. Strengthening institutional capacity and promoting stakeholder engagement are key to successful water governance [10]. Furthermore, incorporating climate change adaptation measures into water management plans is essential to address the potential impacts of changing climatic conditions. By adopting these strategies, the Afghanistan NRB can secure water resources for agricultural production, support rural livelihoods, and ensure sustainable development in the region [3].

## 3. Climate Change Impacts and Anthropogenic Factors Affecting Water Flow

For analyzing the current nature of water scarcity and crop yield losses due to climate change in the north of Afghanistan, the researchers employed an agricultural water management tool known as the Soil and Water Assessment Tool (SWAT). From 2013 to 2018, they performed monthly surface runoff simulations in the Balkhab River Basin (BRB). The different input data included in the SWAT modeling include elevation, slope, land cover, soil maps, and climate data including temperature, precipitation, relative humidity, wind speed, and solar radiation.

During the dry season (July to September), downstream water resources primarily relied on base flow from groundwater. To calibrate the model, the researchers estimated groundwater base flow by analyzing recorded discharges from 190 springs. This improved the SWAT results significantly, with R2 values of 0.70, 0.86, 0.67, and 0.80, Nash-Sutcliffe efficiency (NSE) values of 0.52, 0.83, 0.40, and 0.57, and percent bias (PBIAS) values of 23.4, -8.5, 23.4, and 17.5 across the different sub-basins. The validation phase also yielded satisfactory results. The findings of this study have practical implications for agricultural water resource management, particularly regarding irrigation practices, as well as for assessing the potential impacts of climate change on water resources in the BRB [4], [11].

Various factors such as, human-made contributions play a great role in altering the flow of water in Balkh River systems. Changes in the natural hydrological processes are due to human activities like; agriculture, and urban and industrial development in the region. In the expansion of agriculture, humans construct irrigation aqua ducts, pumping water from the river systems, thus affecting the availability and patterns of water flow [5]. The changes in the habitat have for the part of Afghanistan largely affected the aspect with more than a quarter of the country's total population living in urban areas [14].

It has therefore imposed considerable pressure on the availability of water resources for the growing populations of the urban settings. Some of the impacts of this increasing divide between water availability and demand coupled with the ramifications of climate

change include the up surging temperatures and decreasing water tables right across the land [3], [9]. At the current stage, the extraction of groundwater is much higher than the rate of their recharge which leads to the reduction of groundwater stocks, and it negatively impacts both urban and rural areas [2].

Moreover, water requirements for domestic and industrial purposes by the growing population and urban settlements, as well as the growth of industrial sectors have a negative impact on the river systems due to increased water demand. Land use changes and deforestation are also known to corrupt the conditions of watersheds implying an increment in the rate of surface runoff based on the loss of water retention capacity of the soil. However, poor water usage and control measures such as low-quality irrigation methods and the absence of facilities for proper water usage further water shortage problems and hampers the total flow in the Balkh River systems. Mitigation of these anthropogenic components is vital for the effective and sustainable utilization of water resources to provide the required water to a given sector without deteriorating the ecological flows and health of the river systems [6].

## 4. Trends and Patterns of Water Flow in River Basins

Through the analysis of the water flow trends and patterns of the Balkh River basins, this paper gives an understanding of the hydrological processes of the region. It is for this reason that data on water flow is collected over a certain period to determine this factor in historical form. This analysis is useful in establishing the differences in availed water, the effects of climate change, and in evaluating water management operations [4], [8]. As a result of an assessment of hydrological criteria including precipitation, river discharge, and groundwater levels, one can establish the presence of seasonal changes, inter-annual changes as well as changes in the hydrological cycle [3], [12].

Such information is useful when it comes to decision-making within the context of water distribution, water system development, and management of water resources. Knowledge of water flow rhythms and cycles in the NRB is important to effectively and fairly manage water resources, reduce the vulnerability of water deficits, and support sustainable water practices in the long term in the region [4].

## 5. Materials and Methods

To achieve the above objective, this study centered on the Afghanistan NRB with a primary interest in the water flow in the Balkh River. The basin is located in northern Afghanistan and contains some geographical and hydrological features. Hence, the Balkh River a major tributary in the basin was selected for the current study since it records high water flow importance to the water availability in the region.

The collection of data for this study included a collection of water flow records at different monitoring stations along the Balkh River. The data was collected from various sources such as MEW and other governmental bodies, research organizations, and hydrological databases. It was concerned with the flow rate of water and was usually recorded at set intervals the measurements were realized from the year 2006 to 2021.

The data collected before the quantitative analysis was preprocessed in several steps. This comprises data verification and cleaning whereby the data is checked and screened to

remove all invalid information. Outliers were eliminated or handled using proper statistics if there were any, missing values in the data that were either imputed or estimated to complete the dataset.

This means that data was sorted and analyzed in the temporal domain to identify long-term changes and trends in water flow in the Balkh River. Decomposition and seasonal adjustment of the data as well as the moving average technique were used to determine the seasonality, trends, and other temporal patterns. Trend analysis or change-point analysis was used to establish the existence of patterns or changes above the level of chance.

The findings were then analyzed qualitatively in a way that can be useful in dissecting insights that are relevant to the study's goals and objectives. Specifically, statistical measures and graphs, including charts were employed in the study to make the work clearer as well as easily understandable. Some of the study limitations include constraints in data, other sources of bias were also discussed. Pertaining to ethical issues the study was quite sensitive to the ethical standards of which were complied with.

Most of the data processing stages and techniques adopted were properly documented for purposes of replicability, as well as the statistical tools that were employed. For replication purposes, references and instructions were given.

### 5.1. Statistical Analysis

The quantitative examination of the water flow of the Balkh River was made employing a variety of statistics and statistical analysis methods. By using time series analysis the temporal variation and fluctuations of the water flow data were analyzed for the study period. Regression analysis or other techniques like Autoregressive Integrated Moving Average were employed to analyze symptomatic regression models and to identify possible causal factors within the variation of the water flow.

The data analysis was done using Tableau and Microsoft Excel since these applications provided the features needed for the manipulation, visualization, and statistical analysis of the data being collected. The statistical tools selected for this study were appropriate to the analysis techniques used in this study.

This research work collected both qualitative and quantitative information and stored it in a temporal base for investigating the long-term behavior of the water flow in the Balkh River. Descriptive techniques such as decomposition, seasonal adjustment, and moving averages were used to determine the features of seasonality, trends, and other time-related attributes. Interpretations of trends or changes over time in outbreaks of the infection, conducts of trend analysis and the testing of perspectives using change point analysis determined if the observed patterns were statistically significant.

Findings were analyzed in order to draw important information, which was relevant to the objectives of the study. The use of statistical measures and visual aids inclusive of graphs and charts were incorporated to increase reliability.

## 6. Rabat-i-Bala Station

The Rabat-i-Bala station, situated in the northern river basin of the Balkh River, is a pivotal hydrological monitoring site equipped with a Staff/Recorder gauge. This station

plays a crucial role in understanding the water dynamics of the region, providing invaluable data on the monthly mean water discharge, which is measured in cubic meters per second ($m^3$/sec). Operating over a water year span from 2005 to 2022, the station sits at an elevation of 434 meters above mean sea level, overseeing a drainage area of approximately 17,945 square kilometers.

The geographic coordinates of Rabat-i-Bala station are latitude 36.583611 and longitude 66.957858. Throughout its operation, it recorded the lowest water discharge of 8.06 $m^3$/sec on December 31, 2008, and witnessed a peak discharge of 1,190 $m^3$/sec on May 9, 2014. With an average water discharge of 52.1 $m^3$/sec, the station serves as a key reference point for hydrological studies and water resource management within the Balkh River basin.

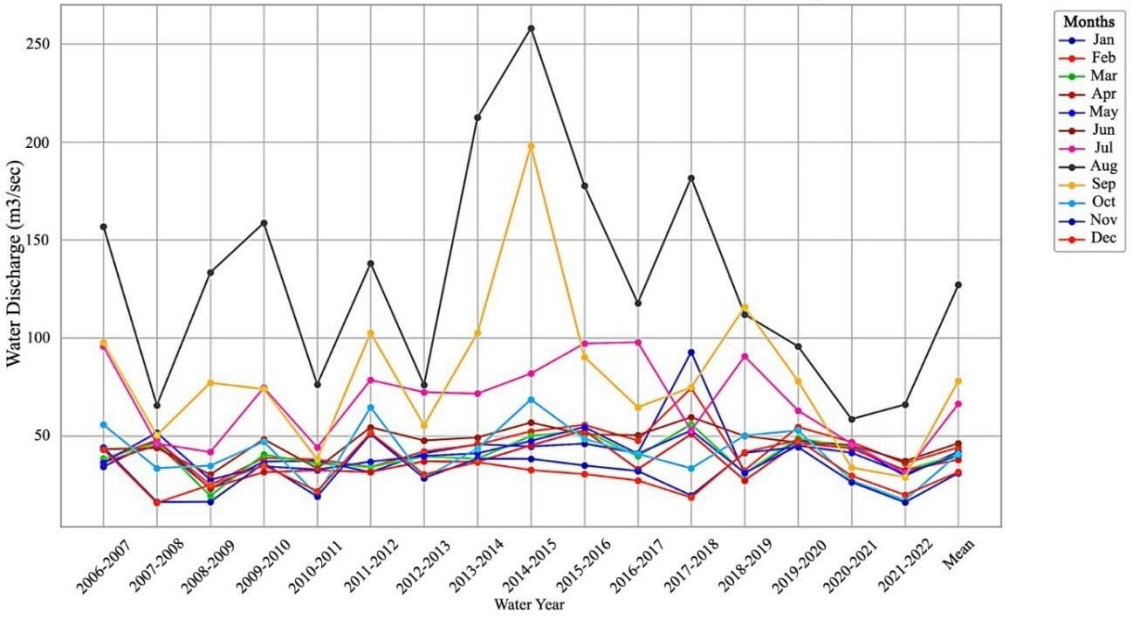



**Fig. 3.** Monthly Mean Water Discharge over Years ($m^3$/Sec)

As the figure above shows, the monthly mean water discharge in cubic meters per second over various water years at Rabat-i-Bala¬ station. Each line in the graphs corresponds to one month, illustrating the changes in water discharge during the year, and from year to year.

Key observations include:

**Seasonal Patterns:** This is not the case with there being no distinct high point that is normally associated with seasonal discharges where there is likely to be a particular period of the year with the highest discharges. This may well refer to the times when rains or snow is falling in a particular region or season.

**Year-to-Year Variability:** The discharge also differs from one year to another, which depicts the annual climatic changes that affect the flow of water.

**Peak Discharge Months:** Some months have always recorded high discharge levels in the different years, which are very significant in water resource planning and flood forecasting.

This paper aimed to establish a preliminary insight into the dynamics of water discharge at Rabat-i-Bala station and the interaction of yearly discharge variability with climatic seasonality for planning and managing water resources.

### 7. Pul-i-Baraq Station

The Pul-i-Baraq station, situated within the North Balkh River basin, operates under the identifier code provided in the dataset. This station utilizes both staff and recorder gages for water measurement, focusing on monthly mean water discharge recorded in cubic meters per second ($m^3$/sec). The geographical and operational specifics of the station include a catchment area of 14,092 square kilometers, with the gage located at an elevation of 647 meters above mean sea level. The geographic coordinates of Pul-i-Baraq station are latitude 36.218158 and longitude 66.904381.

The lowest recorded water discharge at this station was observed on April 12, 2014, at 14.5 $m^3$/sec, whereas the peak discharge was significantly higher, recorded at 404 $m^3$/sec on May 9, 2014. The dataset covers a comprehensive period from 2005 to 2020, offering valuable insights into water flow trends and variability in the region. This extensive temporal coverage allows for detailed analyses of hydrological patterns, contributing to water resource management and planning in the Balkh River basin.

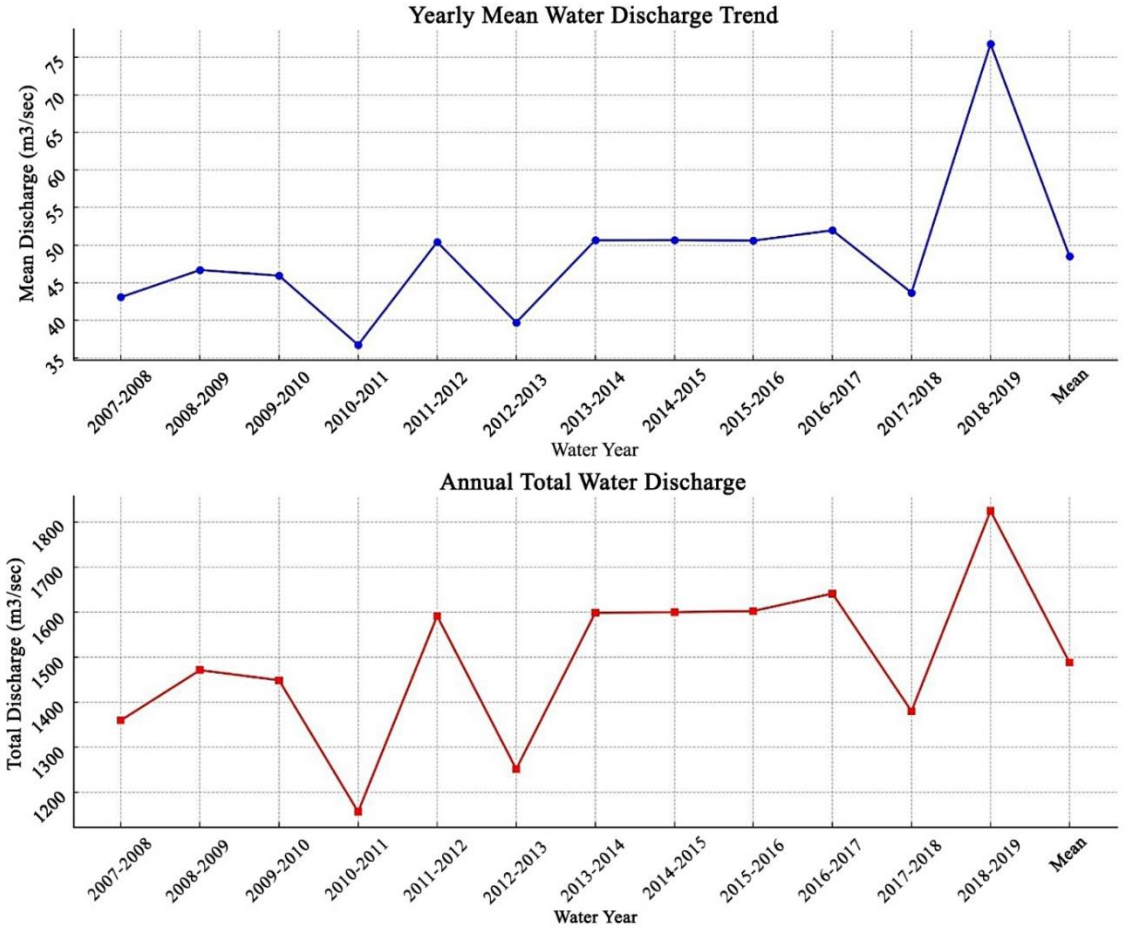



**Figure 4&5.** Yearly Mean Water Discharge Trend and Annual Total Water Discharge

## 8. Nazdik-i-Nayak Station

The "Nazdik-i-Nayak" station, positioned within the North Balkh River basin, operates to monitor water levels and flows, employing staff and recorder gages. Similar to the "Pul-i-Baraq" station, it records monthly mean water discharge in cubic meters per second ($m^3$/sec), reflecting the hydrological dynamics of the area it serves. Located at an elevation of 2613 meters above mean sea level, with a drainage area covering 1385 square kilometers, the station is integral to understanding water resource availability and variability in its region. The geographic coordinates of Nazdik-i-Nayak station are latitude 34.74330278 and longitude 66.99443611.

The dataset spans from 2009 to 2022, encapsulating a significant period for analyzing water trends. The lowest recorded water discharge at Nazdik-i-Nayak was 6.6 $m^3$/sec, and the peak discharge was considerably higher at 39.2 $m^3$/sec on May 15, 2017, highlighting the variability and potential extremities in water flow in the station records.

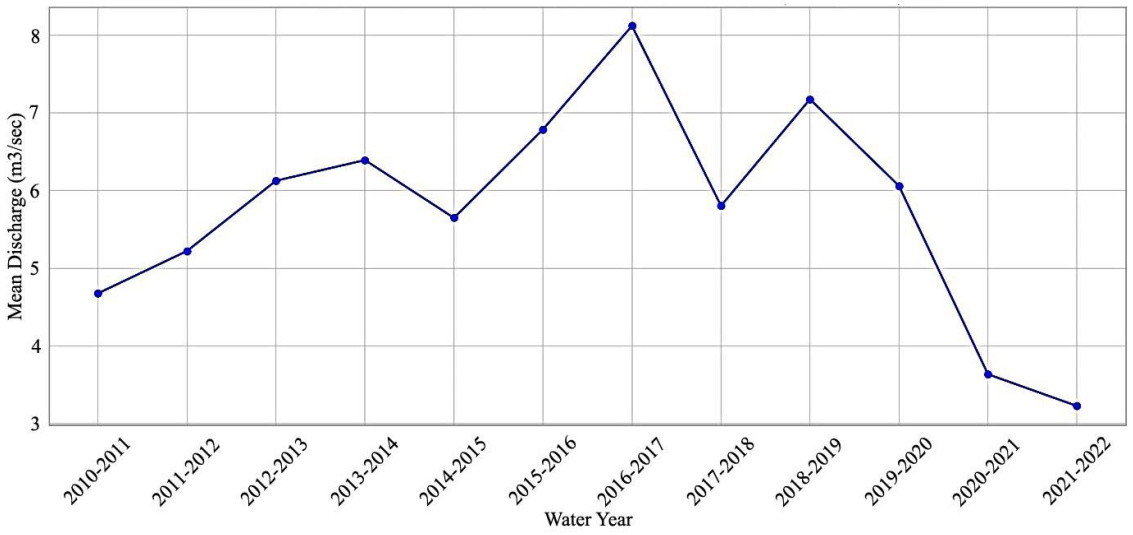



**Figure 6.** Yearly Water Discharge in the Balkh River (2009-2021)

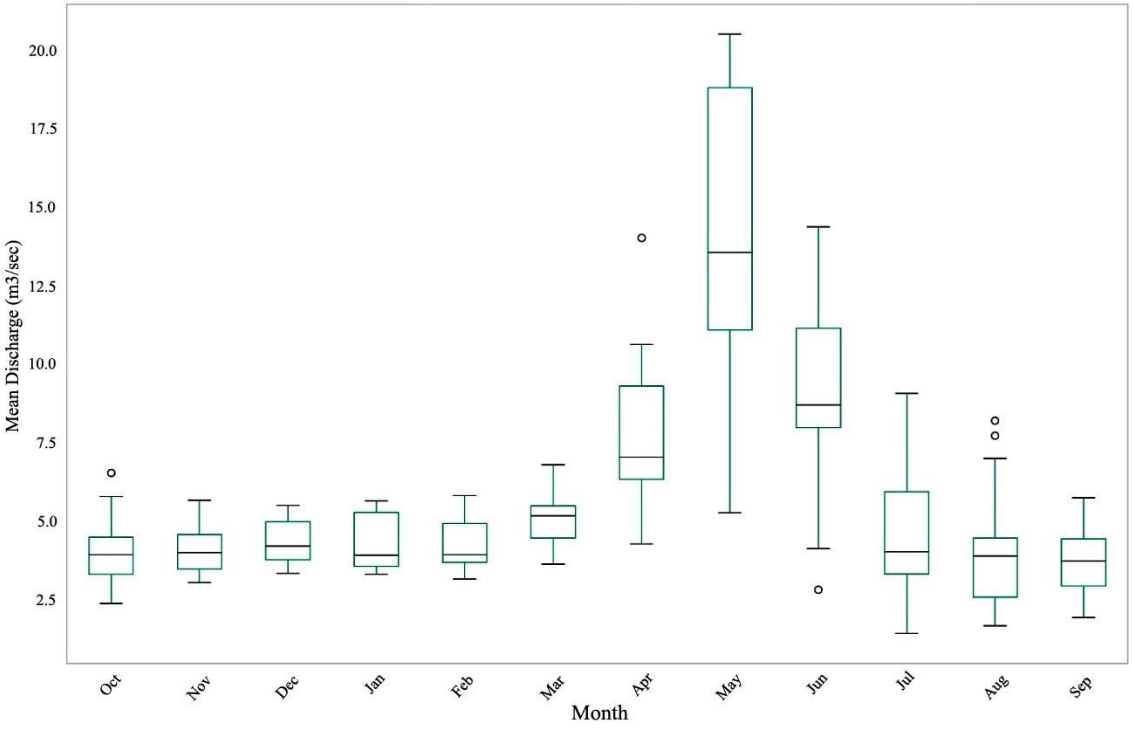



**Figure 7.** Box Plot of Monthly Mean Water Discharge in the Balkh River (2009-2021)

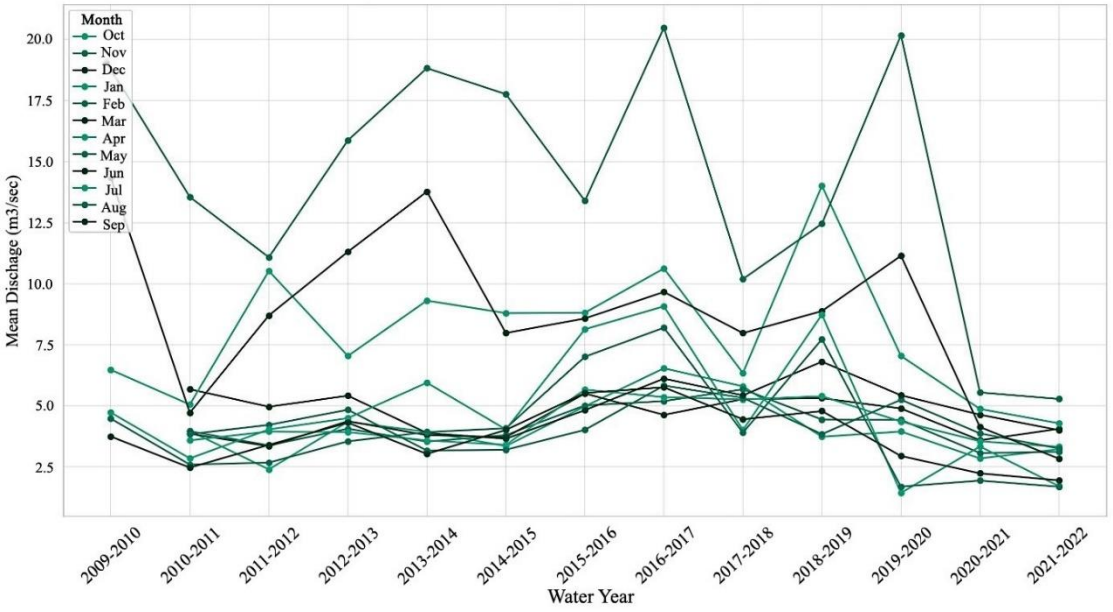



**Figure 8.** Monthly Mean Water Discharge in the Balkh River (2009-2021)

## 9. Discussion and Comparative Analysis

### 9.1. Operational Period and Data Coverage

Rabat-i-Bala has the longest operational record, providing a comprehensive data set from 2005 to 2022, allowing for in-depth analysis of long-term trends. Pul-i-Baraq provides data from the year 2005 to the year 2020, thus enabling the researcher to carry out a long research though with a short span of record as compared with Pul-i-Baraq. As short as it might be, from the year 2009 to 2022, there are useful pieces of information therein to help elucidate the current hydrologic trends of the area identified as Nazdik-i-Nayak.

### 9.2. Geographic and Hydrological Characteristics

**Elevation:** The annual availability at Nazdik-i-Nayak station is much higher than the other two stations and this might have an impact on the hydrological dynamics and precipitation regime felt at this site.

**Drainage Area:** Looking at the results, Rabat-i-Bala shows the highest discharge accumulated over the largest drainage area, which indicates that data collected from this station is characteristic of a wider range of the basin's hydrological response. However, Nazdik-i-Nayak has the smallest size of the studied areas, which may suggest that the researched hydrological conditions are more specific.

### 9.3. Water Discharge Data

Variability and Extremes: The highest peak discharge was noted to have occurred at Rabat-i-Bala thus making it clear that the station has the ¬ability to measure floods of high intensity. Pul-i-Baraq's highest discharge is much lower than Rabat-i-Bala showing that Pul-i-Baraq records a lesser level of extreme events in the hydrological cycle. As, for

the lowest peak discharge, the river seems to have a limited fluctuation of flow possibly as a result of high altitude and a small drainage basin of the Nazdik-i-Nayak.

### 9.4. Insights for Water Resource Management

This detailed analysis of water discharge across different stations indicates that hydrological data related to water should ideally be collected and analyzed, on a local basis to enable efficient management of water resources. Experience from Rabat-i-Bala is useful in determining the maximum discharge rates and floods within the basin due to discharge rates ranging broadly. At the same time, the hydrological processes at higher altitudes or in a small catchment can be described by using data obtained from Nazdik-i-Nayak.

### 9.5. Comparative Analysis of Hydrological Stations in the NRB

Thus, this cross-sectional study demonstrates the specific roles all the stations have in the recognition of the hydrological regimes of the North Balkh River basin. Due to Rabat-i-Bala's long operating history and its expansive drainage area, this system proves most useful for large-scale assessment. Pul-i-Baraq extends such knowledge further by contributing to the analysis of about (40%) forty percent area of the basin with a fairly long record length. Still, relative to larger dams, studies such as the Nazdik-i-Nayak reveal important features of the relative hydrology of higher terrain and that of smaller watersheds. Altogether, these stations constitute a complete system necessary for monitoring water resources in the area and contribute to the general knowledge of water processes, which is integral while managing and planning water resources.

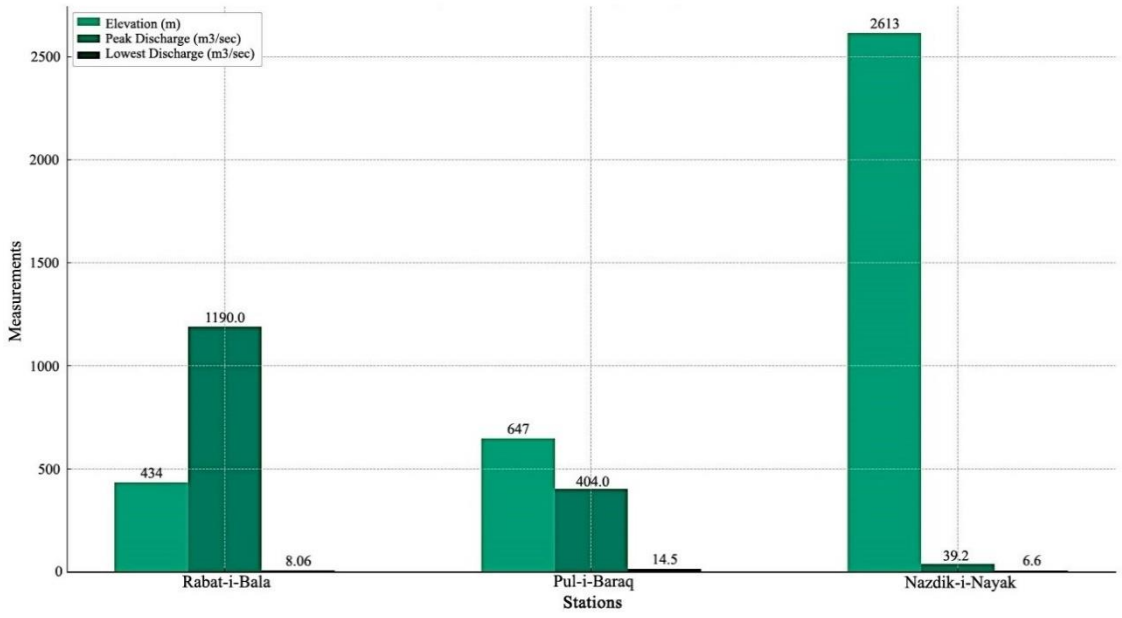



**Figure 9.** Comparative Statues of Hydrogeological Stations

The above graph gives a relative comparison of Rabat-i-Bala, Pul-i-Baraq, and Nazdik-i-Nayak through their elevation characteristics, peak discharge, and lowest discharge. This visualization enables us to compare these key attributes in reference to these stations hence making it easy to see differences in geographical and hydrological characteristics of the stations.

## 10. Results

Based on the information about the Rabat-i-Bala, Pul-i-Baraq, and Nazdik-i-Nayak hydrological stations in the NRB, the following key results can be summarized:

### 10.1. Operational Period and Data Coverage:

- Rabat-i-Bala has the longest operational period ranging from 2005 to 2022 and therefore, the record with the longest duration offers the best record of long-term performance.
- It has data from 2005 to 2020, which helps in understanding the trend over time.
- While some gaps can be observed, in particular, the Nazdik-i-Nayak series starts in 2009 and ends in 2022, however, it can be helpful for identifying the tendencies of the rather recent hydrological year only.

### 10.2. Geographic and Hydrological Characteristics:

- The elevation of Nazdik-i-Nayak is higher (2,613 m) than the other two stations (434 m, 647 m) and this difference can affect the hydrological processes and precipitation.
- Similar to the drainage area, it is evident that the Rabat-i-Bala station covers a larger area compared to the rest of the monitored stations with 17945 sq. km compared to Pul-i-Baraq's 14092 sq. km and Nazdik-i-Nayak's 1385 sq. km.

### 10.3. Water Discharge Data:

- Offering the potential to capture large flood events, Rabat-i-Bala has the maximum peak discharge of 1,190 $m^3$/sec.
- Even at its maximum of 404 $m^3$/sec, Pul-i-Baraq's flow rate, as important as it is, remains far below Rabat-i-Bala's.
- Nazdik-i-Nayak has ¬the lowest peak discharge of 39.2 $m^3$/sec, suggesting a more constrained range of flow variability, potentially due to its high elevation and smaller drainage area.

### 10.4. Insights for Water Resource Management:

- It is evident from the above analysis of values of Q that there are large variations in water discharge within the different stations and there are extreme values of Q at some of the stations This means that there is some need to undertake localized hydrological monitoring to manage the water resources.
- For overall and more specific insights into the maximum capacity and floods in the basin, Rabat-i-Bala's data is essential.

- The data available in Nazdik-i-Nayak offers an understanding of the hydrological processes occurring at higher altitudes and in the small catchment.

### 10.5. Comparative Analysis:

- The three stations make up a holistic network for assessing the water resources in the North Balkh River basin, where every station is valuable in providing information about the hydrology of the area.
- The comparative analysis suggests that the stations are complementary to each other, as the weaknesses of one station can be offset by the strengths of another, resulting in a better understanding of the water dynamics in the basin.

Last, the data obtained at the Rabat-i-Bala, Pul-i-Bara, and Nazdik-i-Nayak hydrological stations, as well as the comparison of the results obtained, can provide a twin view of the water resources and the discharge and hydrological features of the North Balkh River basin, which is essential for efficient water resources management and planning in the area.

## 11. Recommendations for Addressing Gaps and Problems at Hydrological Stations

To improve the reliability and stability of the hydrological monitoring at the Rabat-i-Bala, Pul-i-Baraq, and Nazdik-i-Nayak stations the following suggestions are made:

First of all, it is necessary to increase the accuracy and homogeneously of measuring instruments employed in these stations. Utilizing sophisticated telemetry and remote sensing means can help to obtain real-time data and increase the efficiency of data on the water discharge.

Besides, increasing the number of monitoring sites within the Balkh River basin, especially in the areas not covered well enough, will cover gaps in the spatial coverage and help better understand the hydrological situation in the area. It is vital to find out factors of variation and fluctuations in the water flow, and hence specify early warning systems needed for flood risk management especially at Rabat-i-Bala and Pul-i-Baraq since they constituted the highest peak discharges. The improvement of the data exchange and the fusion of different investigation centers will promote efforts in cooperation as well as in decision-making.

Last but not least, supporting the local hydrologists & station operators in terms of capacity building & training will guarantee the longevity of the monitoring & evaluation process, & the credible assessment of the hydrologic data collected. Implementing these recommendations will go a long way to enhance the management and planning of water resources in the North Balkh River basin enhancing the coping capacity of the area.

## 12. Conclusion

This research has investigated water pattern features of hydrological stations Rabat-i-Bala, Pul-i-Baraq, and Nazdik-i-Nayak in relation to the catchment North Balkh River basin and elucidated the importance of these regions. Every station owing to location characteristics and work capacities provides important information; crucial for water resource management and planning. The characteristics of peak ¬discharge in Rabat-i-Bala with large area and large frequency express the rational arrangement of flood management. Coming from Pul-i-Baraq, these results help us understand the temporal change in hydrological conditions and guide the planning of water distribution and water conservation strategies. The smaller one located at a higher altitude named Nazdik-i-Nayak offers exclusive information related to the hydrology of mountainous regions that is quite vital for evaluating the effects of climate change and water sustainability.

The author's pointer and comparative analysis also exposed the need to modernize technologies available with those operational at these stations, expand the coverage area, and make the exchange of data more efficient. The following recommendations will fill some of the gaps where risks already exist and enhance sustainable water management in the Balkh River basin; Besides, this study contributes to the advancement of hydrological monitoring practices within the ¬region and the development of further research on and policy related to the protection of water resources in the context of changing environments.

Available lessons as indicators of future resilience in the water sector include; a. Continuous monitoring of the water sector, b. Implementation of new technologies in water management and c. implementing regional cooperation nets. The collective efforts in improving the infrastructure and practices of hydrological monitoring will without doubt work towards the improvement of communities, ecosystems, and economy that depend on the Balkh River basin water resources.


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## Author’s Contributions

All the authors have had a common and active contribution in completing this paper, from the beginning to the end, they have worked together with each other in terms of cost and time spent on research and investigation.


## Funding and Conflicts of Interest

This research project was self-funded equally by the authors. We are pleased to report that there are no conflicts of interest to disclose.

**Abbreviations**

| | |
|---|---|
| ADB | Asian Development Bank |
| AFG | Afghanistan |
| BRB | Balkhab River Basin |
| IWRM | Integrated Water Resource Management |
| KBL | Kabul |
| KPU | Kabul Polytechnic University |
| MEW | Ministry of Energy and Water |
| NRB | North River Basin |
| NSE | Nash-Sutcliffe efficiency |
| SWAT | Soil and Water Assessment Tool |

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**APPENDIX I: Monthly Mean Water Discharge (m3/sec) of Rabat-i-Bala Station of Balkh River**

| | | | | | | |
|---|---|---|---|---|---|---|
| **River basin:** | **North** | **Code:** | **12-0.000** | **Water year:** | **2005-2022** | |
| **River:** | **Balkh** | **Code:** | **12-0.000** | **Elevation:** | **434 m+m.s.l** | |
| **Station:** | **Rabat-i-Bala** | **Code:** | **12-0.000- 1M** | **Drainage arae:** | **17945 Km$^2$** | |
| **Gage:** | **Staff/Recorder** | **Latitude:** | **36.58361111** | **Longitude:** | **66.95785833** | |
| **Lowest on Record:** | **8.06 m3/sec Dec.31.2008** | **Mean:** | **52.1 m3/sec** | **Peak on Record:** | **1190 m3/sec May.9.2014** | |

| Year | Monthly Mean Water Discharge ( m$^3$/sec) | | | | | | | | | | | | Yearly summary | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Min | Max | Mean | Runoff(Mm$^3$) |
| **2005-2006** | 38.3 | 39.8 | 38.9 | 37.6 | 38.3 | 39.1 | 43.6 | 75.4 | 45.2 | 27.9 | 25.1 | 28.9 | **23.1** | **93** | **39.8** | **1256.82** |
| **2006-2007** | 34.2 | 38.3 | 38.4 | 36.4 | 36.3 | 43.2 | 95.5 | 157 | 97.6 | 55.7 | 44.1 | 43.1 | **31.5** | **253** | **60.0** | **1894** |
| **2007-2008** | 47.6 | 47.6 | 46.3 | 45.2 | 51.6 | 43.8 | 46.1 | 65.7 | 50.3 | 33.5 | 16.2 | 15.8 | **12.7** | **161** | **42.5** | **1342** |
| **2008-2009** | 23.0 | 25.0 | 19.4 | 23.3 | 27.5 | 30.2 | 41.7 | 133 | 77.1 | 34.8 | 16.3 | 25.0 | **8.1** | **897** | **39.7** | **1255** |
| **2009-2010** | 36.9 | 38.7 | 40.4 | 31.5 | 34.5 | 48.3 | 74.5 | 159 | 73.8 | 47.0 | 36.0 | 34.8 | **28.3** | **445** | **54.6** | **1726** |
| **2010-2011** | 37.2 | 38.0 | 35.8 | 32.4 | 32.7 | 33.4 | 44.1 | 76.3 | 38.1 | 19.8 | 19.1 | 21.8 | **17.2** | **155** | **35.7** | **1127** |
| **2011-2012** | 31.5 | 34.0 | 34.1 | 31.6 | 36.8 | 54.4 | 78.5 | 138 | 102 | 64.5 | 50.9 | 51.5 | **26.8** | **382** | **59.0** | **1868** |
| **2012-2013** | 41.1 | 42.1 | 39.4 | 37.0 | 39.7 | 47.6 | 72.2 | 76.1 | 55.3 | 28.5 | 28.5 | 30.3 | **24.0** | **182** | **44.8** | **1412** |
| **2013-2014** | 45.7 | 45.5 | 38.3 | 36.7 | 41.1 | 49.2 | 71.5 | 212 | 102 | 43.5 | 38.4 | 36.5 | **31.0** | **1190** | **63.4** | **2006** |
| **2014-2015** | 44.6 | 52.3 | 49.9 | 45.2 | 47.4 | 56.8 | 81.8 | 258 | 198 | 68.6 | 38.3 | 32.5 | **24.5** | **710** | **81.1** | **2563** |
| **2015-2016** | 46.0 | 55.6 | 52.5 | 52.8 | 54.5 | 50.7 | 97.1 | 178 | 90.3 | 48.5 | 34.9 | 30.4 | **27.2** | **455** | **65.9** | **2086** |
| **2016-2017** | 41.1 | 47.6 | 39.7 | 33.0 | 40.8 | 50.3 | 97.8 | 118 | 64.6 | 40.8 | 32.1 | 27.2 | **23.6** | **220** | **52.7** | **1667** |
| **2017-2018** | 92.8 | 74.3 | 55.9 | 50.9 | 52.7 | 59.5 | 52.8 | 182 | 74.7 | 33.4 | 19.6 | 18.5 | **16.0** | **1622** | **63.9** | **2021** |
| **2018-2019** | 30.7 | 32.4 | 30.8 | 27.2 | 31.1 | 49.9 | 90.5 | 112 | 116 | 50.1 | 41.3 | 41.6 | **23.8** | **478** | **54.5** | **1721** |
| **2019-2020** | 47.7 | 54.5 | 48.8 | 46.4 | 45.0 | 46.5 | 62.9 | 95.6 | 77.9 | 52.7 | 44.2 | 47.8 | **36.0** | **146** | **55.8** | **1766** |
| **2020-2021** | 45.1 | 46.8 | 44.0 | 43.6 | 41.4 | 45.4 | 46.0 | 58.5 | 33.8 | 27.2 | 26.4 | 29.6 | **24.6** | **128** | **40.6** | **1282** |
| **2021-2022** | 29.6 | 36.0 | 32.5 | 32.4 | 30.7 | 37.1 | 30.9 | 66.0 | 28.9 | 17.2 | 16.1 | 19.8 | **14.3** | **539** | **31.4** | **992** |
| **Mean** | **41.9** | **44.0** | **40.3** | **37.8** | **40.1** | **46.2** | **66.3** | **127** | **78.0** | **40.8** | **31.0** | **31.5** | **23.1** | **474** | **52.1** | **1646** |

**APPENDIX II: Monthly Mean Water Discharge (m3/sec) of Pul-i-Baraq Station of Balkh River**

| | | | | | |
|---|---|---|---|---|---|
| **River basin:** | **North** | **Code:** | **12-0.000** | **Water year:** | **2005-2020** |
| **River:** | **Balkh** | **Code:** | **12-0.000** | **Elevation:** | **647 m+m.s.l** |
| **Station:** | **Pul-i-Baraq** | **Code:** | **12-0.000-2M** | **Drainage arae:** | **14092 Km2** |
| **Gage:** | **Staff/Recorder** | **Latitude:** | **36.21815833** | **Longitude:** | **66.90438056** |
| **Lowest on Record:** | **14.5 $m^3$/sec Apr.12.2014** | **Mean:** | **45.1m3/sec** | **Peak on Record:** | **404 m3/sec May.9.2014** |

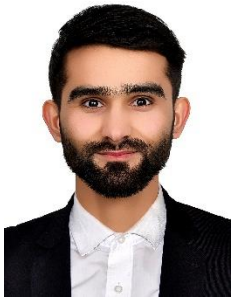
| Year | Monthly Mean Water Discharge ($m^3$/sec) | | | | | | | | | | | | Yearly summary | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Min | Max | Mean | Runoff($Mm^3$) |
| **2005-2006** | 38.5 | 40.9 | 41.3 | 40.2 | 40.8 | 40.6 | 50.6 | 80.4 | 46.0 | 35.2 | 27.9 | 25.3 | **22.4** | **95.3** | **42.3** | **1333** |
| **2006-2007** | 31.6 | 33.1 | 32.0 | 29.6 | 29.7 | 40.0 | 78.2 | 95.7 | 78.3 | 61.5 | 50.6 | 39.3 | **27.2** | **158** | **50.0** | **1574** |
| **2007-2008** | 42.2 | 47.3 | 48.1 | 42.4 | 44.5 | 43.4 | 49.4 | 65.3 | 44.2 | 30.0 | 28.6 | 31.5 | **25.0** | **84** | **43.1** | **1360** |
| **2008-2009** | 32.6 | 37.7 | 35.6 | 34.1 | 38.8 | 43.0 | 64.1 | 99.2 | 70.6 | 48.5 | 29.7 | 26.5 | **26.3** | **257** | **46.7** | **1471** |
| **2009-2010** | 28.1 | 31.1 | 33.8 | 29.1 | 30.7 | 38.3 | 69.3 | 112.7 | 64.8 | 44.9 | 35.9 | 32.8 | **26.3** | **359** | **45.9** | **1449** |
| **2010-2011** | 32.9 | 37.5 | 37.0 | 33.6 | 32.0 | 31.5 | 42.1 | 65.0 | 46.8 | 28.8 | 26.3 | 27.4 | **25.4** | **172** | **36.7** | **1157** |
| **2011-2012** | 31.3 | 44.9 | 42.3 | 39.6 | 39.4 | 56.2 | 78.0 | 92.3 | 77.6 | 43.8 | 29.9 | 29.8 | **26.3** | **297** | **50.4** | **1591** |
| **2012-2013** | 39.4 | 40.4 | 34.6 | 31.3 | 31.1 | 31.2 | 43.7 | 80.8 | 60.3 | 31.5 | 24.7 | 27.5 | **21.1** | **140** | **39.7** | **1251** |
| **2013-2014** | 32.1 | 34.1 | 31.2 | 29.7 | 30.4 | 31.8 | 54.5 | 144 | 95.4 | 53.5 | 36.4 | 34.5 | **14.5** | **404** | **50.7** | **1598** |
| **2014-2015** | 34.6 | 43.0 | 37.9 | 37.8 | 36.7 | 36.8 | 69.9 | 117.6 | 82.7 | 45.9 | 33.6 | 31.7 | **26.5** | **260** | **50.7** | **1600** |
| **2015-2016** | 34.4 | 41.5 | 36.1 | 37.1 | 33.8 | 36.5 | 61.2 | 147.8 | 75.4 | 37.5 | 31.6 | 34.5 | **26.5** | **229** | **50.6** | **1602** |
| **2016-2017** | 32.4 | 35.7 | 35.0 | 31.3 | 36.2 | 40.5 | 79.1 | 130.4 | 81.0 | 47.9 | 38.7 | 35.5 | **24.1** | **222** | **52.0** | **1641** |
| **2017-2018** | 32.6 | 40.2 | 42.1 | 36.0 | 33.9 | 36.7 | 41.4 | 83.8 | 59.1 | 37.4 | 41.8 | 39.3 | **26.6** | **301** | **43.7** | **1380** |
| **2018-2019** | 36.3 | 40.1 | 39.6 | 40.2 | 42.8 | 42.6 | 88 | 121 | 93.2 | 56.7 | 44.4 | 48.5 | **31.8** | **167** | **76.8** | **1825** |
| **Mean** | **34.2** | **39.1** | **37.6** | **35.1** | **35.8** | **39.2** | **62.1** | **102.6** | **69.7** | **43.1** | **34.3** | **33.1** | **14.5** | **404** | **48.5** | **1488** |

**APPENDIX III: Monthly Mean Water Discharge (m3/sec) of Nazdik-i-Nayak Station of Balkh River**

| | | | | | | |
|---|---|---|---|---|---|---|
| **River basin:** | **North** | **Code:** | **12-0.000** | **Water year:** | **2009-2022** | |
| **River:** | **Balkh** | **Code:** | **12-0.000** | **Elevation:** | **2613 m+m.s.l** | |
| **Station:** | **Nazdik-i-Nayak** | **Code:** | **12-0.000-9m** | **Drainage arae:** | **1385 Km$^2$** | |
| **Gage:** | **Staff/Recorder** | **Latitude:** | **34.74330278** | **Longitude:** | **66.99443611** | |
| **Lowest on Record:** | **0.64 m$^3$/sec Aug.5.2020** | **Mean:** | **6.6 m$^3$/sec** | **Peak on Record:** | **39.2 m3/sec May.15.2017** | |

| Year | Monthly Mean Water Discharge ( m$^3$/sec) | | | | | | | | | | | | Yearly summary | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Min | Max | Mean | Runoff(Mm$^3$) |
| **2009-2010** | | | | | | | 6.47 | 18.8 | 14.37 | 4.72 | 4.48 | 3.74 | | | | |
| **2010-2011** | 3.97 | 3.96 | 3.85 | 3.59 | 3.84 | 5.68 | 5.05 | 13.6 | 4.72 | 2.85 | 2.59 | 2.47 | **2.16** | **22.7** | **4.68** | **148** |
| **2011-2012** | 2.40 | 3.38 | 3.34 | 3.95 | 4.22 | 4.96 | 10.5 | 11.1 | 8.70 | 4.03 | 2.67 | 3.40 | **2.16** | **13.7** | **5.22** | **165** |
| **2012-2013** | 4.34 | 4.06 | 4.37 | 3.92 | 4.84 | 5.41 | 7.04 | 15.9 | 11.3 | 4.49 | 3.55 | 4.31 | **2.80** | **24.5** | **6.13** | **193** |
| **2013-2014** | 3.93 | 3.53 | 3.80 | 3.58 | 3.17 | 3.89 | 9.31 | 18.8 | 13.8 | 5.95 | 3.93 | 3.03 | **2.64** | **21.4** | **6.39** | **202** |
| **2014-2015** | 3.35 | 3.80 | 3.71 | 3.40 | 3.20 | 3.65 | 8.80 | 17.8 | 7.98 | 4.03 | 4.08 | 4.01 | **2.70** | **22.2** | **5.65** | **179** |
| **2015-2016** | 4.98 | 5.02 | 5.50 | 5.67 | 4.02 | 4.82 | 8.82 | 13.4 | 8.58 | 8.14 | 7.01 | 5.53 | **3.27** | **19.2** | **6.79** | **215** |
| **2016-2017** | 6.54 | 5.19 | 4.63 | 5.36 | 5.83 | 6.12 | 10.6 | 20.5 | 9.66 | 9.07 | 8.20 | 5.76 | **4.28** | **39.2** | **8.12** | **257** |
| **2017-2018** | 5.80 | 5.68 | 5.27 | 5.26 | 5.33 | 5.43 | 6.34 | 10.2 | 7.98 | 4.01 | 3.90 | 4.45 | **3.54** | **38.2** | **5.80** | **183** |
| **2018-2019** | 3.73 | 4.44 | 5.31 | 5.39 | 3.84 | 6.81 | 14.0 | 12.5 | 8.88 | 8.74 | 7.73 | 4.8 | **2.82** | **28.0** | **7.18** | **227** |
| **2019-2020** | 3.95 | 4.43 | 4.89 | 4.36 | 5.25 | 5.43 | 7.04 | 20.2 | 11.15 | 1.43 | 1.69 | 2.9 | **0.64** | **30.9** | **6.06** | **191** |
| **2020-2021** | 2.84 | 3.06 | 3.59 | 3.55 | 3.87 | 4.64 | 4.87 | 5.55 | 4.13 | 3.33 | 1.94 | 2.2 | **1.65** | **7.65** | **3.63** | **115** |
| **2021-2022** | 3.22 | 3.12 | 4.06 | 3.32 | 3.25 | 4.00 | 4.28 | 5.28 | 2.83 | 1.71 | 1.68 | 1.94 | **1.68** | **6.6** | **3.23** | **102** |
| **Mean** | **4.09** | **4.14** | **4.36** | **4.28** | **4.22** | **5.07** | **7.94** | **14.11** | **8.77** | **4.81** | **4.11** | **3.74** | **2.53** | **22.9** | **5.74** | **181** |

## Authors Profile



**Noorulhaq Qaitmas** received his B.Sc. degree in Civil Engineering from Faryab University in 2019 and his M.Sc. degree in Construction Engineering Management from Kabul Polytechnic University, Kabul, Afghanistan in 2023. Started work with the Ministry of Energy and Water in 2021 for two years, and now he is working at Kabul Polytechnic University as an Expert in Water Laboratory, he has also worked for two years as the honorary deputy of the Social Welfare Organization for Women and Children (SWOWC) in the implementation of development and humanitarian projects. His research interests are Construction Management, Sustainability, and Water Resources.



**Mohammad Hamid Omar** received his B.Sc. and M.Sc. degrees in Hydraulics and Hydro-Technical Structures from Kabul Polytechnic University in 2009 and 2019, respectively. He began his professional career with various national companies and NGOs in Afghanistan. He has been serving as an Assistant Professor in the Hydraulic Structures Engineering Department of the Water and Environmental Engineering Faculty at Kabul Polytechnic University since the beginning of 2022. Additionally, he holds the position of Dean of the Faculty of Water and Environmental Engineering. His research focuses on floods, drought, climate change, hydraulic structures, and water resources.



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**Ahmad Jawad Niazi** received his Bachelor's degree in Architecture in 2010, a Master's degree in Industrial and Civil Construction in 2013, a Master's degree in Urban and Regional Planning, and his Doctorate in architecture and Housing Science. He is currently a professor in the Department of Architecture and Urban Planning at Kabul Polytechnic University. His research areas include urban planning, urban management and planning, sustainable architecture, and Islamic architecture.