SURFACE WATER RESOURCES OF AFGHANISTAN’S NORTHERN RIVER BASIN AND EFFECTS OF CLIMATE CHANGE

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Climate change, which directly impacts human and animal life, is one of the current critical issues worldwide. In Afghanistan, climate change has begun to impact its already limited water resources. This study was conducted using data gathered from the Investigation and Development of Water Resources sector in Afghanistan, which focus on the contributions of the water sector in alleviating poverty as the country strives for the return of peace and stability. A survey of the current state of surface water resources in the Northern River basin of Afghanistan shows that discharge from this basin is 12% higher than in the late 20th century, even though annual precipitation has decreased. The increase in surface temperatures causes an increase in snowmelt volume, and the main source of inputs in this basin has shifted to snowmelt due to climate change.

Key Words : Afghanistan, climate change, rivers, permanent snow, water resources

1. INTRODUCTION

Climate change, population growth, and water resources significantly impact food security and agriculture, and people and land in developing countries are much more at risk of damage from natural hazards. Most streams and rivers in Afghanistan originate from mountains that are covered by semi-permanent and permanent snow and glaciers. In this study, hydrological data recorded over a 60-year period in Afghanistan, with a focus on the Northern River Basin, were used to understand the effect of climate change in the region. This river basin is an important region for the agriculture sector, and it is vulnerable to damage due to natural disasters, particularly flooding. Increasing temperature due to climate change has increased the rate of melting snow and glaciers and has caused flash flooding in the basin¹.

The Himalaya mountain range is bordered on the northwest by the Karakoram and the Hindu Kush mountains of Afghanistan, and this region is mostly covered with permanent snow and glaciers. Investigations showed that future hydrological regimes and glacier cover in the Everest region in terms of stream flow and ice volume in the catchment will largely decrease by 30% and 50%, respectively, by 2100²,³. Climate change is one key phenomenon that has earned high consideration of researchers in the 21st century, and different models have been developed to analyze and represent future climate conditions. Among these, the HadRM3P Regional Climate Model (RCM) has been used to generate future climate conditions over south Asia, and the results show an increase in temperature, monsoon strength, and rainfall, as well as an increased risk of widespread flooding during the monsoon season⁴.
 Flooding is the most common natural hazard in Afghanistan, and annual average damage caused by flooding is around $54 million with the total number of people affected by flooding each year reaching around 100,000. Due to climate change, the number of people affected by flooding in Afghanistan is going to continually increase. Flooding in 2014, which was the most significant in the past 100-year period, occurred in northern Afghanistan and affected 90,000 people, causing more than $100 million in damage. Flooding in Afghanistan is mostly the result of heavy rainfall, snowmelt water, or a combination of the two. Rainfall-induced floods are common from March to May, and floods due to snowmelt are more common during June and July. The interaction of the natural hazards, including earthquakes and flooding, low levels of socioeconomic development, and decades of conflict, contributes to the high disaster risk level in Afghanistan. For example, it is estimated that floods in Afghanistan have increased significantly due to deforestation and vegetation loss, which decrease the water-holding capacity of the land.

Climate change is a major factor contributing to the scarcity of water resources in Afghanistan, and development efforts struggle to keep pace with the challenges. As mountains are the major sources of water, widespread mass loss from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water supplies and hydropower potential, as well as changing the seasonality of flows in basins supplied by meltwater from snow and ice. Furthermore, with more rapid and earlier spring snowmelt, the risk of flash flooding is higher.

This study aims to use Arc-GIS and recorded hydrological data from the Northern River Basin of Afghanistan over a 60-year period to identify and explain the main reasons for increased loading in rivers that have sources in glaciers or permanent/semi-permanent snow cover, which are impacted by global warming.

2. AREA OF STUDY

(1) Afghanistan climate

Although Afghanistan is located in subtropical latitudes, the topography and elevation produce very different climates. Areas to the north of the high mountains are dry or have a continental climate, while areas to the south of the high mountains have a less continental climate. The overall average temperature is 32°C in July and -2°C in January, with extreme maximum of 50°C and the minimum of -50°C on record. Based on hydrological and morphological classification, the country is divided into five major river basins, as shown in Fig. 1: Amu River Basin, Kabul River Basin, Hilmand River Basin, Harirud-Murghab River Basin, and Northern River Basin.

(2) Precipitation in Afghanistan

The average annual rainfall in Afghanistan is 270 mm and it ranges from 1270 mm in the high mountains in the northeast, to 75 mm in the southwest. More than 80% of the precipitation falls as snow. The accumulated snow melts by March, and runoff reaches its peak in May and continues until July, as estimated by the Ministry of Energy and Water of Afghanistan. Annual evapotranspiration in Afghanistan has a wide range from 900 mm to 1200 mm in the Hindu Kush mountains due to low temperatures, to up to 1800 mm in the southern and southwestern regions. The total annual precipitation in Afghanistan is 164 billion cubic meters (bcm) and annual evapotranspiration is 87 bcm, but the total annual available water resources is around 75 bcm. The remainder of 2 bcm could become accumulated permanent snow and glaciers since more precipitation occurs in the mountains with elevations above 4500 m; however, the recorded data are not 100% precise to estimate the balance of the precipitation, evaporation, and remaining surface and ground water resources.

(3) Irrigation in Afghanistan

More than 80% of the country’s water resources originate from the Hindu Kush mountains, where the accumulated snow on the high mountains melts in the summer and forms the mechanism for long-term storage of water resources in Afghanistan. The estimated overall annual potential water resource is 75 bcm, of which 57 bcm is surface water and 18 bcm is ground water. Table 1 shows the estimated current and future surface water and ground water volumes. The meaning of future use in this context according to the Afghanistan Ministry of Energy and Water is for the government to plan building dams along the main rivers; in this case it will be possible to secure the use of more water in the future. Future use is dependent
Table 1 Estimated surface and ground water resources (bcm/year).

| Type of water resource | Potential (bcm) | Present Situation (bcm) | Potential Situation (bcm) |
|------------------------|----------------|------------------------|--------------------------|
|                        |                | Used | Un-used | Used | Un-used |
| Surface Water          | 57             | 17   | 40      | 30   | 27       |
| Ground Water           | 18             | 3    | 15      | 5    | 13       |
| Total                  | 75             | 20   | 55      | 35   | 40       |

*bcm= billion cubic meters

Table 2 Fatalities and damage from flash floods on the Northern River basin of Afghanistan, May 2014.

| Minor river basin | Human fatalities | Domestic animals | Damaged houses | Agricultural land (hectares) |
|-------------------|------------------|------------------|----------------|-----------------------------|
| Balkh             | 9                | 3187             | 1097           | 917                         |
| Sare Pul          | 32               | 2175             | 4431           | 5064                        |
| Shirinta-gab      | 43               | 14872            | 2926           | 9984                        |
| Khulm             | 0                | 500              | 1700           | 4400                        |

(4) Northern River Basin Profile

With respect to the other basins in Afghanistan, the Northern River Basin has lower annual flows, and thereby a lower capacity for water resources. However, due to the high population density that heavily depends on agriculture, this basin represents a significant area for investigation. It is a necessary area for study in order to understand the patterns in water resources in Afghanistan, as well as to propose plans for the improved management of these water resources. The basin originates from the Hindu Kush and Baba mountains, which are covered by permanent snow and glaciers.

On the left bank of the Amu River, most parts of the plains are semi-arid with desert-like conditions, and humidity is low throughout the year. All of the houses in the rural area are constructed in an unplanned area, and most in the floodplain are at risk of flood damage as well as other natural hazards. The fundamental materials for house construction are clay soil with raw brick and mostly slab made of wood sticks; these types of structures cannot withstand severe flooding events. Table 2 shows the fatalities and damage from a flash flood due to heavy rainfall that occurred in the Northern River basin of Afghanistan in April 2014.

The Northern River basin has a total area of almost 71,000 km² and is located in the northern part of Afghanistan covering five provinces: Balkh Province, Sare Pul Province, Faryab Province, Jawzjan Province, and Samangan Province. Geographically, the elevation ranges from 250 m to 4454 m, as shown in Fig. 3. This basin receives a mean annual rainfall of two-thirds is actually cultivated during very good rainfall years as shown in Fig. 2b. Most of the irrigation systems are constructed in the traditional style, which has low efficiency, meaning that it is not currently possible to irrigate the land to maximize its use. Due to the lack of water resource management, much of the irrigation infrastructure has been seriously damaged by flooding, erosion, and the ongoing civil war in the country. The insufficient number of specialists in the field of water resource management also contributes to the problem.
nearly 270 mm\(^8\). The major rivers in this basin are perennial and flow from central Afghanistan to the north, irrigating all the agricultural land of the northern provinces. The rain-fed cultivation area (depending only on rainfall) in the Northern River basin is around 5300 km\(^2\) and the irrigated area in this basin is almost 6426 km\(^2\), as shown in Fig. 4.

Water resources in the Northern River basin are distributed among the major rivers: Sare Pul River, Shirintagab River, Khulm River, and Balkh River, as shown in Table 3.

The Northern basin is composed of watersheds of short perimeters that have their sources in the high mountains of the central highlands. All of the water in the basin is used within the national boundaries and the rivers dry up in irrigation canals or desert sands long before reaching the Afghan border and the Amu Darya River. It should be noted that in the event of exceptional floods, the Balkh River may at times drain water into the Turkmenistan lowlands just on the other side of the border.

Historically, in the northern Turkistan plain, the river deltas were close to the

### Table 3 Discharge of rivers of the Northern Basin.

| River name       | Discharge (m\(^3\)/sec) | Drainage area (km\(^2\)) | Main uses                                                                 |
|------------------|--------------------------|---------------------------|---------------------------------------------------------------------------|
| Sare Pul River   | 6.9                      | 7,800                     | Irrigation, merges with Shorab River as it flows into Sheberghan Province |
| Shirintagab River| 2.7                      | 13,600                    | Irrigation and farming                                                     |
| Khulm River      | 3.2                      | 8,400                     | Irrigation and drinking                                                   |
| Balkh River      | 54                       | 18,700                    | Flows to the 18 canals irrigate the agricultural land                      |

![Fig. 3 Elevation map of the Northern River basin of Afghanistan.](image)

![Fig. 4 Cultivated land and irrigated land in the northern river basin of Afghanistan.](image)

Amu Darya, but with the development of traditional irrigation schemes centuries ago, these rivers no longer contribute to this river, drying up in canals 50 km –100 km short.

The Northern basin has the smallest annual flow contribution in Afghanistan. The total endowment of water in the basin is only about 21 billion cubic meters. All the four sub-basins in this river basin are independent of each other and the rivers dry up before they reach the national border.\(^{160}\)

### 3. METHODOLOGY

#### (1) Hydrological data collection

A flow gauge (Staff Gauge) was installed at Hilmand River, and hydrological data collection and analysis dates to 1946. Collection and analysis of the data was organized by USGS specialists, and the number of gauges gradually increased to 133 at different rivers across the five major river basins of Afghanistan. By the year 1980, however, gauges were destroyed in the ongoing civil war. The 20-year dataset collected from 1960 through 1980 is available from the Afghanistan Ministry of Energy and Water.\(^8\)

Three types of floating gauges were installed throughout the basins: Ott-type (German), which is capable of recording monthly data readings, a Russian gauge with adjustable reading intervals from 1 to 5 months, and a Steven A gauge (American) with readings at intervals from 1.5 to 2.5 months.

After a long gap in data collection, three gauges were installed in 2004 at three different locations in Kabul, and gradually the number of gauges increased to 174 over the five river basins by 2007; 105 of these gauges are digital and have automatic recording. Collection of data is recorded and distributed by specialists within the Afghanistan Ministry of Energy and Water.\(^8\)
It is noted that the Northern basin region of Afghanistan has limited resources for data collection and many sub-basin regions and rivers have only begun rebuilding collection capabilities within the last few years after the civil war.

(2) GIS data

Shuttle Radar Topography Mission (SRTM) digital elevation data were downloaded from the USGS website and the aggregated land cover metadata was obtained in shapefile format, published by FAO, December 2012. These were used to create the elevation figures and maps, as well as a basis to create predictions for potential flood risk areas surrounding the rivers in the basin.

(3) Methodology

To analyze the data sets collected over time, the Mann-Kendall test was used to determine if a consistently increasing or decreasing trend exists. It is possible to use the Mann-Kendall test with the following assumptions: the data are not dependent on season (or if in this case, the seasonal Mann-Kendall test can be applied), there are true conditions at sampling times, and there are unbiased observations of collection over time. The test does not require that the data be normally distributed or linear. The slope of the trend can also be determined with Sen’s slope, which can also handle seasonality in the data.

In this study, the discharge data are given as an annual mean value, so the standard Mann-Kendall test is performed using statistical technique packages in R, an open-source software environment for statistical computing supported by the R Foundation for Statistical Computing. After determining if a trend exists, the Sen’s slope is then calculated in R and plotted alongside the data.

In order to determine the reasons for the change in river discharge, the major sources for the rivers were examined: the amount of precipitation and the change in permanent glaciers that feed the rivers. The amount of annual precipitation is collected by scientists at the Ministry of Energy and Water. The changes in permanent glaciers in the region are determined through observations and local narratives.

4. RESULTS

The rate of change in surface water resources in the Northern River basin was examined. The annual discharge of the main rivers is shown in Figs. 5 and 6. In Table 4, differences in discharge are shown for both historic and contemporary time intervals: 1969 to 1978, and 2008 to 2018, respectively. While the net difference in discharge volume is not significant in the other rivers of the Northern basin, the Balkh River shows a considerable increase, as shown in Table 4.

On the other hand, decreasing precipitation in the Northern River basin of Afghanistan as shown in Fig. 7 reflects the changing source for these rivers from rainfall to permanent snow cover and glaciers, which originate in the Hindu Kush mountains, as shown in Fig. 8. In addition, the main reason for the increasing discharge in Shirintagab River, while only somewhat

| Table 4 Difference in annual mean discharge for rivers in the Northern River basin for historical data (from 1969 to 1978) and current data (2008 to 2018) in m³/sec. |
|---------------------------------|----------------|----------------|----------------|----------------|
| Time interval                  | Balkh River   | Sare Pul River | Khulm River    | Shirintagab River |
| 2008-2017                      | 53.9          | 6.9            | 3.2            | 2.7            |
| 1969-1978                      | 47.4          | 8.4            | 2.4            | 2.4            |
| Difference                     | 6.6           | -1.4           | 0.8            | 0.3            |
| %Difference                    | 12%           | -21%           | 25%            | 12%            |

(a) | (b)

Fig. 5 Annual mean discharge of 3 rivers in the Northern River basin for (a) 1969 – 1978 and (b) 2008 – 2017.
affected directly by melting permanent snow and glaciers, is from the water coming into the river indirectly. After the permanent snow melts, it goes to the underground water supply and comes out as springs to increase the amount of discharge in this river, as explained by hydrologists of the Ministry of Energy and Water of Afghanistan.

5. ANALYSIS AND DISCUSSION

The Mann-Kendall test was used to detect trends in the data collected over both the historic and current time interval. Discharge graphs shown in Figs. 5 and 6 show the annual mean discharge data plotted with Sen’s slope. Using the results of the Mann-Kendall test and calculating Sen’s slope, the current discharge data show some small positive trend. This indicates that discharge is still increasing over time despite the significant decrease in rainfall as seen in Fig. 7. The Balkh River and Khulm River show the most significant increasing trend in discharge, while the Shiringatab and Sare Pul show only minor increasing trends, confirmed by the Mann-Kendall test analysis.

The locations of the rivers are shown in Fig. 9. The flow of the Balkh River increased much more significantly than the other rivers studied owing to its proximity to permanent snow coverage and elevation. The Balkh River starts from the Band-e Amir lakes at the foothills of the Hindu Kush mountains at an elevation of 3000 m.

The Khulm River is also affected to a certain degree by permanent snow melting, as the river starts from the Kara-Kotal Pass at 3600 m. The Sare Pul River starts further in the lowlands at Koh-e-baba ridge and is fed mostly by springs, so it is not affected much by the permanent snow melt. The Shirintagab River is located near the north slope of the Tirbandi Turkistan Ridge and also fed by groundwater springs in the lower elevations of the valley, so this river is also less affected by the melting glaciers in the region.

The data series was analyzed using Pettitt’s test, Standard Normal Homogeneity (SNH) test, and von Neumann ratio test to better understand the quality of data to check for homogeneity and breaks. The sample sets are on the smaller side, so the results of the detection analysis were not very significant, though

Fig. 6 Annual mean discharge for the Balkh River for (a) 1969 to 1978 and (b) 2008 to 2017.

Fig. 7 Mean annual rainfall of the Northern River basin.

Fig. 8 Permanent snow cover in the northern river basin of Afghanistan.
the series showed a mostly homogeneous nature. Overall, Afghanistan is still in the beginning stages of revitalizing its research into water resources and river discharge after many years of civil conflict that had plagued the country. These data sets are the first emerging trends recorded from the scarcity of available data. Over time, as the country overcomes political and economic issues, the government will be able to strengthen the ability of researchers and engineers to collect more data from all rivers and streams in the region, making it possible to further analyze these emerging trends to have a clearer grasp on the severity of the climate crisis affecting the area.

Due to climate change, other changes, such as the increase in mean annual temperature and a decrease in spring precipitation, as well as change in the intensity and frequency of extreme weather events, are expected to occur. The mean annual temperature in the northern part of Afghanistan from 1951 to 2010 has increased by 1.6°C and precipitation has decreased by 9.2%[19]. Over this period, the frequency of “hot” days and nights in Afghanistan has increased in each season since 1960. The average number of “hot” days per year increased by 25 days, while “hot” nights per year increased by 26 nights between 1960 and 2003[20]. Afghanistan is already seeing an increase in deviations from average weather patterns.

Climate change effects have been observed around the world, and these effects negatively impact water resources of Afghanistan. In early spring, there is flooding in Afghanistan, then later in the season, there are water shortages in most rivers while crop water requirements are very high. Having enough water reach the field is required to improve yield and economically support villagers and farmers; without effective irrigation and without water security, it is very difficult to achieve food security. Drought in Afghanistan has caused some land in rain-fed cultivation to lie fallow and a decrease in the area of irrigated land, which leads to declining job opportunities in rural areas and emigration to Europe and other countries in order to avoid starvation.

The people of Peshghor village in Panjshir Province Afghanistan were the victims of global warming. On one night in July 2018, a glacier breakdown at Panjshir Lake destroyed around 500 houses and killed 9 people[21]. This area at the top of a high mountain of Panjshir Province was historically covered with permanent snow cover. Photo 1 shows the melting glaciers in the area. According to the narrative of local residents, the glaciers were large rocks always covered by permanent snow, but as of four years prior to the incident, the permanent snow cover was completely depleted and the area settled by almost 4 m. Global warming is considered the main reason for the uncharacteristic melting of permanent snow cover and glacier. This incident is a warning to the government of Afghanistan and people living in floodplains and other areas prone to natural disasters that the damage due to global warming can be severe. Thus, involvement of the government is warranted to set up measures to properly maintain water resources and mitigate against seasonal flooding. Although Afghanistan produces less than 0.5% of the total greenhouse gases worldwide, owing to its traditional agriculture system and limited industry, it is near the top of the list of countries suffering from the effects of global warming and greenhouse gases.

6. RECOMMENDATION

The effects of the impact of climate change have already begun to show in Afghanistan. Increased temperatures have triggered the melting of glaciers and permanent snow. This in turn increases the mean annual discharge of rivers in areas with permanent snow coverage. However, the annual precipitation is on a downward trend and there are serious droughts...
as the current water resources are not properly managed. In the future, as these permanent snow and glaciers are depleted over time, these water resources will cease to exist and the river discharge will be reduced with the decreasing precipitation. This will create a severe situation in the future for Afghanistan as drought conditions worsen and water resources are not well managed.

Generally, the government of Afghanistan takes action only after a natural disaster has occurred. Currently, the government agencies are not equipped to adequately predict natural hazards or to provide essential facilities that at least mitigate the risk of hazards. Currently, there is very limited ability to efficiently capture water resources to be used for agricultural use. Despite the increase in annual river discharge, there is decreased snowfall and other forms of precipitation. Without the ability to utilize water resources efficiently, rain-fed agricultural land and forests are suffering more severely from drought, while pasture areas are also decreasing; this has a negative impact on wild and domestic animals as well. It is important to consider these effects on the surrounding environment of Afghanistan, and to maintain a balanced ecosystem for both humans and animals. Further solutions need to be developed to increase the ability of capturing and preserving precious water resources; however, the cost and current lack of specialists is a constraint. An example of a low-cost option to mitigate the situation is for the government of Afghanistan to promote the cultivation of crops, such as saffron, which have low water requirements, and to take measures, such as supplying sufficient fuel, to prevent cutting down forests. Drastically increasing plantings on mountains to avoid landslides and increasing greenery in the area would be effective measures for soil conservation. Planting trees and other vegetation along rivers may also be a mitigating factor to decrease the risk of flood hazards on plains for a cost-efficient alternative to expensive hard structural measures.

7. CONCLUSION

Water resources are one of the most important issues in the world and play a vital role in human life and the environment. Despite Afghanistan’s dry climate and its mountainous areas, it has the potential to be among the richest countries in terms of water resources; however, due to civil wars and the lack of specialists, only 30% of the water resources are utilized, while the remainder of uncaptured resources naturally flow across borders to neighboring countries. Without capturing these water resources for irrigation, this leaves deserts in the agricultural land of the countryside. Moreover, the effect of climate change is increasingly melting the permanent snow cover in the high mountains and is increasing surface water resources by 12% in the Northern River Basin of Afghanistan, despite the decreasing trend in annual precipitation. If this disturbing trend of permanent snow melt continues as a result of climate change, flooding disasters not only present a serious risk to Afghanistan’s rural sectors, but also presents some serious concerns for the future of Afghanistan’s depleting water resources.

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