Climate Change Impact on Variability of Water in upper Kabul Basin

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Abstract

For climate change it is important to develop understanding on the ways that variability in the climate is emerging at the local level, and the areas of water use likely to be impacted there from. It was in this context that this research, was undertaken to analyze the pattern of climate change and the likely implication to the availability of water in Upper Kabul River Basin. Upper Kabul Sub-Basin was selected for this study for the reason that this is the most populous area in the country and any variability in climate and water would mean livelihood impact to large population. This has also been the area where competing uses of water have been large.

The study involved extensive review of literature on climate change and resulting uncertainties to water availability in Afghanistan and in other parts of the world. Alongside the literature review, analysis of hydro-meteorological data specific to Upper Kabul Sub-Basin was carried out to assess the pattern of variation and trends in temperature, rainfall and stream flow. The trend analysis of temperature, rainfall and stream flow was carried out by fitting regression models to observed pattern of rainfall, temperature and stream flow. The relationship between rainfall and stream flow over the River Basin was established and this was used in projecting the variability and uncertainty in availability of water in the Sub-Basin. A combination of statistical analysis is done to perform to infer future stream flows. The largest reduction in mean stream flows and rainfall is expected in the study area.

Keywords: Regional climate change, climate change, temperature increase, rainfall decrease, water variability.

Paper type: Case Study and Literature review

1. Introduction

The hydrologic system, which consists of the circulation of water from ocean to atmosphere and back to the oceans, is an integral part of the global climate system (Critchfield, 2002). Therefore, any change in the climate system may not only cause changes in the hydrologic system but also further modification of the climate itself due to the new changes in the hydrologic system. Glaciers are very sensitive to climate change, therefore they can be considered as good indicator of past climate changes (Nesje and Dahl, 2000).

Decreasing snow cover and the melting of glaciers as a result of warming provide a positive feedback to warming due to decreased surface albedo and increased absorption of solar energy (Meehl, 1994). The estimated quantity of the earth's total water is about 1.4 x 10^9 cubic kilometer, however only about 2.5% of this is the fresh water reserve. About 97% of the world's water is contained in the oceans which is not suitable for direct human consumption due to high salinity (Singh and Singh, 2001). Out of the available fresh water, about 77% (30x10^6 cubic kilometer) is frozen in the polar ice caps and in the glaciers and the remainder is contained in the lakes, reservoirs, rivers, and atmosphere and in the aquifers under the ground. Therefore, the melting of ice sheets and glaciers due to warming is a threat to the limited freshwater reserves of the earth (Suresh, 2005).

In developing countries, people belonging to poor and marginalized groups are especially vulnerable to climate change, because of their high level of exposure, low incomes and greater reliance on climate sensitive sectors, especially agriculture, for livelihood. People exposed to the most severe climate hazards are often those, who have least ability to cope with the associated impacts, due to their limited adaptive capacity. This in turn poses multiple threats to economic growth, poverty reduction and health and nutrition (Davies et al, 2009).

Preliminary evidence indicates that predicted warmer temperatures, accelerated glacial melt, reduced winter snow cover and associated changes in river flows, and more frequent and intense drought and floods threaten the stable water supply for agriculture, hydropower, and human consumption in the arid and semiarid region of central and west asia. More frequent droughts, catastrophic flooding from glacial lake outbursts, and landslides caused by destabilization of mountain slopes will lead to a progressive increase in economic losses and risk to the population, and reduce the ability of communities to move out of poverty. These impacts threaten to stall economic development in Central Asia, and endanger the health and safety of its growing population. Climate change causes temperature, wind, and precipitation to vary, with profound effects on natural systems. These in turn have effects on the health, safety, and livelihoods of people - especially poor people (ADB, 2016).

The impact of climate change has always been very important for the use and management of water resources at the global level. In Afghanistan, where different climatic conditions prevail in small geographical area, the effects of climate change can be more crucial. Mountains in Afghanistan cover over 80% of the total area, which is covered under snow mostly during the winter and is a good source of water flow in most rivers in Afghanistan. Snowmelt water from these glaciers contribute significantly to the river flows in the dry season that supports diversified water uses on the downstream, including irrigation, drinking water and hydropower generation. Due to climate variations, and the changes in the temperature and precipitation patterns, the impacts on the river flows in the arid and semi-arid regions of Afghanistan are expected to be large.

The occurrence of snowmelt-related drought caused by reduced winter snowfall in parts of the Hindu Kush Mountains seems to have primarily affected Kabul and surrounding regions. These densely populated areas, which produce much of the country's vegetables, fruits and cereals are heavily dependent on irrigation from the Kabul river and its tributaries, which are partly fed by snowmelt from the Hindu Kush (UNEP, 2016).

Since 1960, the mean annual temperature in Afghanistan has increased by 0.6°C at an average rate of around 0.13°C per decade, whereas changes in the precipitation regime vary more between regions. The mean annual rainfall of Afghanistan decreased slightly at an average of 2% per decade since 1960. Additionally, in Afghanistan, drought during the period 1993–2003 is considered to provide major physical evidence of climate change. Floods are also specific complex and risky phenomena, occurring several times in different provinces of Afghanistan. According to climate change and its implications on stream flow in the Kabul River Basin, for the future period of the 2050 under RCP 4.5 and 8.5 using GCMs, shows, the mean annual temperature at this basin will increase by 2.2°C and 2.8°C under RCP 4.5 and RCP 8.5 respectively, whereas the precipitation does not show a clear trend (Sidiqi and et al 2018).

Current models indicate significant warming across all regions of Afghanistan with average predicted increases in temperature of between 2°C and 6.2°C by 2090, dependent on global emissions scenarios. Warming is most rapid in spring/summer with this trend being marked in the north and the central plains of Afghanistan. These increases are also consistent with the broad regional observed temperature trends in central asia. All projections indicate substantial increases in the frequency of days and nights that are considered 'hot' in current climate, especially during summer months. By 2090, the range of projections by the 2090s under any one emissions scenario is around 1.5 to 2.5°C. The range of potential annual temperature increases is noticeably influenced by global emission scenarios. In the short term, average rainfall is projected to show a small increase, although by little more than about 10-20mm. Mean annual rainfall changes in the 2090s show conditions are generally drier (by between 10-40 mm) over much of Afghanistan. Much of the drying is due to decreases in spring rainfall (MAM). Winters are expected to be significantly drier in the South. Projections of mean annual rainfall from different models are broadly consistent in indicating decreases (Savage and et al. 2009 and NEP, 2015).

The source of most of Afghanistan's surface water is rainfall and winter snowfall at high altitudes. It is documented that long periods of summer drought limits the area under crop cover (Freitag, 1971). According to the European Union Emergency Humanitarian Aid (WUEHA), in a time frame of past 15 years, at least three periods of prolonged drought have prevailed in Afghanistan, with a frequency of 1 in 5 years. In recent years, however, there has been marked tendency of this drought cycle to occur more frequently. Since 1960, the country experienced drought in 1963-1964, 1966-1967, 1970-1972 and in 1998-2006. This situation has been exacerbated by declining rainfall amount. Increased frequency of drought has been responsible for the failure of rain-fed crops, which is estimated to constitute up to 80% of the cultivated land in Afghanistan and, therefore, this has large implication to the food security and livelihood of millions of farming households, especially, those in the north, west and central regions of the country (CCDP-WG, 2008).

Afghanistan is frequently ranked among the countries most vulnerable to climate change due to a combination of low adaptive capacity and high exposure to climate fluctuations. Over the past four decades, armed conflict has destroyed the country's infrastructure, damaged its institutions, and led to widespread poverty and underdevelopment, which collectively underpin Afghanistan's vulnerability and lack of adaptive capacity to climate change (Valentin Aich and et at, 2017).

It was in this context that this study was conceived to look into the "Climate Change Impact on Variability of Hydrometeorological parameters in Upper Kabul Basin" resulting from climate change in the upper part of Kabul Basin and mapping out the climate induced variability in water resources. The focus of the study on geographically delineated area and analysis of observed rainfall and temperature pattern was expected to derive many inferences that would be relevant to the planning, use and management of water in the basin.

2. Problem statement

While climate change is a global phenomenon, the effects of climate change are local. Although the specific physical impacts of climate change are determined by geography and micro level interactions between global warming and existing weather patterns, in Afghanistan, the impacts of climate change are likely to be particularly severe due to the arid/ semi-arid nature of the climate, the importance of natural resources for rural livelihood and the extreme poverty within which a large proportion of the Afghan population lives.

In arid and semi-arid climate like that of Afghanistan, there will be more change in the spatial and temporal distribution of temperature and precipitation due to climate change, which in turn will increase both the intensity and frequency of extreme events like drought and floods and also increase vulnerability of the people and their production system to the climate change.

Upper Kabul Basin is selected for this study for the reason that this has been the most populous area in the country and any variability in climate and water would mean livelihood impact to large size of population. This has also been the area where competing uses of water have been large. Increased water withdrawal from surface and groundwater sources to meet the irrigation and domestic water needs by people has already produced visible stresses on the available water sources. The variability in available water would mean further intensification of the magnitude of water stresses, which would affect the livelihood of the people, negatively.

3. Research objectives

The overall objective of this study is to assess the variability in hydrometeorological parameter resulting from climate change in Upper Kabul Basin and identifying the possible impacts of the climate and water variability.

4. Limitations of the study

There have been two important limitations of the study. The first and the foremost relates to the availability of needed information specific to the study area and the second is provided that Afghanistan is currently in the process of social and political transition and in building its physical and institutional infrastructures, very few research/studies have been carried out on climate change and other pertinent water issues in the study area. There are very few research centers that could provide relevant information and data for the purpose of this study.

5. Study area description

The entire country is divided into five river basins: Amu Darya, Kabul Basin, Northern, Helmand and Harirod-Murghab Basin, 41 watersheds and 3000-4000 micro catchments (Favre and Monowar, 2004). The locations of the five river basins are shown in Figure 1. Water resources in the country are unequally distributed in the five major river basins, which are also characterized by varying degree of water availability and consumption pattern (WSS, 2007).

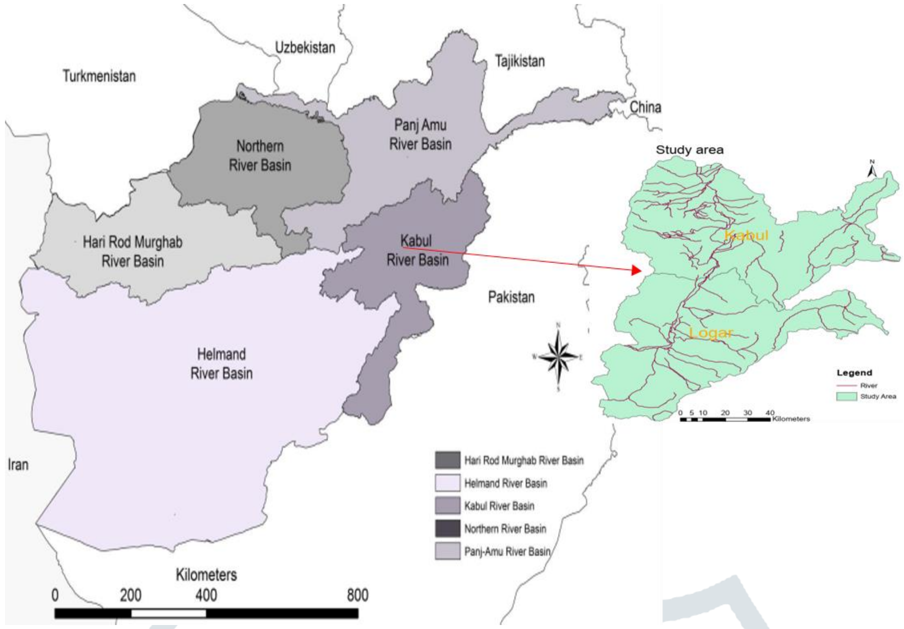


Figure 1. Major river basins in Afghanistan (Akhtar, 2017)

The upper Logar- Kabul basin covers an area of 1,600 km^2, which is nearly 12.41 % of the total catchment area of 12888 km^2 in Kabul River Basin. For the purpose of this study the data recorded at the meteorological and hydrological station at different upper and lower parts of the study area have been selected. The data provides opportunity to look into changes in the climatic pattern at the basin level and link the observed changes in the river hydrology with pattern and trend of rainfall and temperature in the study area.

6. Result and Discussion

Poor developing countries like Afghanistan are especially vulnerable to climate change because of their geographic exposure, low incomes and greater reliance on climate sensitive sectors, especially crop and animal farming. People, who are exposed to more serious climate related hazards, are often those, who have low ability to cope with the associated impacts, due essentially to their limited adaptive capacities. This in turn poses multiple threats to economic growth, poverty reduction and the achievement of the Millennium Development Goals (ADB, 2003*;* Stern2006).

In the context of Afghanistan, climate change impacts on water resources are expected to be both direct as well as indirect. The likely consequences of climate change on available water supply are direct, in terms of changes in the occurrence, quantity and distribution of precipitation. Contrarily, the consequences produced to water resources demand and its linkages in the production system constitute the indirect effects. For example, loss of soil moisture due to temperature increase and inadequate precipitation would be linked to forage production in the posture lands, crucial for livestock production in the highlands. Similarly, increased dryness of soil is expected to accelerate soil degradation, which is liable to reducing land productivity. The dry lands of Afghanistan are the areas susceptible to the risks of more intense drought and desertification. In these areas agriculture would be the most susceptible sector to climate change. This is attributed to the fact that climate change affects the two most important climatic attributes of agricultural production system, precipitation and temperature that have important effects on the crop growth and production (ADB, 2002; ANDS, 2008). Climate change also indirectly affects agriculture by influencing emergence and distribution of crop pests and livestock diseases, exacerbating the frequency and distribution of adverse weather conditions, reducing water supplies and irrigation and enhancing severity of soil erosion.

Most of the population does not have access to improved drinking water and waste treatment systems. As stated earlier only 5% of rural and 16% of the urban residents have access to sanitation systems, and only 11% of rural and 19% of urban residents have access to improved drinking water systems (AWSA, 2006). This would mean that people in Afghanistan face increasing risk of water and sanitation-related diseases, such as cholera, dysentery, scabies and trachoma.

6.1 Climate trend in Upper Kabul Basin

This section attempts to analyze and present the pattern and trend of temperature and rainfall in Upper Kabul Basin and derive implication of these changes to the availability and distribution of water in the basin. The temperature and rainfall data used in the analysis are those for the different period (2003-2015 & 1958-1983) and recently some other Hydrometeorological station also established at study area the data record is from (2008-2017. No record was available for the period 1984-2001, because of the intensified war during this period that led most of the institutions in the country becoming non-functional and therefore to cessation of data collection during this period.

6.2. Observed pattern and trend in temperature

The daily records of maximum and minimum temperature for the period 1958-1983 and 2002-2015 was averaged to obtain monthly summary of mean daily, mean maximum and mean minimum temperature for each month for the stated period. The temperature records were further worked out to obtain seasonal summary for four seasons: winter (DJF), spring (MAM), summer (JJA) and autumn (SON), in the study area.

6.3. Trend of temperature departure

Considering gap of 19 years in the temperature record, it was found useful to look into the departure in the observed temperature pattern during 2002-2015 with that recorded during 1958-1983. The plot of monthly temperature records during 1958-1983 and 2002-2015 is shown in Figure 2. The figure clearly shows increase in monthly temperature for all the months for the period 2002-2015 over those during the period 1958-1983. This shows a consistent pattern of warming in the study area in all the twelve months of the year. This also indicates that the departure in the monthly temperature has been larger during winter than in the summer months, indicating that the rates of warming during the winter months have been larger than in the summer months.

In order to look into the pattern of monthly mean temperature in the study area, these values obtained from total of 8 years of record, were plotted for each moth of the year (Figure 3). The normal monthly temperature of the study area was estimated to ascertain the cooler and warmer months. This clearly shows four distinct periods in terms of variations in temperature in the study area that produce the four seasons: winter (December-February), spring (March -May), summer (June-August) and autumn (September-November) Figure 3.

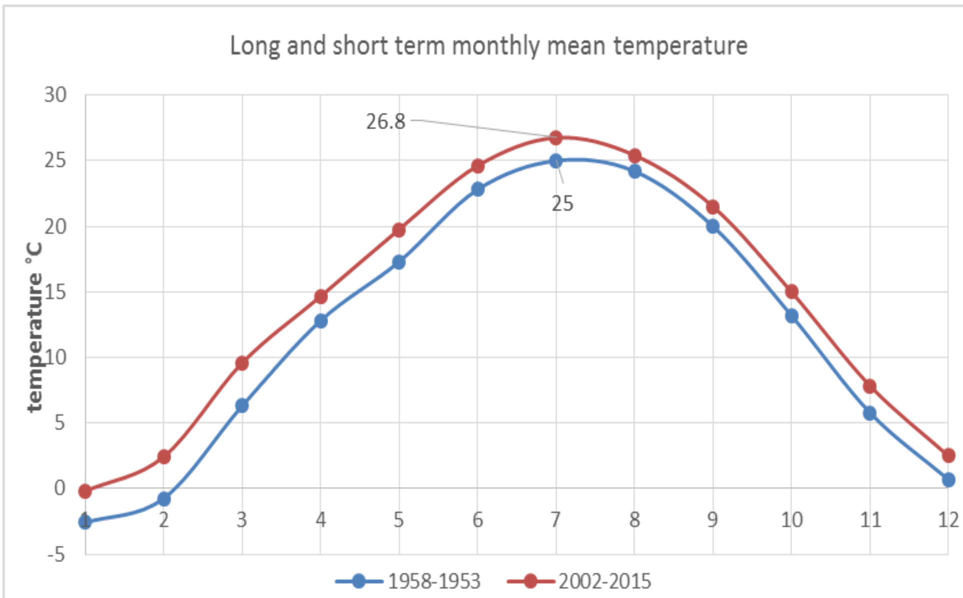
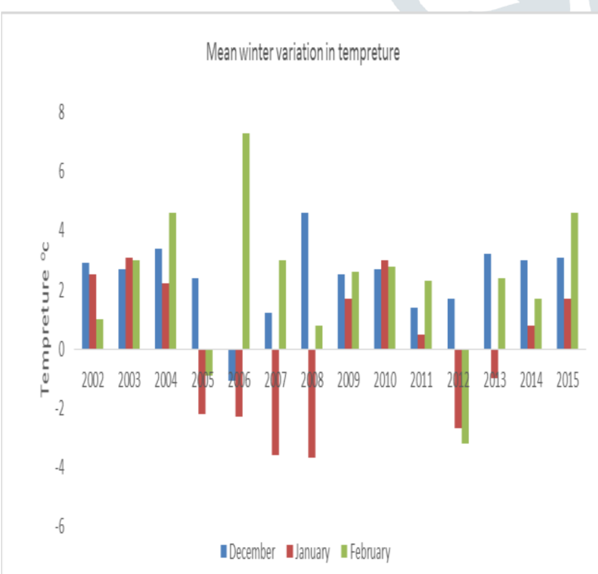
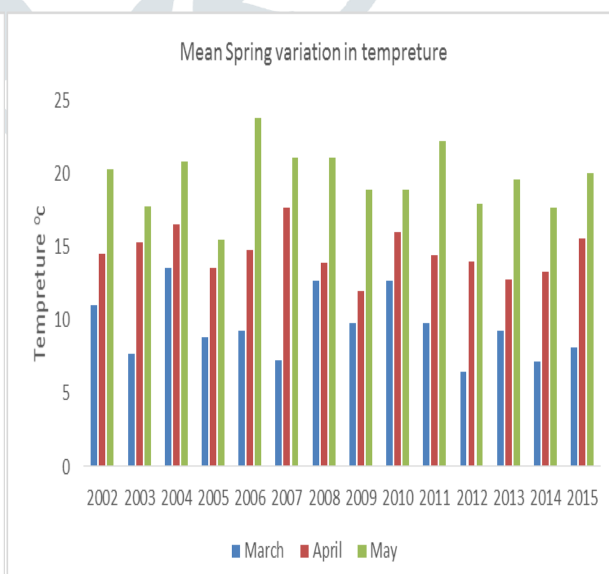


Figure 2. Departure in monthly temperature records for the period 2002-2015 from 1958-1983 in Kabul River Basin**.**





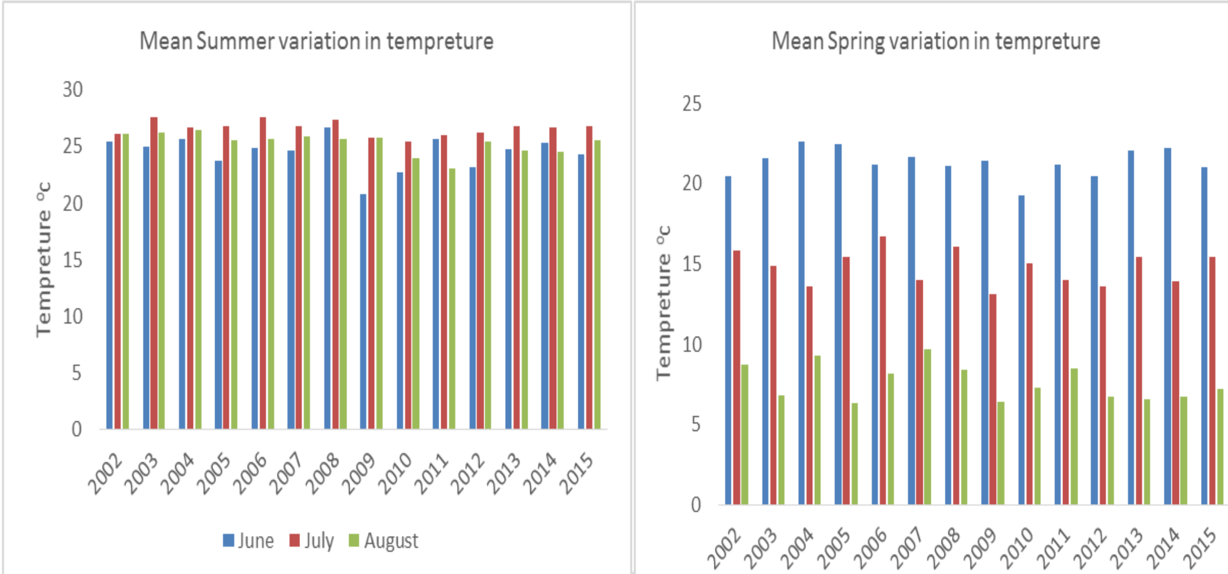


Figure 3. Seasonal mean monthly temperature pattern in the study area**.**

6.4. Annul temperature trend

In order to analyze the trend of annual temperature in the study area, the mean, maximum and minimum temperatures were plotted for the period 1958-2010 (Figure 4) and 2002-2015 (Figure 5). The pattern shows a sinusoidal variation in annual temperature during the stated period with a cycle of low and high temperature in different years. For example, in 1970 there has been a peak in the annual temperature with the highest temperature recorded in the month of August (33.6 °C). Similarly, the lowest annual temperature was in 1964 with the lowest value in the month of January (-17.5°C) in same year. Figure 4 also shows increasing trends in mean, maximum and minimum temperatures though the mean annual (R^2= 0.471) and mean minimum temperature (R^2= 0.488) show more convincing trend of increase than the increase in the mean maximum temperature (R^2= 0.133). This would mean that there is increasing trend in daily minimum and mean temperature in the study area.

Figure 5 shows increasing trends in mean temperatures of winter, though the mean annual (y=0.05 ^{o}c), mean reducing temperature in spring (y= -0.13 ^{o}c), mean increasing trend in temperature of summer (y=0.08 ^{o}c) and also mean increasing temperature in autumn (y=0.12 ^{o}c). increasing trend shows more convincing trend of increase in autumn than the increase in the mean increase of summer temperature (y=0.12). This would mean that there is increasing trend in daily mean temperature in the study area.

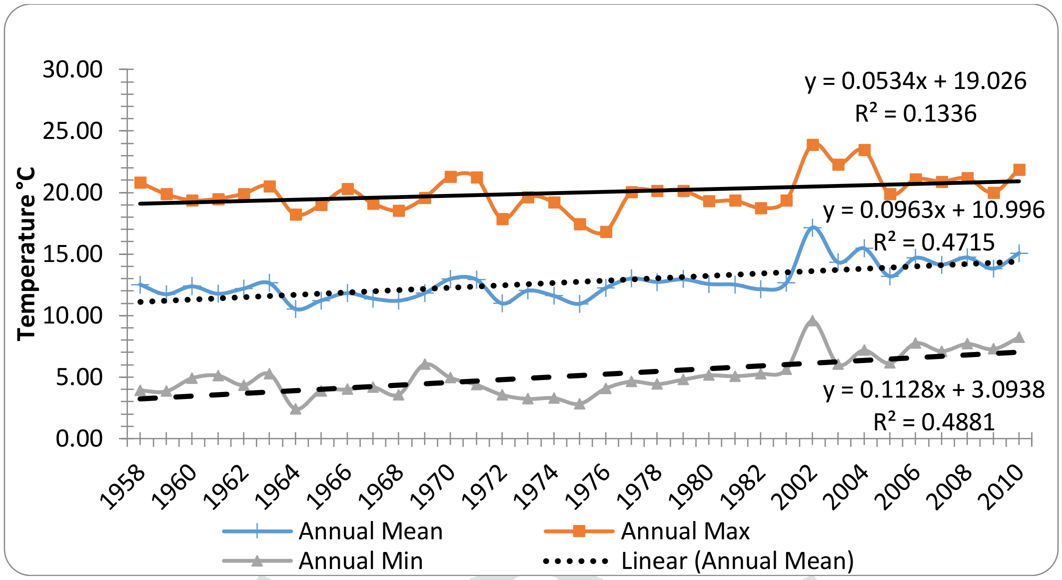


Figure 4. Annual (maximum, mean and minimum) temperature trend in the study area for the period 1958-2010.

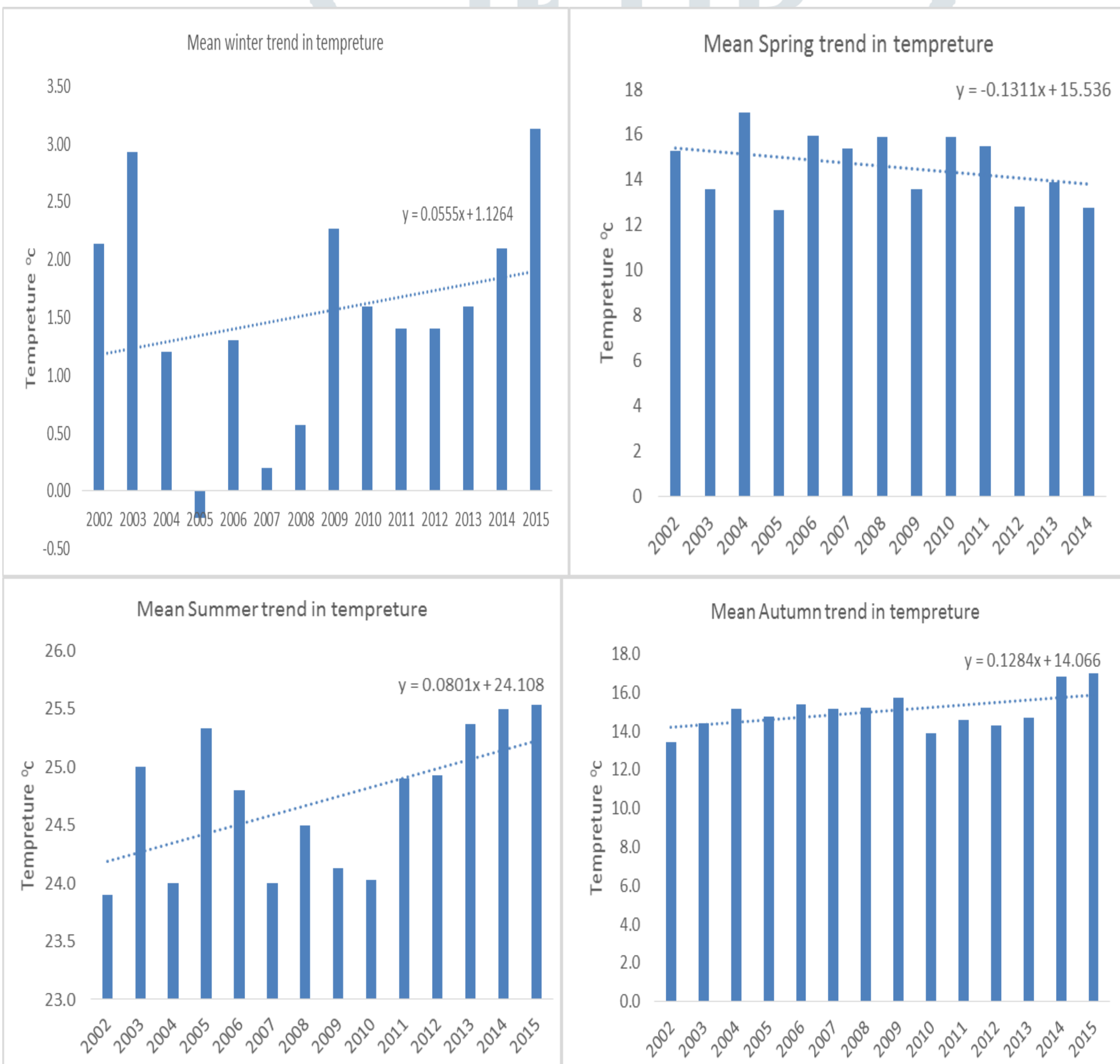


Figure 5. Seasonal mean temperature trend in the study area for the period 2002-2015.

6.5. Rainfall pattern and trend

The daily records of the rainfall at the Kabul Airport for the period 1957-1983 and 2003-2015 were used in generating monthly summary of rainfall for each month for the stated period.

6.6 Departure in monthly rainfall pattern

Rainfall in Afghanistan concentrates over five months from December to April with the highest rainfall occurring in the month of March. The period from June through October is the dry period. The pattern of distribution of monthly rainfall for the period 1957-1983 and that for the period 2003-2015 is shown in Figure 6. This figure shows clear departure in the rainfall pattern in the recent times than in the past. The comparison of monthly rainfall amount for these two time periods show reduction in the monthly rainfall amount in the period 2003-2015 than the period 1958-1983. This reduction was noted to be as large as 22 mm in the month of March and 7 mm in the month of April, which are the months known for higher amount of rainfall occurrence in Afghanistan.

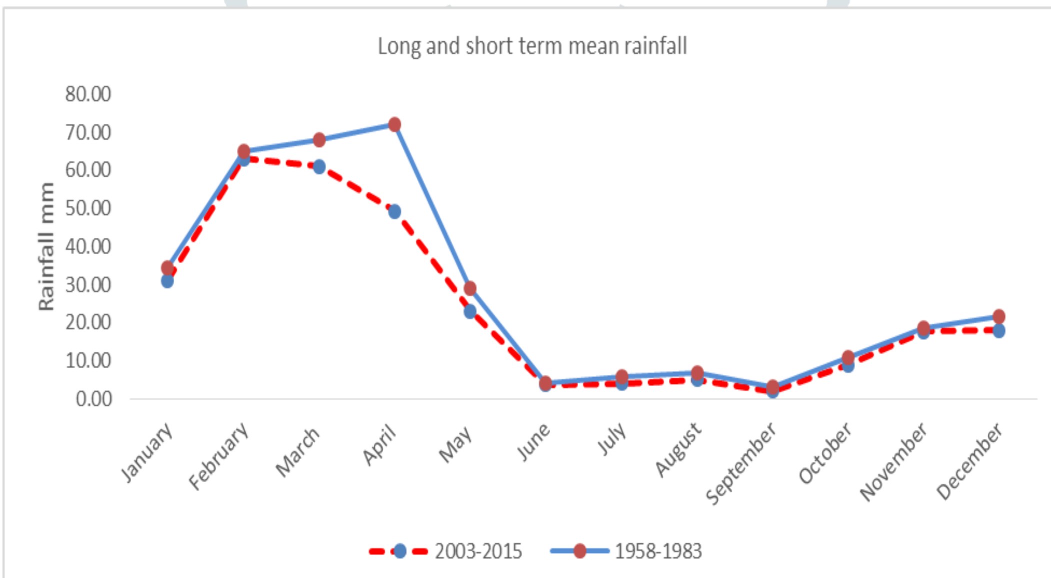


Figure 6. Pattern of departure in monthly rainfall between the periods 1958-1983 and 2003-2015.

6.7. Annual rainfall trend

The pattern of annual rainfall over the period 1958-1983 for the study area is shown in Figure 7. This shows variation in annual rainfall from one year to another with the normal annual rainfall of the study area during the stated period being 26.03 mm. The highest rainfall recorded during the stated period was 66.23 mm in 1959 while the lowest rainfall was 12.82 mm recorded in 1977. Annual rainfall of the stated period shows a declining trend over time with the rate of decline in the annual rainfall being 0.470 mm per annum (R^2= 0.132). The annual rainfall during the period 2003-2015 also show declining trend at the rate of 0.53 mm (Figure 8), however, this trend cannot be considered convincing because of smaller length of record for this period.

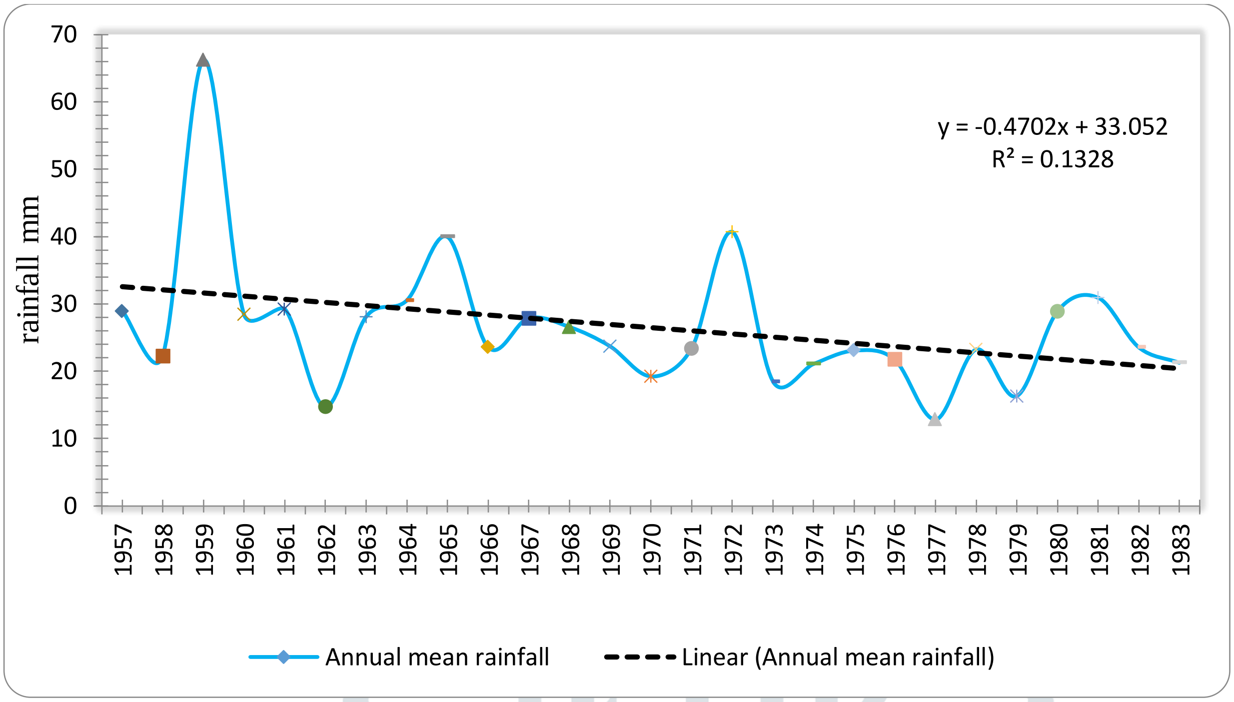


Figure 9. Trend of annual rainfall in the study area (1957-1983).

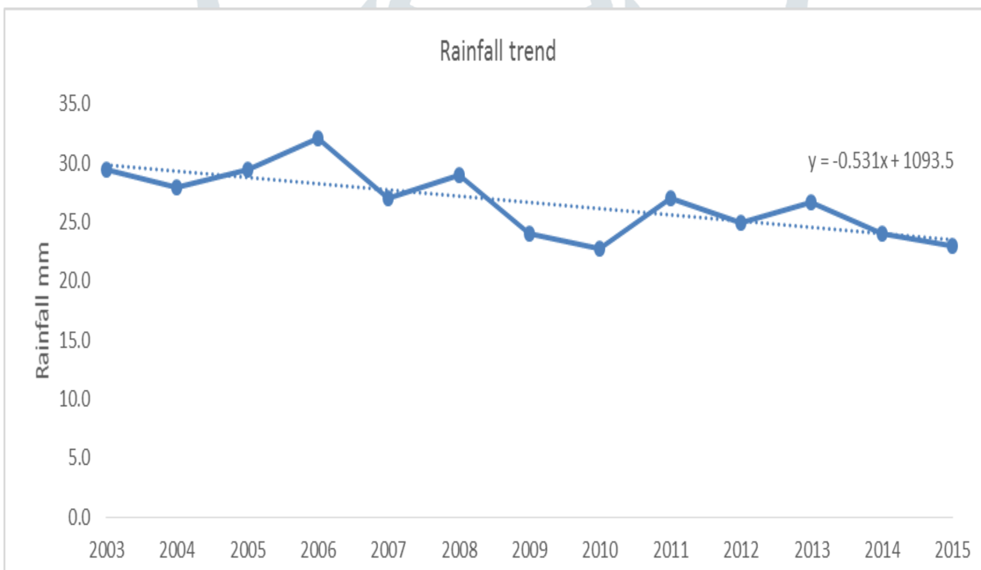


Figure 8. Trend of annual rainfall in the study area (2003-2015).

6.8. Observed flow of water at study area

Long term stream flow record is crucial to plan water use in a river basin. The decision for allocation of water in a river basin depends on the available flow and its time distribution. This section presents the observed pattern and trend of flow in Kabul River based on the available flow records at stations Tang-i-Gharu for the period (1960-1980) and (2008-2015), Tang-i-Sayedan (2008-2017), Sang-i-Naweshta (2006-2017) and Qala Malik (2009-2017).

6.9. Monthly and annual mean stream flow

The monthly and annual mean flow of Kabul River recorded at the upstream, middle and downstream of study area. These values were computed from observed daily flow of the gauging station for different months of the year from 1960 to 1978 and 2008 to 2015. The pattern of distribution of monthly river flow for the period 1957-1983 and that for the period 2008-2015 is shown in Figure 9. This figure shows clear departure in the river flow pattern in the recent times than in the past. The comparison of monthly river flow amount for these two time periods show reduction in the monthly river flow amount in the period 2008-2015 than the period 1960-1983. The figure clearly reveals high flow in the river over six months from December to May, while the river flows in the rest of the months have been at low levels. Further, the river flow has been highly variable from year to year.

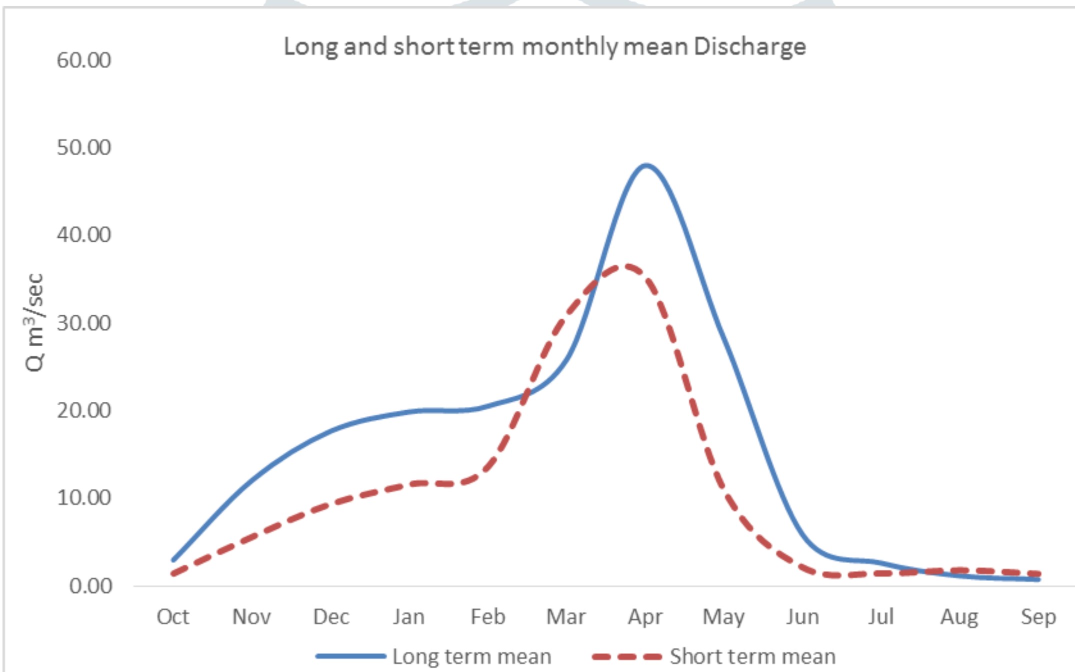


Figure 9. Observed long and short term monthly mean discharge of Upper Kabul River at Tang-i-Gharu

6.10. Annual stream flow pattern and trend

The pattern of variation of annual flow of Kabul River at Tang-i-Gharu, Tang-i-Sayedan, Sang-i-Naweshta and Qala-i- Malik for different period are presented in Figures 10 and 11, respectively.

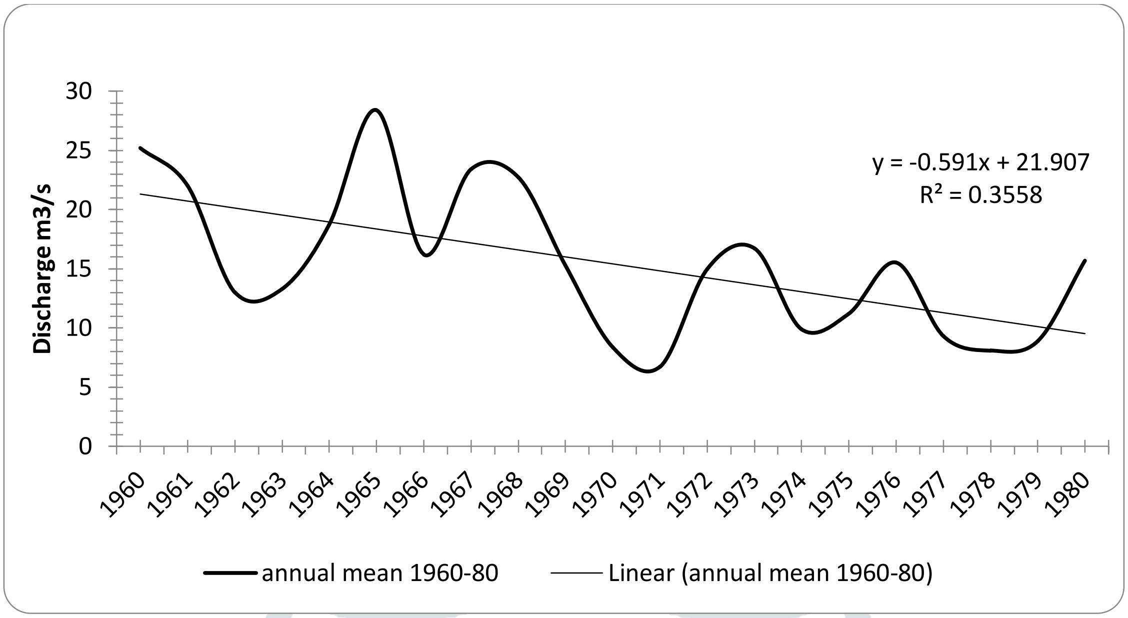


Figure 10. Annual stream flow in Kabul River at Tng-i-Gharu (1960-1980).

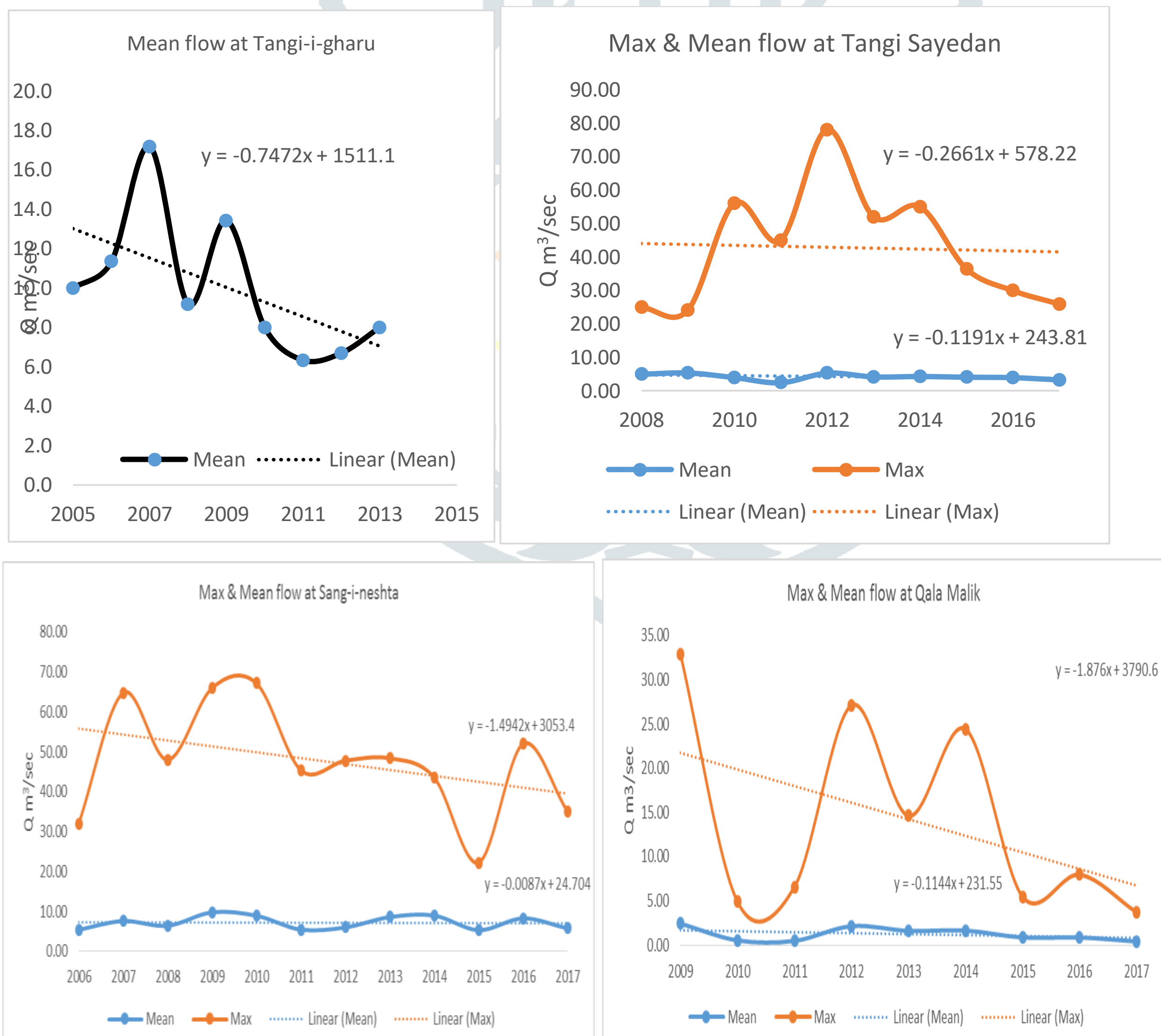


Figure 11. Annual stream flow in Upper Kabul River at Tng-i-Gharu (2008-2015), Tang-i-Sayedan (2008-2017), Sang-i-Neshta (2006-2017) and Qala Malik (2009-2017).

The analysis of trend of river flow at the gauging station shows progressively declining trend in flow over time with the rate of decline in the annual flow being 0.591 m^3/s (R^2= 0.355) per annum. The trend of both annual rainfall and annual stream flow show a declining trend though the rate of decline indicated by the slope of stream flow curve (-0.591) was noted to be larger than the slope of annual rainfall curve (-0.470) which would mean that the rate of decline in the stream flow is much higher than the rate of decline in the annual rainfall. This would also mean that rate of decline in the rainfall alone does not totally explain the rate of decline in the stream flow.

6.11. Stream flow and rainfall relationship in Upper Kabul River

Scarcity of water and for that matter occurrence of drought, in a basin can be examined using two different perspectives- climatic perspective that considers the amount of rainfall and its occurrence at different times of the year and hydrologic perspective that considers the variations in the stream flow available for intended uses. Climatic drought is therefore defined by a persistence of rainfall below a threshold. In contrast, hydrologic drought is defined by condition of flow in the river below a threshold. However, there is certain degree of dependence of hydrologic draught and climatic drought because rainfall is an important input to maintaining the river flow.

The observed pattern of rainfall and stream flow in upper Kabul River Basin is shown in Figure 12. This clearly reveals that the stream flow is closely related to occurrence of rainfall in the river basin. This would mean that any variability in the rainfall would result to variability in the stream flow. The analysis is however incomplete because this study did not include the snowfall in the river basin which has obviously significant contribution in the stream flow in the Logar-Upper Kabul Sub-Basin.

In recent drought events, Kabul Basin experienced severe water shortages especially in the area around Kabul. Several events of drought were noted to have occurred in the basin between 1960 and 1978. The condition of drought in the basin prevailed because of low rainfall as well as low level of stream flow, thus there were prevalence of both climatic as well as hydrologic draught in the basin. The event of draught in 1970, 1971 and 1978 were serious because of the limitation of the stream flow.

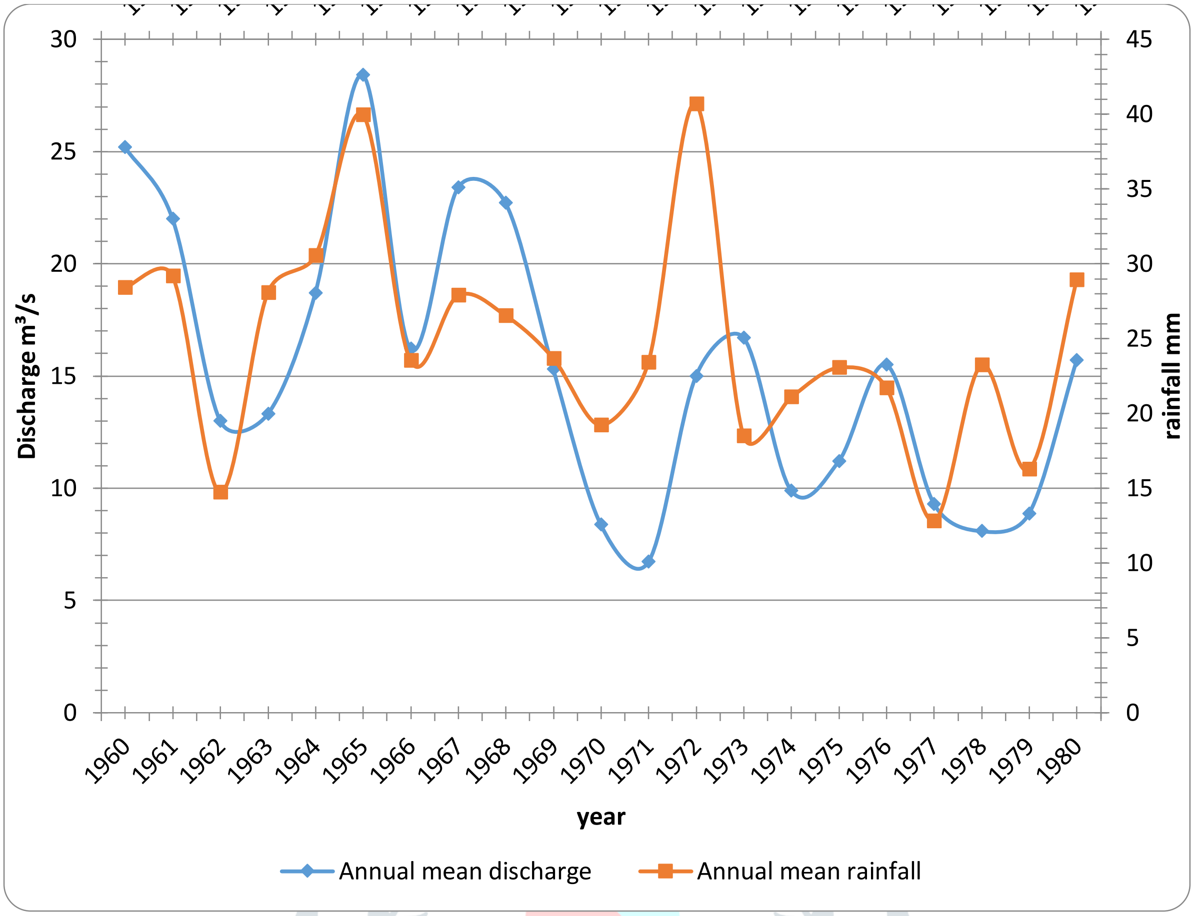


Figure 12. Observed relationship between rainfall and stream flow in Upper Kabul River Basin (1960-1980).

7. Conclusion

The analysis stated above lead to following conclusions that have implication to variability of water resources in the study area as well as in the country as a whole:

The findings of the study clearly revealed increasing trend of warming and decline in the rainfall and stream flow of Kabul Basin on annual cycle. Also, the rate of warning and decline in the rainfall was noted to be large during the spring season, which is the period known for large amount of rainfall occurrence in the basin and in other parts of the country.

Increasing trend of warming in winter would also mean early snow melt from the mountainous areas in the basin, thus brining changes in the stream flow pattern. These changes in the climatic trend noted in the basin clearly point to increasing possibilities of frequently occurring hydrologic and meteorological draught in the study area. This would mean progressively increasing shortage of water in the basin to meet the livelihood needs.

The normal monthly temperature of the study area was estimated to ascertain the cooler and warmer months. This clearly shows four distinct periods in terms of variations in temperature in the study area that produce the four seasons.

The pattern shows a sinusoidal variation in annual temperature during the stated period with a cycle of low and high temperature in different years. For example, in 1970 there has been a peak in the annual temperature with the highest temperature recorded in the month of August (33.6 °C). Similarly, the lowest annual temperature was in 1964 with the lowest value in the month of January (-17.5°C) in same year. Also shows increasing trends in mean, maximum and minimum temperatures though the mean annual (R^2= 0.471) and mean minimum temperature (R^2= 0.488) show more convincing trend of increase than the increase in the mean maximum temperature (R^2= 0.133). This would mean that there is increasing trend in daily minimum and mean temperature in the study area.

Rainfall in Afghanistan concentrates over five months from December to April with the highest rainfall occurring in the month of March. The period from June through October is the dry period. The pattern of distribution of monthly rainfall for the period 1957-1983 and that for the period 2003-2015. The rainfall analysis shows clear departure in the rainfall pattern in the recent times than in the past.

The comparison of monthly rainfall amount for these two time periods show reduction in the monthly rainfall amount in the period 2003-2015 than the period 1958-1983.

Annual rainfall of the stated period shows a declining trend over time with the rate of decline in the annual rainfall being 0.470 mm per annum (R^2= 0.132). The annual rainfall during the period 2003-2015 also show declining trend at the rate of 0.53 mm, however, this trend cannot be considered convincing because of smaller length of record for this period.

The pattern of distribution of monthly river flow for the period 1957-1983 and that for the period 2008-2015 shows clear departure in the river flow pattern in the recent times than in the past. The comparison of monthly river flow amount for these two time periods show reduction in the monthly river flow amount in the period 2008-2015 than the period 1960-1983.

The analysis of trend of river flow at the gauging station shows progressively declining trend in flow over time with the rate of decline in the annual flow being 0.591 m^3/s (R^2= 0.355) per annum.

The trend of both annual rainfall and annual stream flow show a declining trend though the rate of decline indicated by the slope of stream flow curve (-0.591) was noted to be larger than the slope of annual rainfall curve (-0.470) which would mean that the rate of decline in the stream flow is much higher than the rate of decline in the annual rainfall. This would also mean that rate of decline in the rainfall alone does not totally explain the rate of decline in the stream flow.

The population of Kabul city alone is estimated to have crossed 8 million. In Kabul, water use has increased significantly over recent years, due to population and economic growth and changes in the lifestyle of the people. Since much of the drinking water needs in the city of Kabul and other rural and urban areas in the basin are met from groundwater and the groundwater in the basin has declining trend, it would be important to promote regulated use of groundwater in the basin. It would be desirable to consider managed groundwater recharge as an important element of managed use of groundwater in the basin.

Considering increasing risk of future water uncertainty in the study area, it would be important to pursue irrigation development program that promotes efficiency of irrigation water use in the study area. A two pronged approach to irrigation development would be essential. While development of new irrigation systems and improvement of the physical infrastructures of the existing irrigation systems would be essential, it would also be immensely valuable to promote integrated management of crop and water in the irrigated areas to achieve increased water use efficiency in the irrigated agriculture.

8. Recommendation

Following recommendations have been made based on the findings of the study:

The findings of the study clearly point to the need of improving the management of existing water resources in the basin, and in other areas of Afghanistan, in order to address the emerging uncertainty and increasing variability of available water supply.

The four decades of armed struggle in the country has led to complete dysfunction of the institutions responsible for water resources management. Developing these institutions to plan, organize and deliver water services in the basin would be immensely important in order to manage current and future needs in the realm of increasing uncertainty of water.

Many of the findings of the study have been inconclusive in the absence of required length of climatic records used in the analysis. The temperature and rainfall data used in the analysis were those for the period 1958-1983 and 2002-2015 and that no records were available for the period 1984-2002. Similarly the stream flow data used in the analysis were for the period 1960-1980 and 2006-20015, with the missing data for the period 1980-2006. Also, these data used in the analysis were available only for few meteorological and one hydrologic station in the basin.

WMO has recommended need of minimum of 40 years of climatic records to approach robust analysis of climate change, which could not be met in this study in the absence of needed data. Another limitation of the study has been lack of snowfall data in the headwater of Kabul River which has important contribution to the stream flow

In future study on water variability in the basin, contribution of snowfall in the stream flow and likely variability resulting from temperature and rainfall changes would be immensely important in order to produce more conclusive results.

The researcher had to rely on secondary sources of information. It would be desirable to conduct field based inquiries to be able to document and analyze the variability of water as a consequences actually faced by different groups of people in the study area.

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