# 2015

## THESIS

# IMPACT ASSESSMENT OF CLIMATE CHANGE ON WATER RESOURCES IN THE KABUL RIVER BASIN, AFGHANISTAN

**Submitted by**

**Mohammad Tayib Bromand**

**Graduate School of Science and Engineering**

**In partial fulfillment of the requirements**

**For the Degree of Master of Environmental Systems and Civil Engineering**

**Ritsumeikan University, Shiga, Japan**

**Fall 2015**

**Master's Committee:**

**Advisor: Prof. Keisuke SATO**

**Prof. Naouyuki KAMIKO**

**Prof. Atsushi Ichiki**

## ACKNOWLEGMENTS

First and foremost, I would like to express my gratitude to my supervisor Professor. Keisuke SATO for his excellent guidance, encouragement and suggestions during my research at Ritsumeikan University. He gave me the opportunity to carry out my M.Eng thesis under his supervision. I honored to thank my Co-supervisor Professor Naoyuki KAMIKO for his kind suggestions. I feel honored to thank Prof. Atsushi Ichiki for his guidance and suggestions as well.

I would like to deeply thank and appreciate the leardership of the Ministry of Energy and Water for transparent process of running PEACE project and selection of best candidates for Master's degree course and dispatch to Japanese universities for the purpose of enhancement and promosion of young generation capacity, those who envolved and worked in the fram work of the ministry of energy and water.

I would like to thank all the Watershed Informative laboratory members for their kindness, supports and cooperations. It is my pleasure to thank and acknowledge Mr. Thomas J. Mack for his scientific investigations report, sharing data and recommendations for the study.

I honored to thank Prof. Mohammad Naim Eqrar, Sayed Shabair Shobair, Engineer Sultan Mahmood Mahmoodi, Enginner Azim jan and many others who shared their time, expertise, data and experience throughout this study.

My deepest gratitude goes to my family members, my mother, my father and my siblings for their prayers, support, encouragement and love that enabled me to complete my studies.

My sincere thanks to the government of Japan for providing the scholarship and financial support that enabled me to follow the master program at Ritsumeikan University. Sincerely thank to Ritsumeikan University for accepting me as one of the students.

My deepest thanks go to the PEACE-Project Director, coordinators and members for their excellent guidance, regular meetings , cooperation, talks and recommendations, that enabled me to fulfil my studies.

# Abstract

Water resources in the Kabul river basin have been increasingly stressed by climate change and population growth. Assessment of long-term impacts of projected changes in climate, population, land use and land cover and ground water availability of catchment water resources is critical to the sustainable development in the Kabul river basin. The overall objective of this study include: (1) to fully estimate water availability potential based on quantitative; (2) to apply several climate scenarios to identify the precipitation and temperature trends for the purpose of climate change impact assessment: (3) to evaluate the sectoral water demand (irrigation, domestic, environment and industries); (4) water stress evaluation in the Kabul river basin. In this study local and global data sets collected and the soil and water assessment tool (SWAT2012) model were applied to evaluate water availability potential and statistics have been applied to estimate sectoral water demand.

The model shows its capability in producing the streamflow discharge in the calibration process. The performance criteria of $R^2$ computed indicates that the model satisfactory simulates the streamflow volume in the catchment during 2008 to 2012. In the sensitivity analysis, it was found that the parameters of TIMP, SMTMP, GW_DELAY and CN were the most sensitive parameters to the model output. Using an optimum data available, three different climate change scenarios (A2, A1B and B1) being applied in the in the model for simulation of past and future water availability. The investigated hydrodynamic characteristics were rainfall, snowfall, surface water, evaporation and potential evpotranspiration. These impacts have been investigated using the SWAT model for the twenty first century. The study found that the Kabul river basin is very sensitive to population explosion and climate fluctuations, suggesting that slight increase in the mean temperature could alter present hydrologic conditions and its water resources. Based on the result obtained, by increasing mean temperature 2.9°C in the period of 2046 - 2064, the Kabul river basin will experience a water scarcity, the study area will face about 24% reduction in water availability and expected that potential evapotranspiration increase about 18%. SWAT successfully achieved the aim of this study; to test its capability as a hydrological model for climate impact assessment and to assess the impact of climate change on water resources in the study area. Nevertheless, uncertainty cannot be avoided in this study since the utilization of the modelling for making the future prediction.

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# CHAPTER ONE

# INTRODUCTION

## 1.1. Background

Water supply is threatened by increasing population growth and climate change since the last century. the population of Kabul river basin increased two times since 2000. Using of nonrenewable energy has increased respectively, means demand for water is increasing due to population explosion and climate chage resulted water stresses in the Kabul river basin [1]. By decreasing surface water supplies, ground water consumption have been quickly expanded which has resulted in aquifer depletion. For instance, 2 meters in the shomali and panjshir sub basins, more than 4 meters paghman and central Kabul [2] Nearly all shallow well supply wells affected to the same degree in different areas such as upper Kabu, middle Kabul and lower Kabul as well. By adding another factor, climate change, the competition between water demands ( urban development, agriculture) is becoming more severe. The increasing amount of carbon dioxide ($CO_2$) can lead to changing the global climate drastically during this century [3] By increasing amounts of carbon dioxide and concentration of greenhouse gases, the average temperature of the earth's atmosphere rising since the 19th century. This is known as the global warming phenomenon. Global warming can have important effects on the water resources and water demands like urban and agricultural uses. Precipitation and Evapotranspiration, two important Hydrologic variables, can be altered by changing temperature. Understanding the interaction of climate and water resources can help researchers and policy makers to mitigate the negative effects of global warming by introducing proper management scenarios. There is anticipation that water resources will be increasingly stressed by climate change, therefore the gap between water supply and demand for water will expand. In general, with warmer weather, water demand is anticipated to increase while the water supply is anticipated to decrease. For instance, agriculture consumption, which is the major demand for water supply, will be increased due to both decreasing precipitation and increasing Evapotranspiration. In water stressed basins, where the water demand is already approaching the available supply, the impacts of climate change can be especially severe. To address this need, this study evaluates the impact of climate change on available water resources in one of five river basin of Afghanistan known as Kabul river basin using SWAT model. In a big portion of my study area SWAT model applied to evaluate the water availibiliy potential and climate change and other drivers that water managers commonly confront.

## 1.2. Problem statement

In the Kabul River Basin the available land and water resources are not utilized effectively to improve the livelihood and socioeconomic conditions of the inhabitants. The existing land and water resources system of the area is adversely affected by rapid growth of population and climate change, land degradation and deforestation. Effects of climate change on the water resources in the Kabul river basin significantly causing changes in quantity, type (snow or rain) and timing of precipitation on the other hand, intensive population growth in the upper Kabul causing water scarcity. The most populated parts of Kabul river basin such as Kabul and Nangarhar widely consuming ground water with poor quality which is drastically caused to decline ground water level. Simulated ground water level declines were large in the western part of the central Kabul sub basin [4]. This area receives very little recharge from direct precipitation and the dense population creates the greatest water demand. Different climate and water balance models have been developed to estimate potential impacts of climate change. But all these models required field reliable and accurate data such as precipitation, temperature, streamflow runoff and evapotranspiration. Lack of availability of reliable historic meteorological records, complex topography make modelling more difficult. However the reliability global data sets verified with observed data prior to model application. Soil and water assessment tools (SWAT) model was used to evaluate water resources availability and project precipitation and temperature change for the case study, Kabul river basin. In contrast to the assessment of variations of the climate driving force for regional hydrology, the trends and impacts may be different on a watershed to watershed or from sub-basin to sub-basin scale. Therefore, in order to focus on the assessment of the relationships between climate change, water availability and water demand –supply management on the catchment scale integrated hydrological components required. In this regards, two research questions were defined.

i. How sensitive is the study area to climatic change with regard to its water available?
ii. What is the impact to the water quantity in the study area? Will it decrease or increase?

## 1.3. Study objective

The overall study goal is to demonstrate the use of the modeling framework to assess the impacts of climate change on a vulnerable Area, Specifically the selected area of the Kabul river basin.The study objectives are:

- Estimation of current (2008-2012) available water resource potential using the SWAT2012 model in the Kabul river basin (whole basin).
- Future water availability assessment based on climate change scenario analysis till (2064).
- Water supply and demand (Agriculture, Domestic, Environment and Industry) analysis and water stress evaluation and projection.
- Present and future water stress estimation based on population explosion and climate change.

## 1.4. Limitation of the study

The first and foremost limitation of this study was the non availability of reliable observed meteorological and hydrological data to be representative of all elevations in the Kabul river basin. After 2004, 29 Hydrometeorological stations installed across the Kabul river basin [5], due to insecurity and technical problems, some of these stations are not recording properly and only few stations which are located in the plain areas of the basin records meteorological condition but cannot be representative of hilly and more hilly areas of the basin. To fill this gap, research on many global climate data sets preformed. Near real time precipitation records with unique records to be representative of hilly and semi hilly areas, TRMM dataset selected, after comparison with observed data obtained from the Ministry of Energy and Water. Then, applied TRMM for further studies for Water resources potential assessment in the Kabul river basin.

## 1.5. Thesis layout

This thesis contains eight chapters and organized as follows: Chapter one gives a general introduction to the study area with its objective, relevance and research questions. Chapter two deals with the materials and data set explanations adapted for the study. Chapter three describes Hydro-meteorological data processing and comparing. Chapter four related to Hydrological modeling. Chapter five deals with sectoral water demand analysis. Chapter six concerned with climate change and water stress assessment. Chapter seven describes result and discussion. Chapter eight contains conclusions and recommendations of the study.

## 1.6. Afghanistan river basins overview

Afghanistan is a landlocked country with a total area of about 652000 km$^2$. It is bordered by Turkmenistan, Uzbekistan and Tajikistan to the north, China to the northeast, Pakistan to the east and Iran to the west. Afghanistan, according to its topography and water resources divided into five major river basins [27]. These river basins are consisted in: (1) Kabul river basin, (2) Helmand river basin, (3) Harrirud-Murghab river basin, (4) North river basin and (5) Amu river basin. The map of all these river basins shown in figure 1.1.

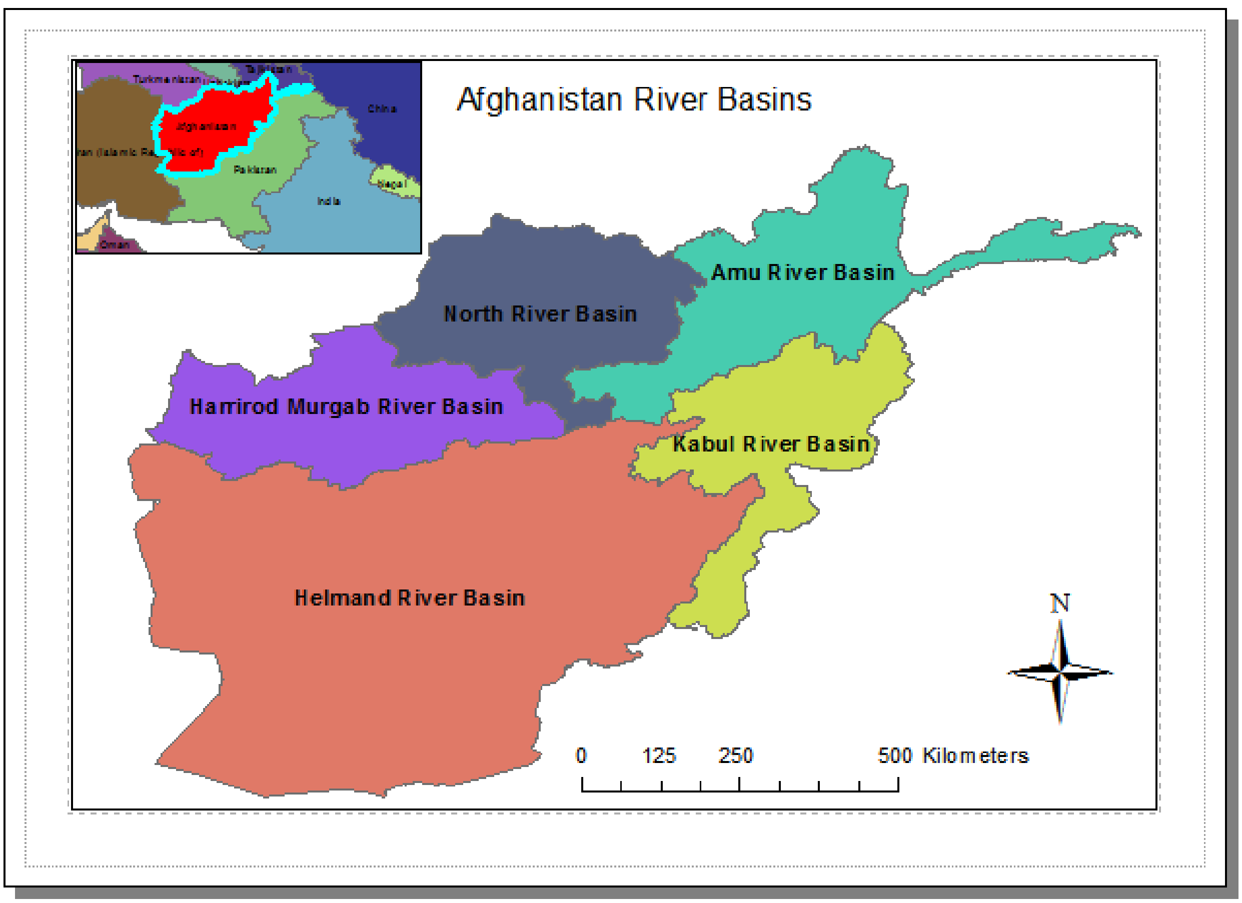



**Figure 1.1 Five river basins map**

## 1.7. Study area

### 1.7.1. Location

The Kabul River Basin is Trans-boundary catchment. It is located in the eastern part of Afghanistan and Chatral valleys of Pakistan. It lies between 33 ° - 37 ° N latitudes and 67 ° - 74 ° E longitudes as shown in figure 1.2 with the drainage area of 65202 $km^2$. This basin is divided into 23 sub-basins and 10 provinces, including Kabul, located in this drainage area. The upper catchment of the Kabul river basin consists of steep mountain valleys in the Hindukush mountain range, which reaches over 7500 meters above the sea level. The Kabul river basin is divided into four distinct areas [6]. (1) The logar-maidan Kabul areas includes three river branches such as, the Maidan, Paghman and Qargh rivers, originates from upstream of Kabul. (2) Panjshir-Ghorband area contain three tributaries such as, Ghorband, Salang and Shatul rivers. (3) Lower Kabul comprises an area which is influenced by Panjshir and Maidan rivers in this distinct area. It comprises two large sub-catchment to the north and contains rivers such as, Kunar and Laghman rivers. Finally, all these tributaries and rivers joint in the Aba area of Nangarhar province and pass the border throughout the Pakistan territory.

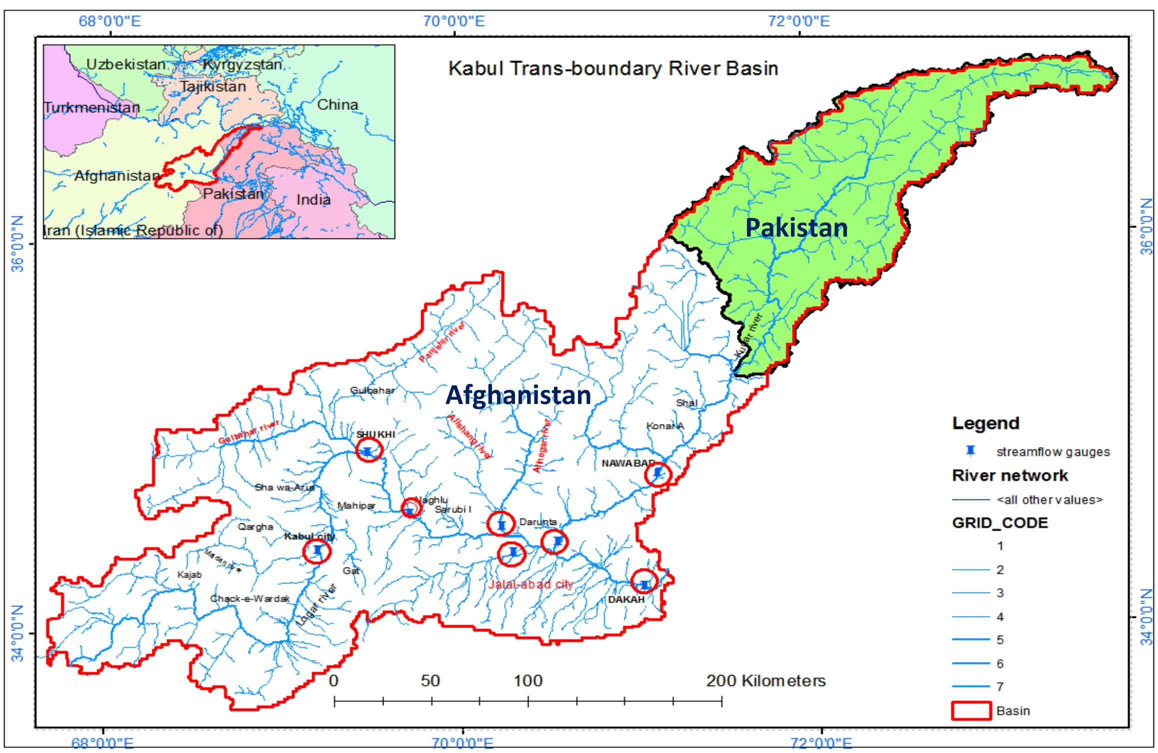



**Figure 1.2 Study area, The Kabul river basin map.**

### 1.7.2. Climate

The Kabul river basin experiences a semi arid and strongly continental type of climate [7] with major daytime and night-time temperature fluctuations. It is characterized by hot summer and cold winter. The mean annual precipitation estimated (516 mm) figure 1.3 and the annual average temperature estimated (9°C) Figure1.4 Maximum precipitations occur during the winter season, including December, January and February. Minimum precipitations are expected to occur during the summer season, June, July and August. The temperature and precipitation in the Kabul river basin differ from watershed to watershed, these climate elements depend on elevation. The maximum temperature measured (48°C) in the Kabul river basin in Nangharhar region, which is located in the plain area in the summer and minimum temperature (– 28°C) recorded in the Chatral valley in the high elevation which is located in the east part of the catchment.

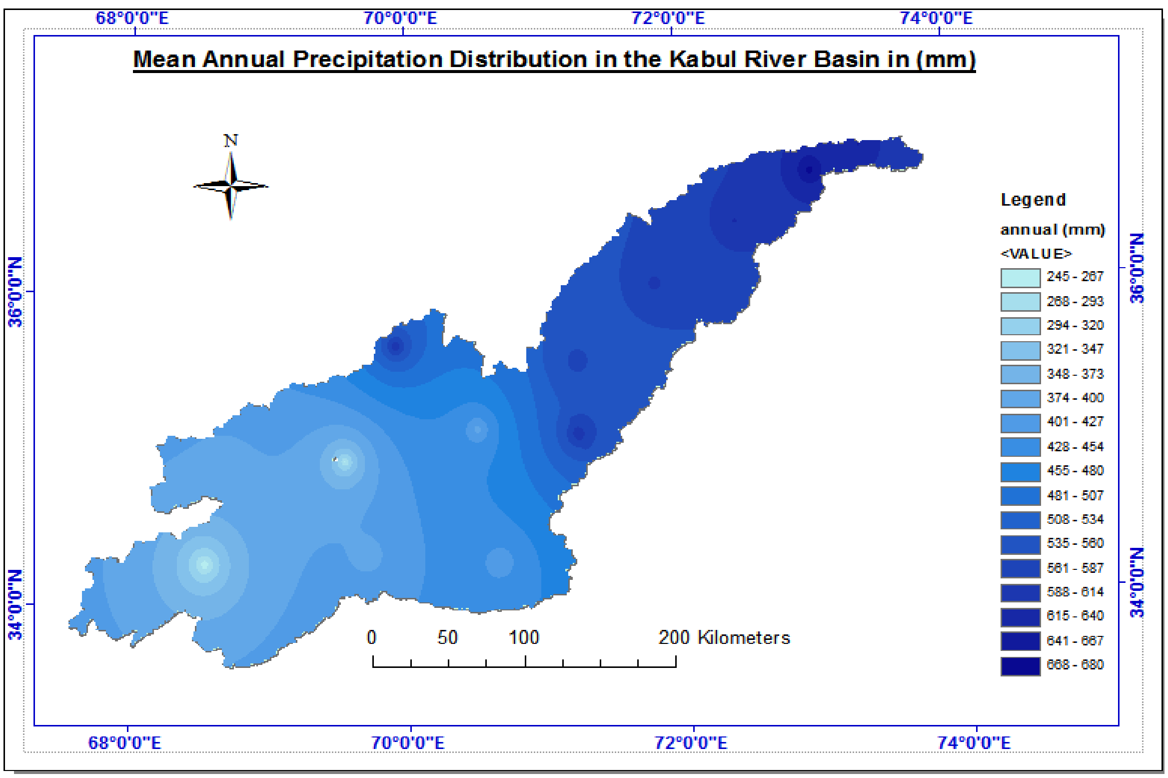



**Figure. 1.3 The mean annual precipitation distribution in the Kabu river basin from (2007- 2012). Data sources: Tropical Rainfall Measuring mission (TRMM).**

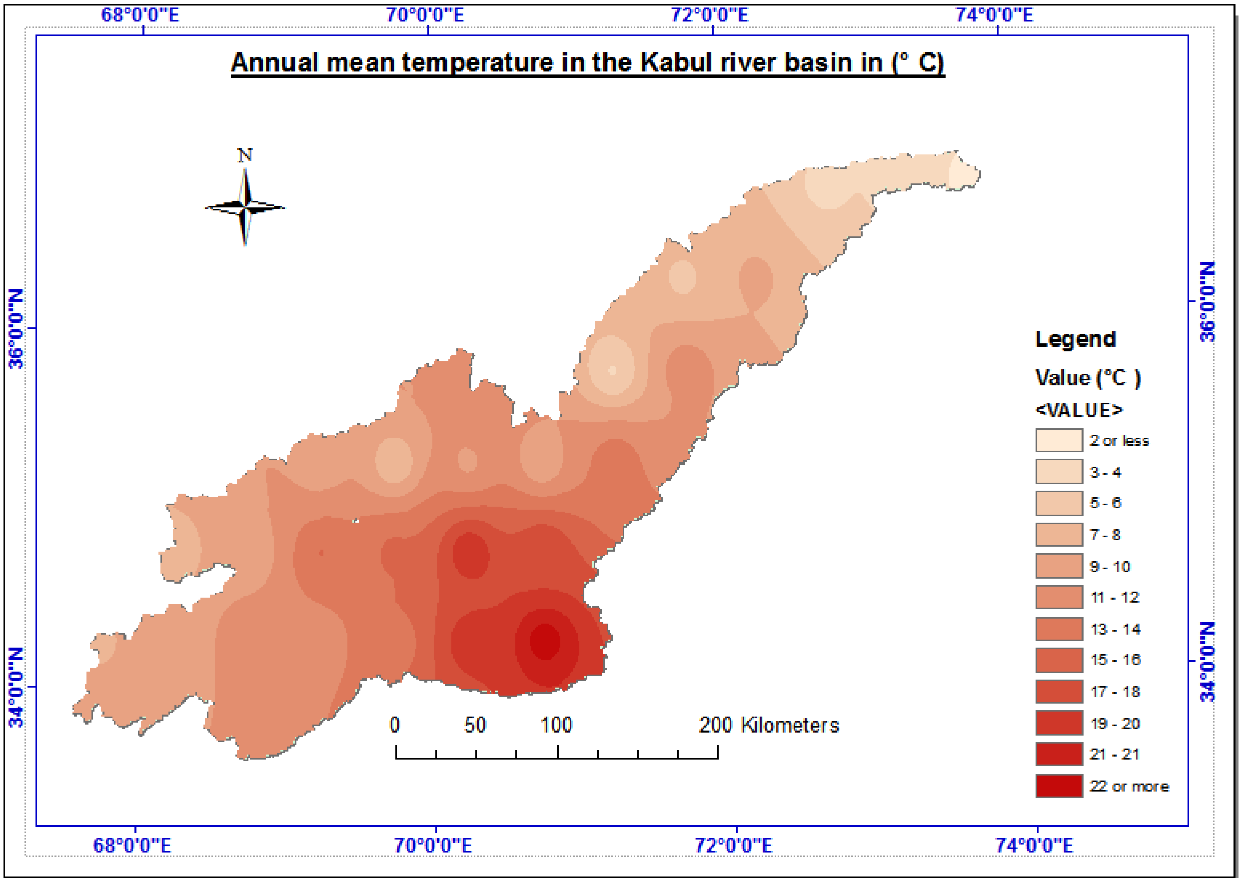



**Figure 1.4 T annual average precipitation distribution in the Kabul river basin from (2007-2012). Data source: National Centers for Environmental Prediction (NECP).**

### 1.7.3. Water resources

The snow pack in the mountains in the north and northeastern regions in the river basin constitutes the major runoff in the basin so water supply varies from year to year. In general, more than 72 percent of the runoff occurs between May and September and 40 percent occurs between October to April. A trans- Basin division also transports water from the Chateral valleys, Pakistan to the Kabul river basin Figure 1.5. There are dams and reservoirs and lakes in the basin and their functions for generating electricity, irrigation and domestic water use are important. The peak runoff generally is during June and July due to snow melt while the peak demand for water usually is during July and August because of demand from the Agriculture sector. Furthermore,There are some reservoirs and lakes are used for irrigation, domestic purposes. There are four aquifers in the Kabul area [8]. The Paghman-Darulam area has tow aquifers lying along the course of the Paghman river and the upper Kabul river. The two other aquifers are located in the Logar sub basin.  The main sources of recharge for this aquifer are infiltration of surface water from the river, irrigation and the ditches and canals. These aquifers are the main source of domestic water supply and supplemental for irrigation purpose.

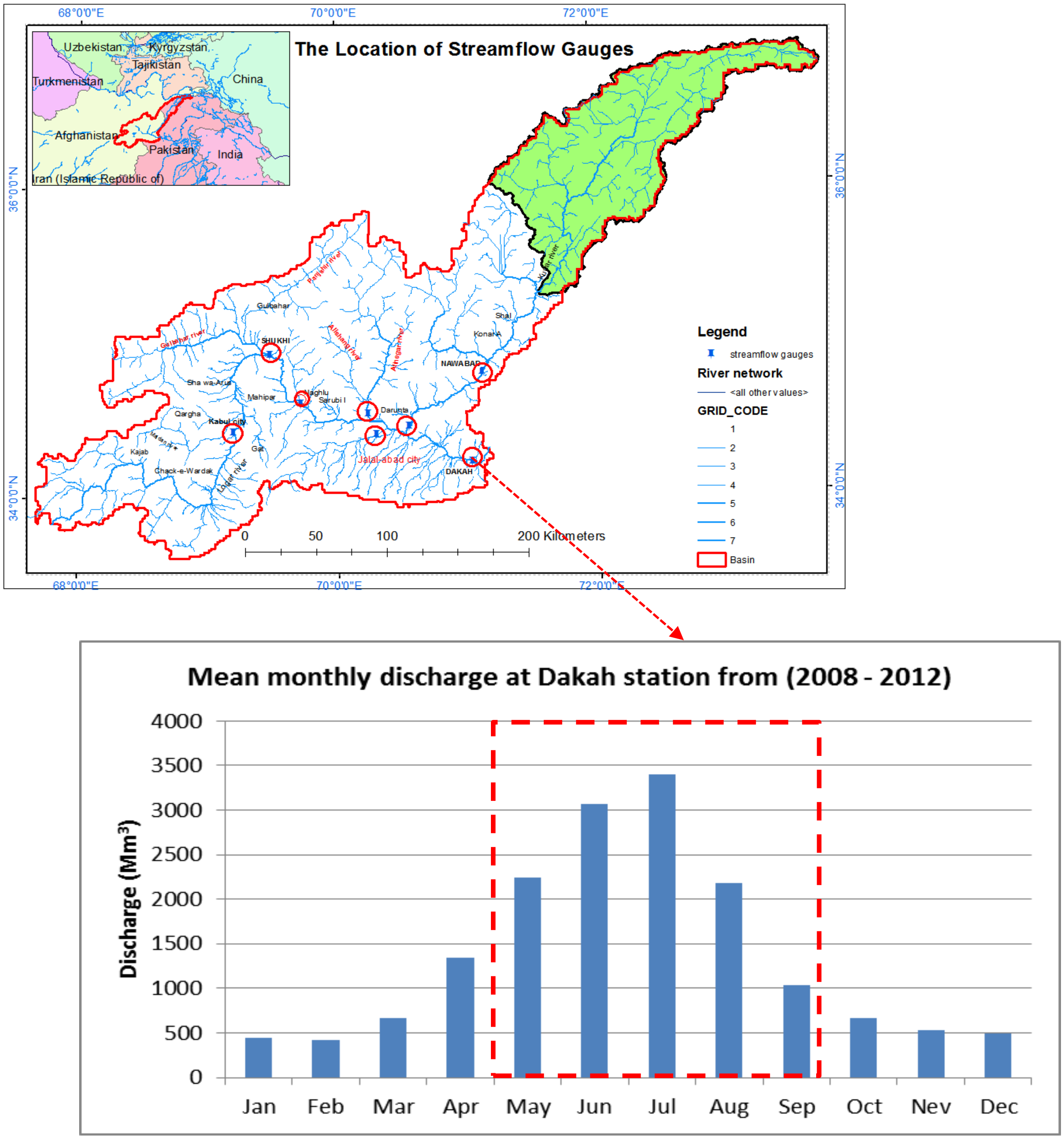



**Figure 1.5 Mean monthly discharge at Dakah station in the period of 2008 – 2012. Data source:Ministry of Energy and Water.**

# CHAPTER TWO

# MATERIALS AND DATASET

## 2.1. Data collection

Data gathering is the most important step toward the hydrologic modelling, demand evaluation and climate change assessment. In this study, the following datasets are collected and used to estimate potential water availability, sectoral water demand and climate change impact assessment in the Kabul river basin: (1) Digital Elevation Model (DEM) downloaded from NASA website, (2) poor and incomplete daily and monthly hydrological and meteorological data were collected from the Department of Water Resources (DWR), Ministry of Energy and Water (MoEW) and Ministry of Agriculture, Irrigation and livestock (MAIL), Kabul, Afghanistan, (3) dialy precipitation obtained from Tropical Rainfall Measuring Mission (TRMM) in NASA, (4) daily temperature downloaded from (CFSR) website, (5) Land cover raster obtained from USGS, (6) Soil dataset downloaded from FAO/UNESCO website, (7) population raster obtained from SATO Keisuke, my academic advisor (8) Climate scenarios, B1, A1B and A2 and climate change models daily data, such as precipitation and temperature downloaded from, CCCMA CGCM3.1, MIROC3.2(medres), GFDL CM2.1 and CNRM-CH3 wibsites.

### 2.1.1. Digital Elevation Model

Topography was defined by DEM that describes the elevation of entire the points and the area at the specific resolution. DEM with resolution of 30m*30m ($\sim 1km^2$) as show in Fig 2.1, was downloaded from SRTM (Shuttle Radar Topography Mission) website on March 2014. The data sets are mosaicked and projected in UTM projection using GIS10.2. The DEM was applied in the SWAT model to delineate the watersheds and to analyze the drainage patters of the land surface terrain. Subbasin parameters such as slope gradient, slope length, and stream network characteristics such as primary, secondary streams and rivers which were derived from the DEM.

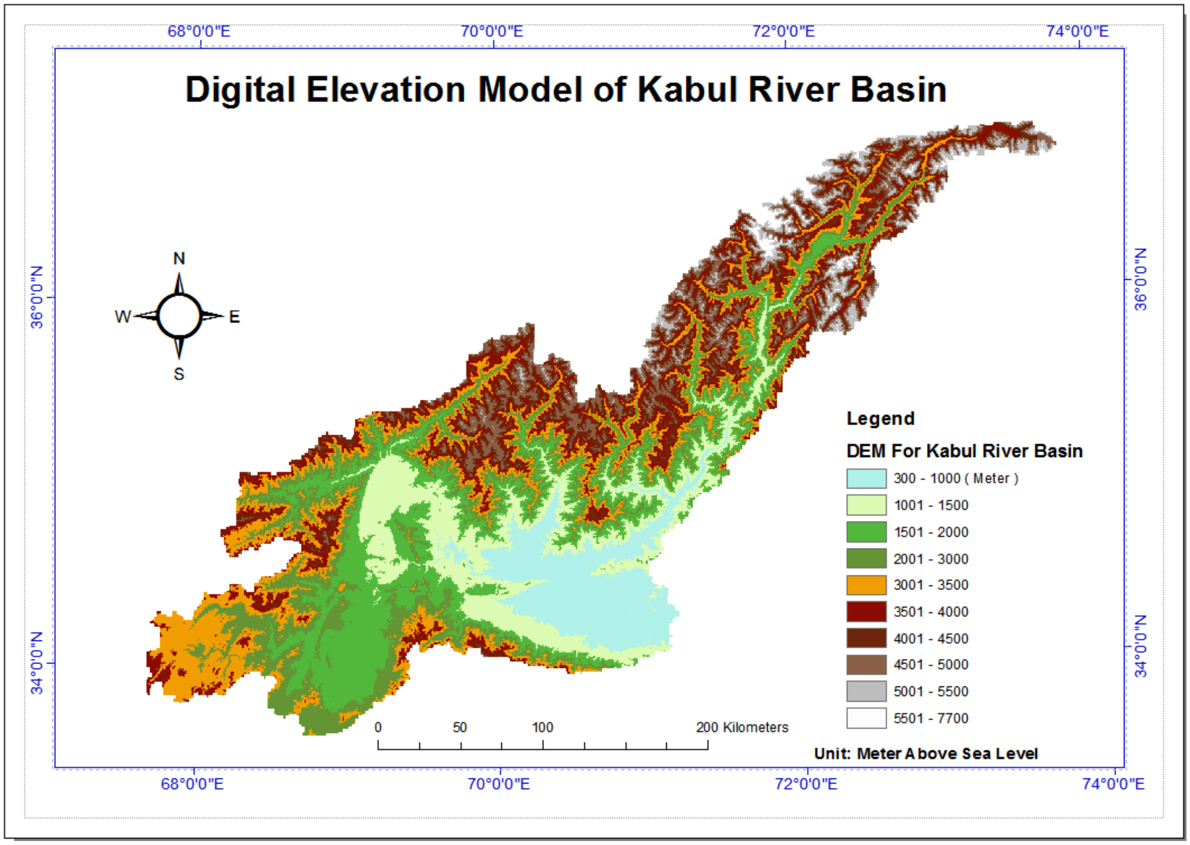



**Figure 2.1: Digital Evevatin Model of Kabul river Basin. Source : NASA**

### 2.1.2. Meteorological Data

Lack of a sufficiently dense network of weather station for measuring precipitation and temperature in the Kabul river basin was the main obstacle for my research. Since 1967 till 2006 there is a gap of meteorological records in the study area due to insecurity and civil war [9]. From 2006 up to now, Ministry of Energy and Water with financial cooperation of World bank installed 31meteorological stations in the Kabul river basin [10], but the majority of these stations due to insecurity and technical problem do not record properly. In my field trip to Afghanistan on October, 2014, only obtain 8 Hydro-meteorological stations data from 2008 to 2012 in an area of greater than 65202 Km$^2$. This is far below the World Meteorological Organization (WMO) standard of one station for 100 to 250 km$^2$ of area for the mountainous region [11]. There are no weather stations in the high altitude of 3000 meters above sea level is this basin, however the majority of this basin area is over 2500 meters above sea level as shown in figure2.1, where the majority of precipitation occurs as snow in the winter season and early in spring. However, all these 8 stations are located in the most flat and plain area of the basin as shown in figure 2.2. On the other hand, these stations due to security problem can not operate regularly. Even these existing stations which are operating after 2006, are full of errors and missing records during the months and years of their records. The detailed method for Hydro-meteorological data filling and screening and comparison of observed precipitation from two sources, MoEW and MAIL and TRMM stations for data quality assessment will describe in the chapter three.

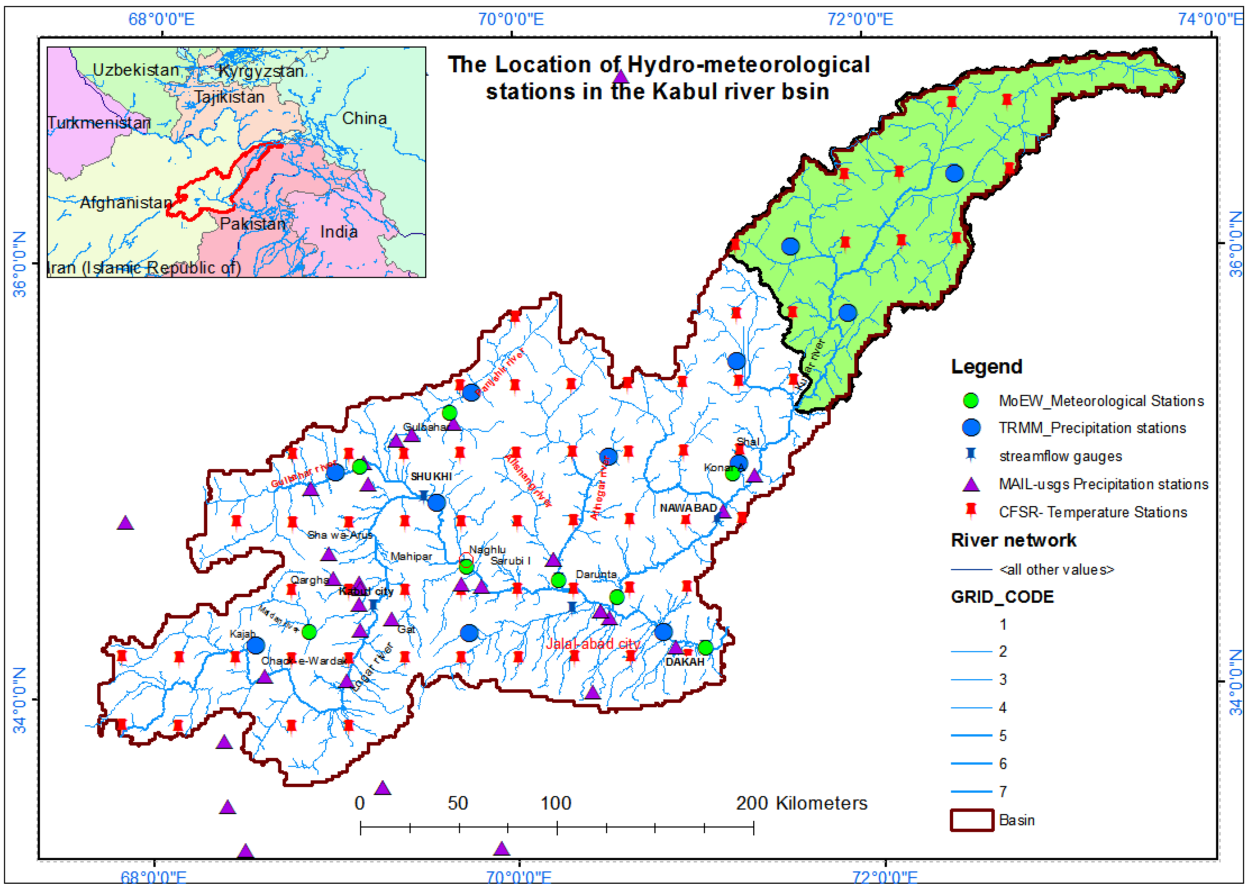



**Figure 2.2 Hydro-meteorological stations from five sources in the Kabul river Basin.**

### 2.1.3. Tropical Rainfall Measuring Mission (TRMM)

TRMM, Tropical Rainfall Measuring Mission, was launched by the H-11 ricket from Tanegashima Space Centre of The National Space Development Agency of Japan (NASDA) on 28 November, 1997. This satellite has been developed as a joint project between Japan and US, which is the first space mission dedicated to measure rainfall (NASDA, 2001), TRMM works by combining both TIR and MW sensors [12]. The MW channel carefully measures the minute amounts of microwave energy emitted and scattered by the earth and its atmospheric constituents. TRMM also operates in active radar. TRMM satellite orbits the earth at a 35° inclination angle with respect to the equator. TRMM covers an area of the earth's surface that extends well beyond the tropics, covering a swath between 38°N to 38° S. TRMM makes these data available in both near real time and delayed research quality formats. The TRMM rainfall products have a spatial resolution of 0.25° and a temporal resolution of 3h. For this study, 12 station points have been selected and downloaded the TRMM product 3B42 version7, and used to fill ground data gaps, compared with ground precipitation records for quality assessment and applied TRMM daily data in the SWAT model for annual water availability estimation. For detail description, see the chapter three.

#### 2.1.4. Ministry of Agriculture, Irrigation and Livestock Weather Stations

The Ministry of Agriculture, Irrigation and Livestock (MAIL) and The USGS Agromet project was initiated in Afghanistan in 1st January, 2004 to install Agro-meteorological stations all over the country for the purpose of agriculture development services. This project installed 87 precipitation recorders in the most flat and plain areas of five river basins [13] The MAIL/USGS project has 90 observers to record daily precipitation and developed an Agrometeorological database and information system from 2004 till new. The Agromet project is working closely with the United States Geological Survey (USGS), regular data analysis and transmitted regularly to over 1150 local and international users around the country and outside the country as well. In my field trip to Afghanistan On October, 2014, I have obtained monthly precipitation records of 87 stations in five river basins. In my study area, I have applied 31 stations which are located in my study area and compared four stations of this source with other stations sources for quality assessment. The detail description of comparison shown in chapter 3. The overall comparison of blocking method shown that, Agromet stations have very good quality of precipitation records in the flat areas. The location of the stations shown, in figure 2.2.

#### 2.1.5. Climate Forecast System Reanalysis (CFSR)

The CFSR was designed and executed as a global, high resolution coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains for the study period. It is the first reanalysis system in which the guess fields are taken as the 6h forecast from a coupled atmosphere ocean climate system with an interactive sea ice component and assimilates satellite radiances rather than the retrieved temperature and humidity values. The CFSR global atmosphere data has a spatial resolution of approximately 38 km and Precipitation, Temperature, Solar radiation, Humidity and Wind speed data are available from 1979 till 31/7/2014 globally, for my study area, I have obtained 64 temperature stations which are appropriately covers all my study area, and applied in the SWAT model for the purpose of water availability estimation in the Kabul river basin as shown in figure 2.2**.**

#### 2.1.6. Landcover/Landuse data set

The 1981-1996 Land cover dataset had downloaded from Global Land Cover Facility (GLCF) with a resolution of (1km) was used for the land use and land cover baseline. And 0.5 km MODIS-based global land cover dataset (2001-2010) also added for comparison. All land use and land cover classes were aggregated into seven major categories according to their hydrologic properties. These include rangeland, grassland, mixed forest, barren, cropland, settlement and water. Land use is a major driver for hydrologic model estimates of watershed scale evapotranspiration. Land use change at the basin level from 1981 to 2010 assessed based on SWAT model. Changes in land area allocation among settlement, water rangeland, grassland, mix forest and agriculture land and land cover and land use change could be driven by population increases and housing values. Analysis of two land cover data sets and comparison of them uses, Arc SWAT2012 suggest that, urbanization dominates land use changes in patterns. Urban areas increased from 11215 hectares in 1982 to 14692 hectares by 2010 which shows 31% increase, Rangeland  and mixed forest shown a decrease in the area of -22 percent, - 56 percent respectively. Water body, grassland, cropland and barren saw decreases in the area of 17 percent, 12 percent, 183 percent and 84 percent in the Kabul river basin respectively. The overall trend of land cover /land use in the basin described by hectares and percent in figure 2.3.

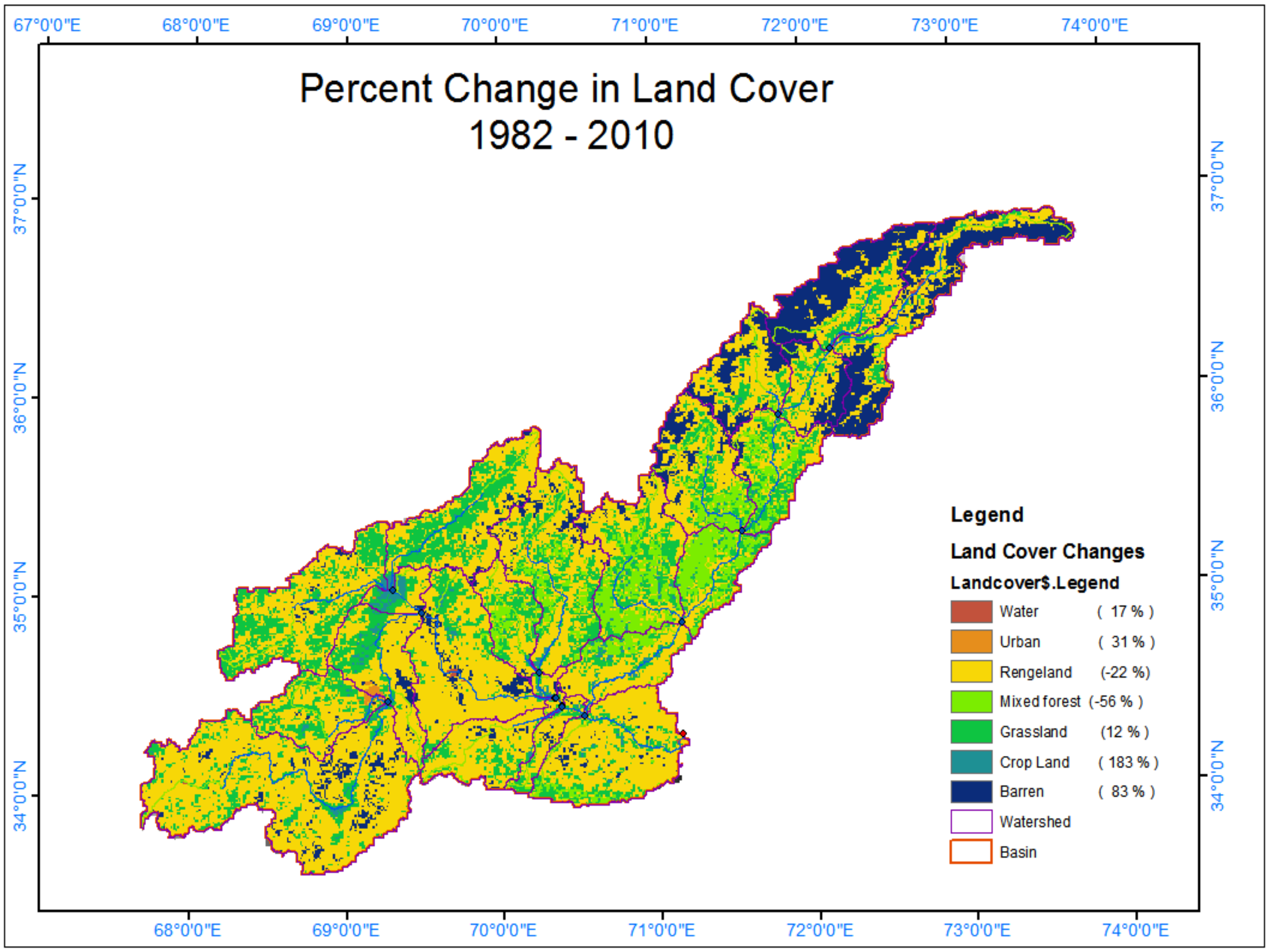



**Figure 2.3: Land cover changes in 28 years in the Kabul river basin.**

### 2.1.7. Soil classification

The SWAT model requires different soil textural and physic-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. In this study, soil dataset obtained from FAO/UNESCO-ISWC (FAO/UNESCO-ISWC, 1998) with the resolution of 90m*90 meter and projected based on UTM, then applied in SWAT in Hydrological Respond Unite (HRU). Definition of soil characteristics mentioned in shown in figure 2.4

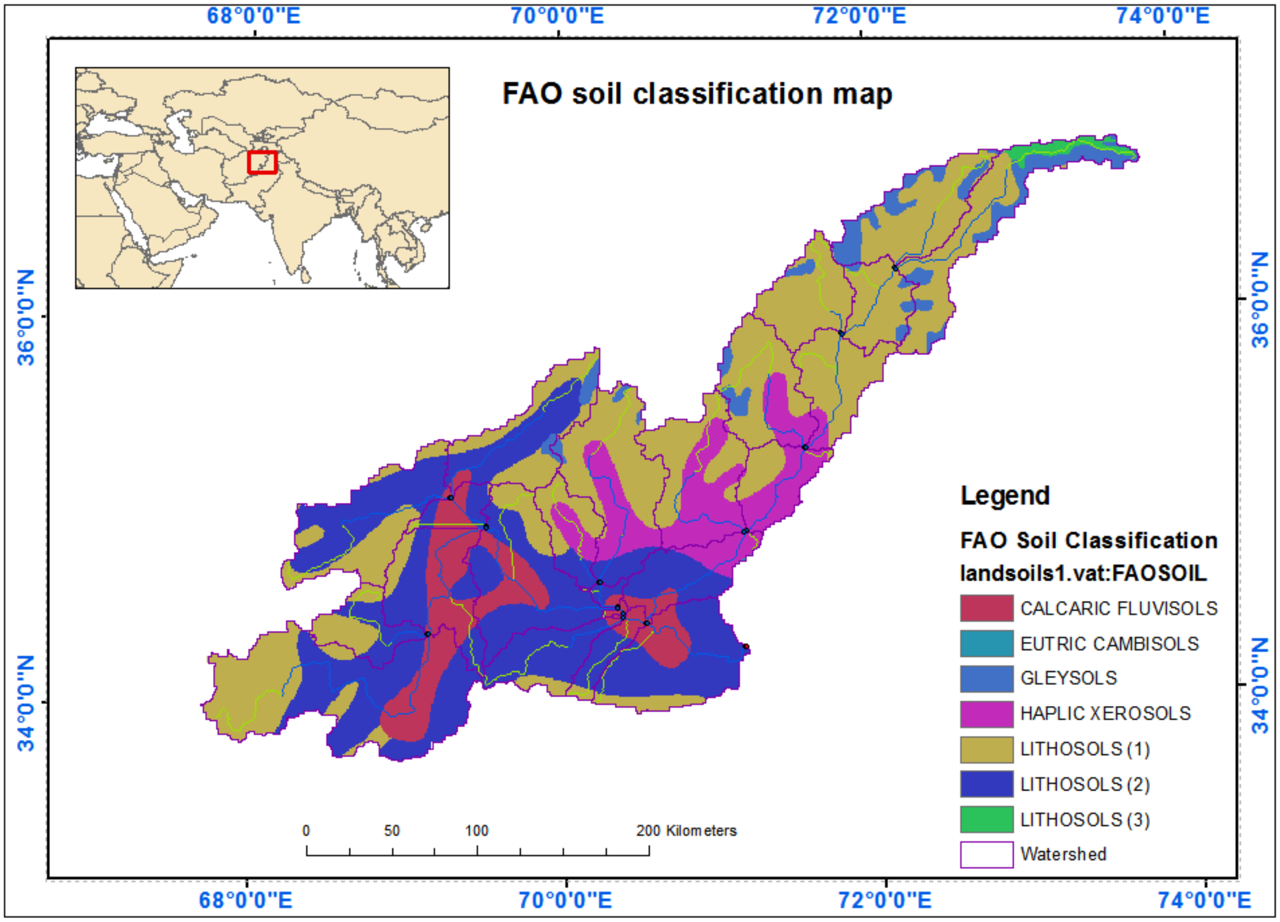



**Figure 2.4 Soil classification map of Kabul river basin**

### 2.1.8. Population data

To analyze water availability in the catchment or reviver basin, population data are important. I have obtained population raster data as LandScan raster data set of 2000 and 2005 from Professor SATO Keisuke my academic advisor, Watershed informative laboratory. The LandScan global population database has developed by Oak Ridge National Laboratory (ORNL) for the United States Department of Defense (DOD). Today this dataset widely use all over the globe for the purpose of research and academic investigations. I have applied GIS 2012 for zonal statistic and extraction of the population in my study area, Kabul river basin including its 23 sub-watersheds. The Identifying population growth rate is a crucial element for long term sustainability analysis. It represents a fundamental indicator for water resources planning and decision making in the Kabul river basin.

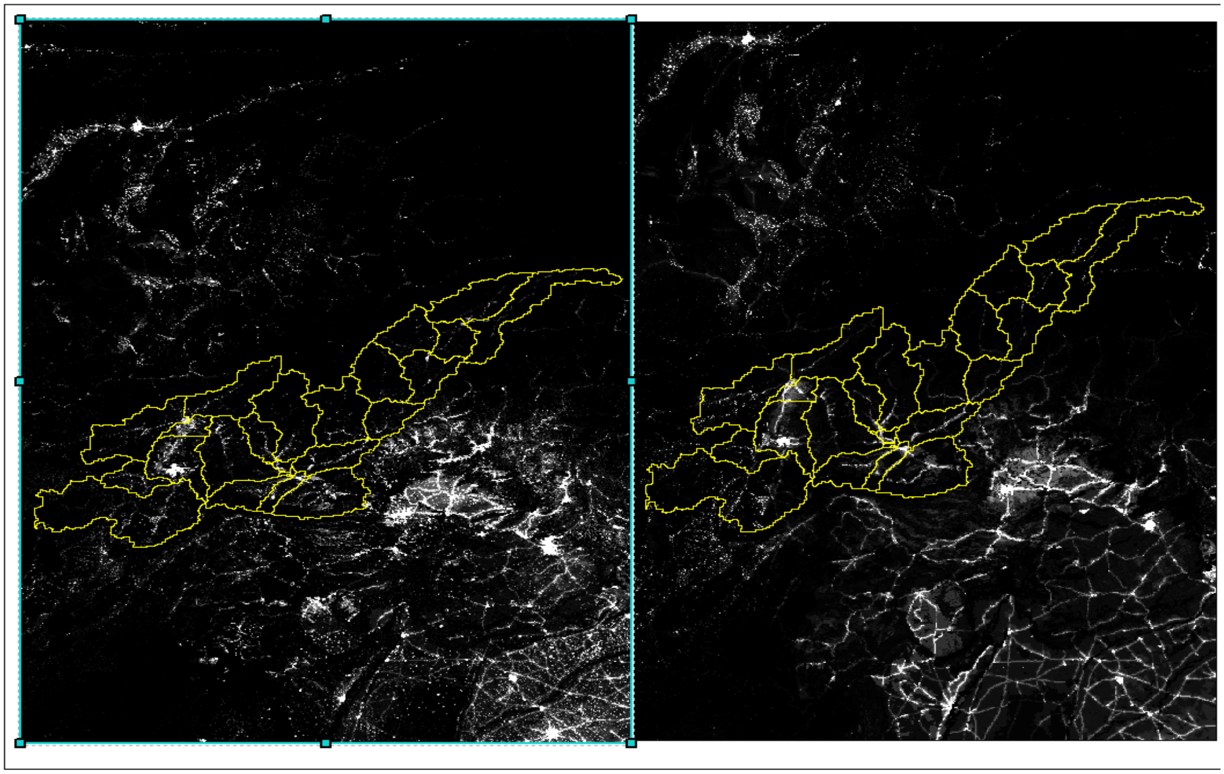


**Figure 2.5 Global population dataset sub-watershed boundaries**.

### 2. 2. Climate Change Scenarios

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) to assess the Environmental and socioeconomic implications of climate change [14]. The intergovernmental panel on Climate Change (IPCC) developed long-term emissions scenarios in 1990 and 1992 these scenarios have been widely used in the analysis of possible climate change [15].These changes in understanding relate to, e.g. the carbon intensity of energy supply, the income gap between developed and developing countries, and to sulfur emissions. The latest IPCC assessment report stated that Earth’s average temperature is unequivocally warming. The report documented that anthropogenic factors (due to human activity) are responsible for most of the current global warming [16]. The primary anthropogenic source is the emission of greenhouse gases such as carbon dioxide, which is mainly produced by the burning of fossil fuels. Although scientists are confident about the fact of global warming and climate change due to human activities, substantial uncertainty remains about just how large the warming will be and what will be the patterns of change in different parts of the world. A world range of emission scenarios was developed by the IPCC in a Special Report on Emission Scenarios (SRES), the main scenario storylines are as follows:

- **A1** Storyline describes a world of rapid economic growth and rapid introduction of new and more efficient technology.
- **A2** Storyline describes a very heterogeneous world with an emphasis on family values and local traditions.
- **B1** storyline describes a world of dematerialization and introduction of clean technologies.
- **B2** Storyline describes a world with an emphasis on local solutions to economic and environmental sustainability. The SRES team defined four narrative storylines shown in figure 2.6

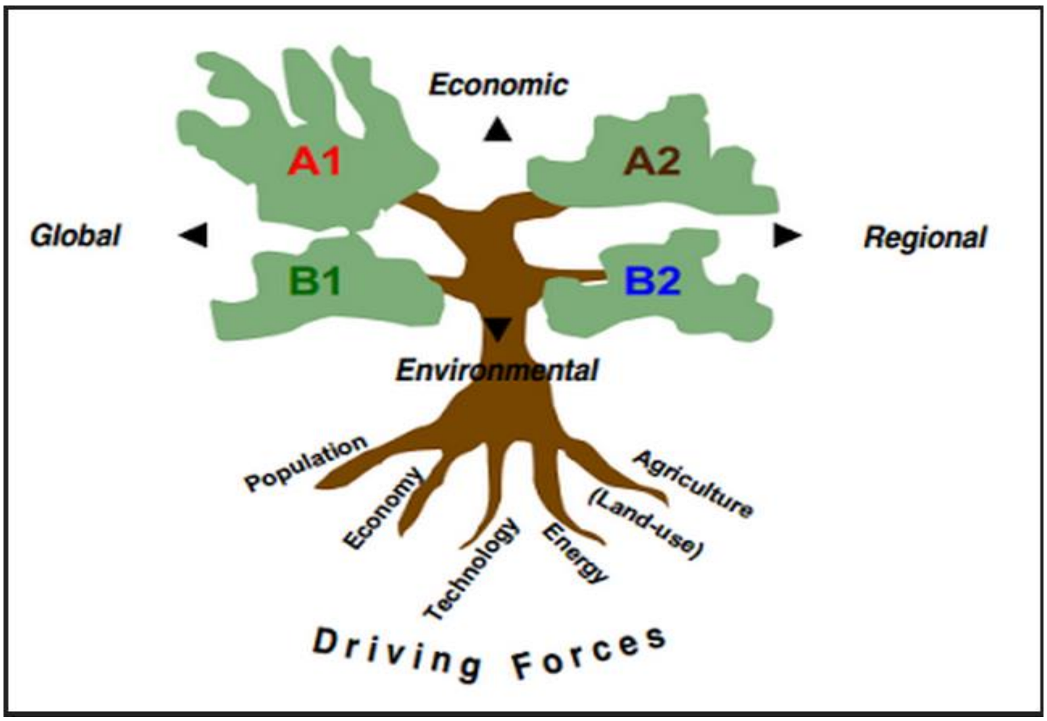



**Figure 2.6: labelled A1, A2, B1 and B2, describing the relationship between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways (IPCC, data simulation)**

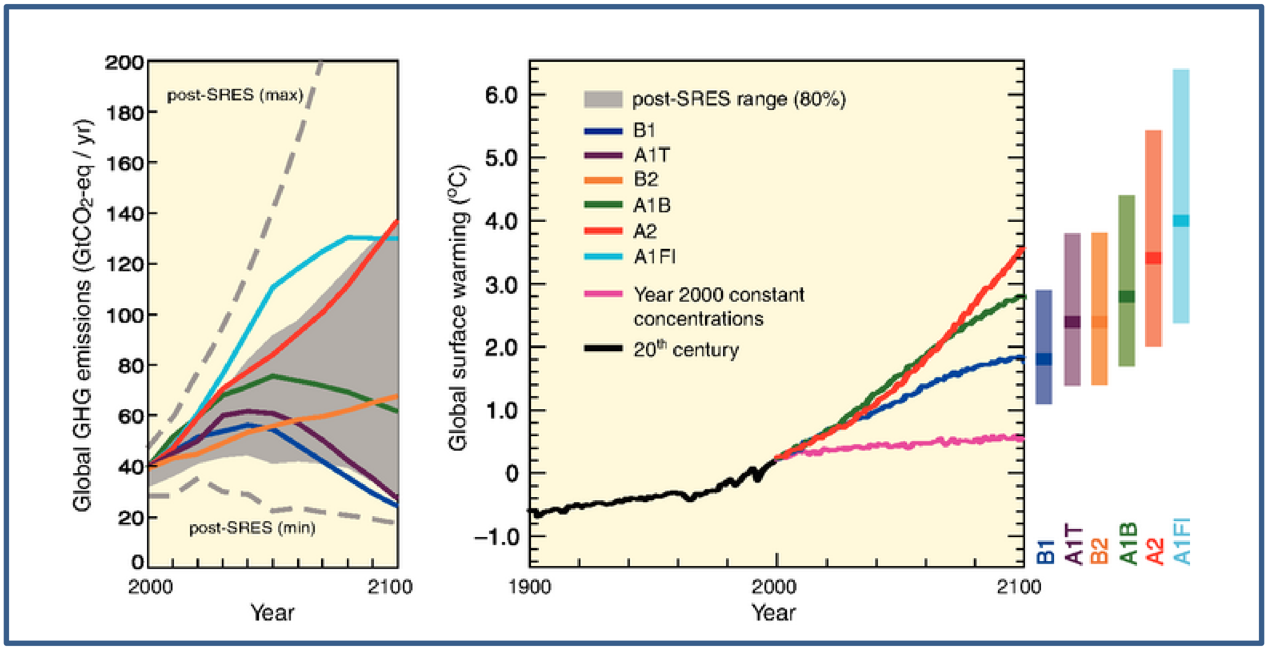



**Figure 2.7 Global warming projection to the year 2100 based on climate change scenarios.**

### 2.3. Global Circulation Models

The Global Circulation Models are the most complex of climate models, since they are attempt to represent the main components of the climate system in the three dimensions. GCMs are the tools to perform climate change experiments from which climate change scenarios can be constructed [17]. The GCMs output used in this chapter were prepared to investigate the impact and uncertainties of climate change on the Hydrology of the Kabul River Basin (KRB). A set of four criteria was used to select representative GCMs for the KRB. (1) Availability of daily precipitation and temperature, (2) positive correlation coefficient of monthly average observed and GCMs output, (3) heterogeneity of model source such as country or sponsor institution (4) applicabe to apply in the SWAT model. A peirod of 1950- 2000 is used as a baseline and the future period 2046 2064 were downloaded from for GCMs as listed in the table 3. For the evaluation of GCMs rainfall and temperature as recommended by WMO in assessments of climate model performance. Four GCMs with daily simulation outputs or rainfall and maximum and minimum surface temperature were applied in the SWAT model to assess the variation of hydrologic components in the past, present and future. List of GCMs which are applied in this study shown in the table 2.1

**Table 2.1 List of GCMs used for this study with daily mean precipitation, maximum and minimum temperature data availability for A1B, A2 and B1 SRES scenarios.**

| No | CMIP3 ID | Organization Group | Country |
|---|---|---|---|
| 1 | MIROC 3.2 (Med) | Center for Climate System Research (The University of Tokyo), National Institute For Environmental Research, Studies, and Frontier Research Center for Global Change (JAMSTEC) | Japan |
| 2 | CGCM 3.1 (T47) | Canadian Centre for Climate Modeling and Analysis | Canada |
| 3 | GFDL-CM2.0 | US Department of Commerc /NOAA/ Geophysical Fluid Dynamics | USA |
| 4 | CNRM-CM3 | Meteo-France /Centre National de Recherches Meteorologiques | France |

# CHAPTER THREE

# DATA PROCESSING AND COMPARING

Regression –based approach and Normam ratio methods for precipitation and temperature data reconstruction has been used to fill the gaps in the series of meteorological data in 8 staions which obtained for my study area, form the Department of Water Resources, Ministry of Energy and Water, Kabul, Afghansitan. The method presented is characterized by a dynamic selectin of the reconstructing of stations and of the coupling period that can precede or follow the missing data, each type of gap considerd as specific approach. Identifying the best set of stations and the period that minimizes the estimated reconstruction error for the gap. Thus permitting a potentially better adapting to time dependent factors affecting the relationships between stations.

## 3.1. Meteorological data screening

Appropriate collecting and processing of data which is very important for local flood forecasting and accurate water potential estimation [18] On October, 2014, I traveled to Kabul, Afghanistan. The main objective of this trip was Hydro-meteorological data collection. 8 meteorological stations with daily records of Precipitation and temperature and 8 hydrologic station with daily discharge records from 2008 to 2012, obtained form the Department of Water Resources, unfortunately, there were wide gaps in daily, monthly and yearly records in these observed stations, for example, Dohabi station recorded precipitation in March, April, but there is no records for May or the station recorded precipitation from January to middle of August, then there is one week gap in the daily records. The list of these stations shown, in the table 3.1

**Table 3.1 List of Meteorological stations obtained from the Ministry of Energy and Water**

| No | Name of the stations | Latitude | Longitude | Daily Records | | Length or records | |
|---|---|---|---|---|---|---|---|
| | | | | Precipitation | Temperature | Begin_Date | End_Date |
| 1 | Naghlu | 34.62000 | 69.72000 | ✓ | ✓ | 01/01/2008 | 30/12/2012 |
| 2 | Dohabi | 35.32340 | 69.63401 | ✓ | ✓ | 01/01/2008 | 30/12/2012 |
| 3 | Pul-i-Qarghai | 34.55000 | 70.23000 | ✓ | ✓ | 01/01/2008 | 30/12/2012 |
| 4 | Pul-i-Kama | 34.4700 | 70.5500 | ✓ | ✓ | 01/01/2008 | 30/12/2012 |
| 5 | Daka | 34.2325 | 71.0394 | ✓ | ✓ | 01/01/2008 | 30/12/2012 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6 | Maidan Wardak | 34.3200 | 68.8500 | ✓ | ✓ | 01/01/2008 | 30/12/2012 |
| 7 | Bagh-i-Lala | 35.0800 | 69.1300 | ✓ | ✓ | 01/01/2008 | 30/12/2012 |
| 8 | Asmar | 35.0300 | 71.2060 | ✓ | ✓ | 01/01/2008 | 30/12/2012 |

## 3.2. Dynamic Method for Gap filling

Multiple linear regression approach, using a set of surrounding stations as regressors is the most conventional method, suitable for gap filling of the precipitation and temperature records, the approach used for the selection of the stations and identification of the best period of coupling of reconstructing and target stations can be summarized in figure 3.1

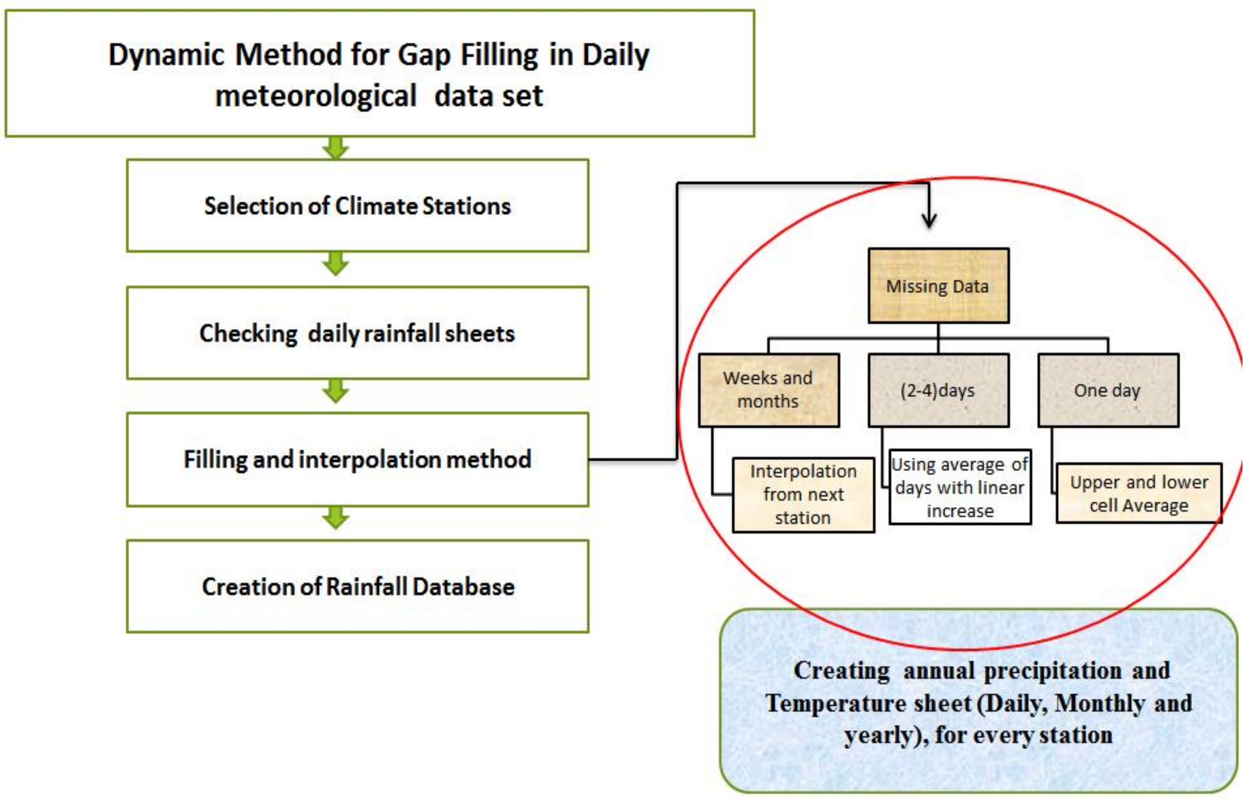



**Figure 3.1 Dynamic method for gap filling in Daily meteorological dataset**.

- Analysis of the target station to identify a period without gaps of sufficient length contiguous to the gap to be filled preceding and or following the gap.
- Identification of two groups of stations (high gaped stations and low gaped stations) for data reconstruction in the neighborhood of the target station.

- Selection of the period to be considered (before or after the gap).
- Identification of the subset of stations, in the period previously identified, giving the best correlation with the target station for the specific gap to be filled
- Identification of best sampling size ( length of the period used for data coupling) that minimizes the reconstruction errors.
- Reconstruction of the gap and creating monthly and yearly climate data

## 3.3. Normal ratio Method

Normal ratio method Equation.1 is the most conventional methods, suitable for gap filling of the precipitation and temperature records, particularly in ratio method, when the normal annual precipitation at any index station differs from that of the interpolation station by more than 10%. This method has been used in various places of the world .The method is one of the simpler ways of predicting missing values, but repeating calculations make it hectic if the number of records is very large.

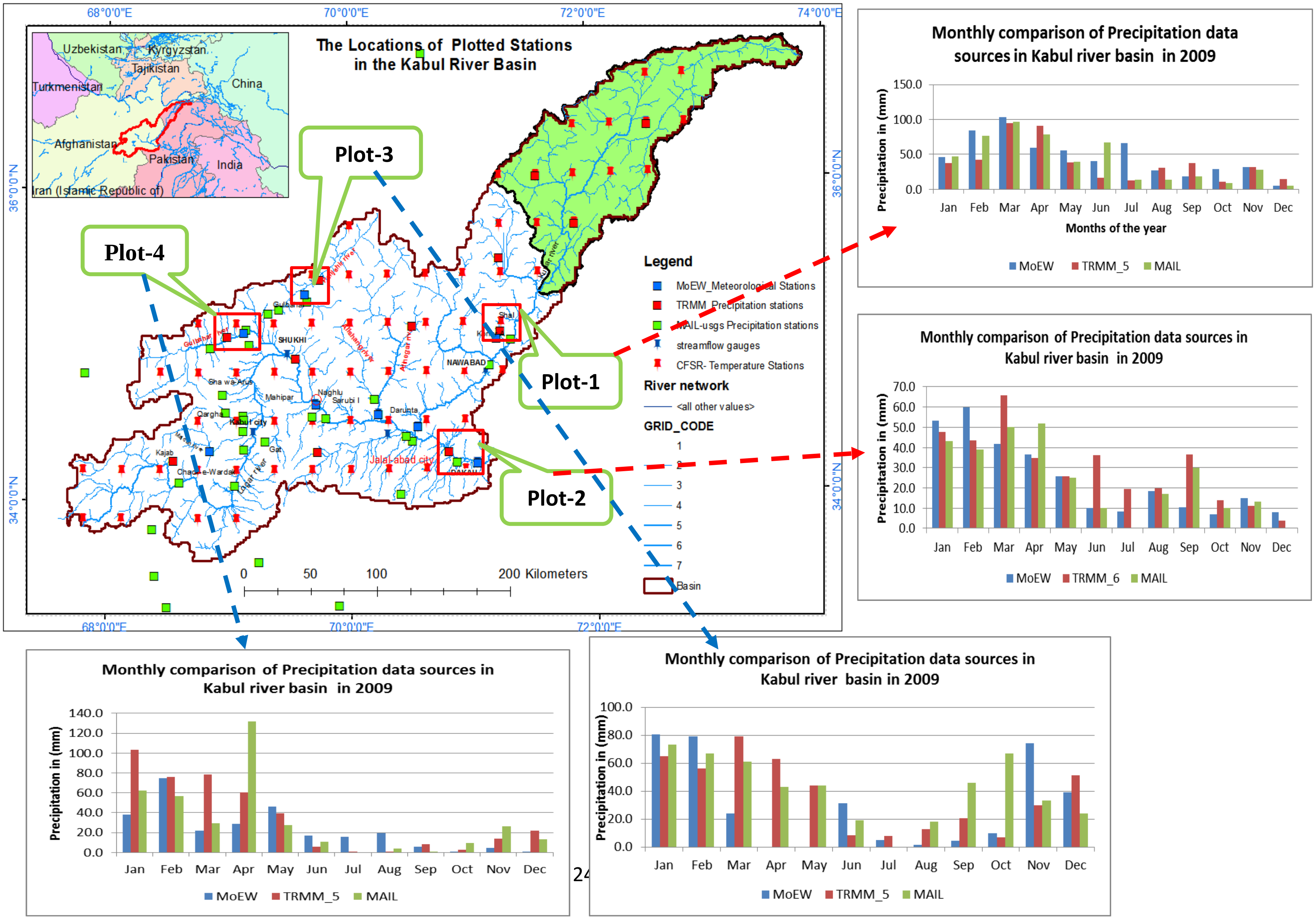
$$P_x \frac{N_x}{n}\left[\frac{P_1}{N_1}+\frac{P_2}{N_2}+\frac{P_3}{N_3}+\cdots+\frac{P_n}{N_n}\right] \qquad (1)$$

Where, $P_x$ = missed rainfall of station X to be filled; $N_x$ = is annual average rainfall of stations-x; $P_1$ , $P_2$, $P_3$ and $P_n$ and $N_1$, $N_2$ , $N_3$ and $N_3$ corresponding missing values of stations for which rainfall data are available. Four stations with maximum missing values in months used Normal ratio method, and short-term missing records used by dynamic method, which is a very conventional method as shown in figure 3.1.

## 3.4. Comparison of precipitation records based on different data sets

Three precipitation data sets are compared over the Kabul river basin. These data sets include four Precipitation stations from the Ministry of Energy and Water (MoEW), four precipitation stations products from the Ministry of Agriculture, Irrigation and Livestock (MAIL), and four gauges-only precipitation products from the Tropical Rainfall Measuring Mission(TRMM) as shown in figure 3.2 The main objectives of this comparison were consistency analysis, among these three observed and non-observed data set and selection of best data source for the SWAT model application. Plotting method has been applied in the four different areas of the basin with different climate patterns. Quantitatively, the differences in monthly precipitation records in these three data sets are significant. The differences in annual precipitation between MAIL and TRMM are less then 5%,  in these four blocks.

**Figure 3.2 Comparison of precipitation records based on three different data sets according to bloking method in 2009 (Monthly)**



**Figur 3.3 Comparison of precipitation records based on three different data sets according to bloking method in 2010 (Monthly)**

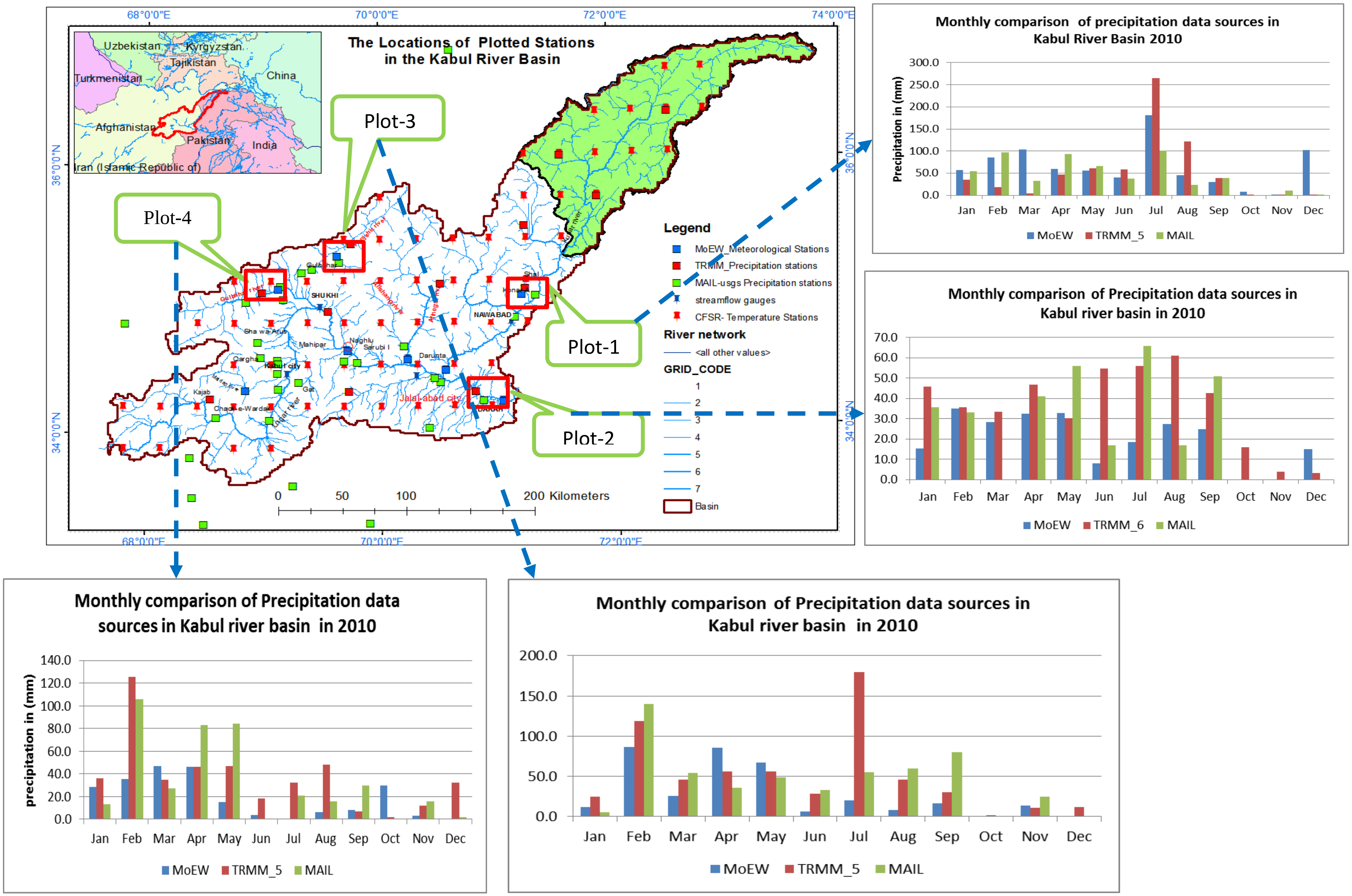
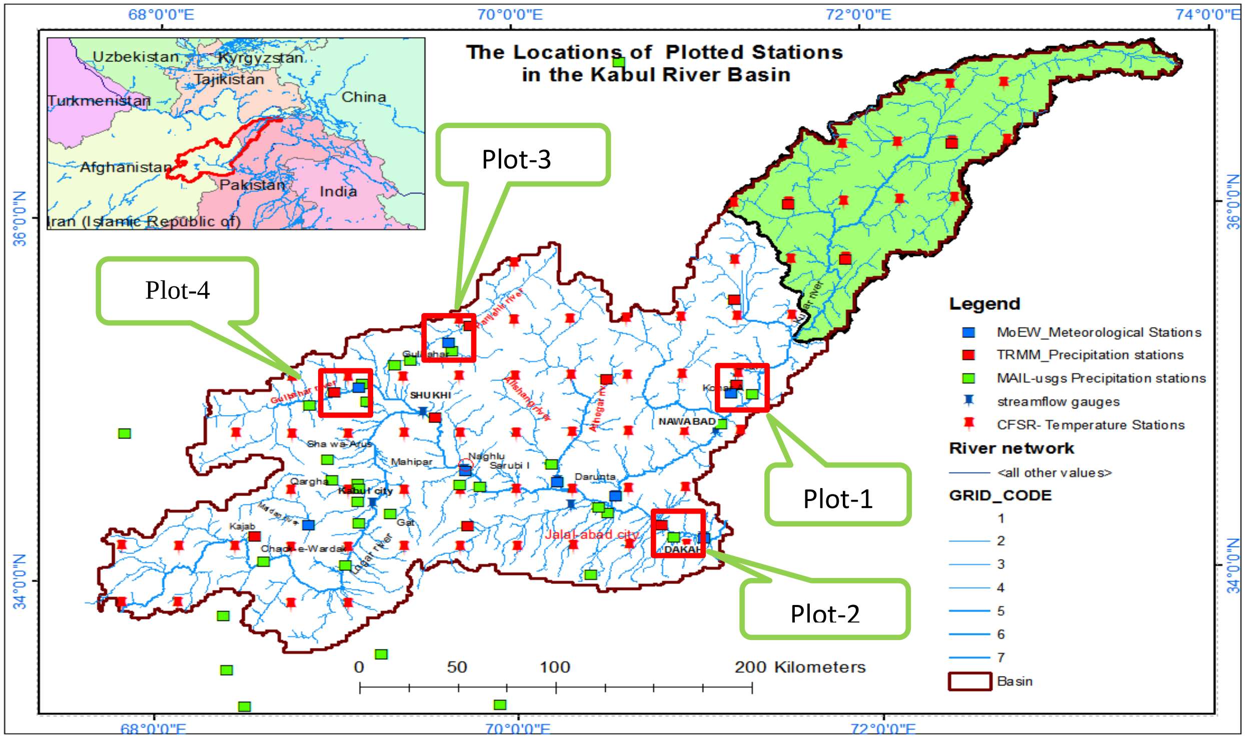
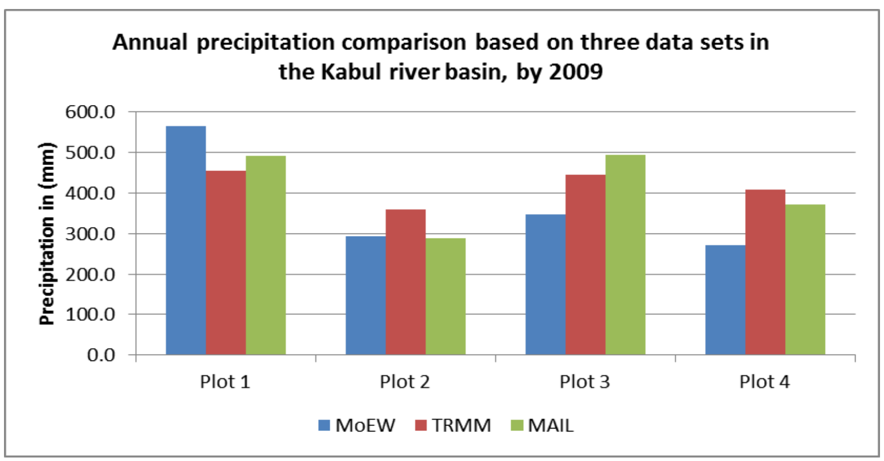
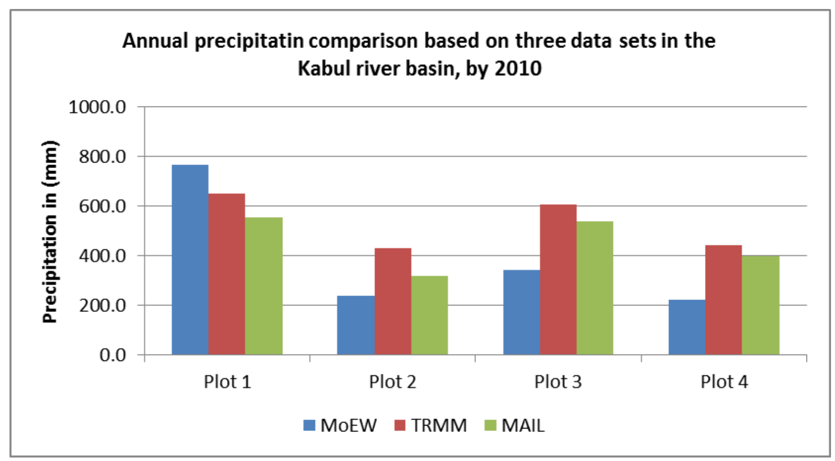


**Figure 3.4 Comparison of annual precipitation records based on different data sets in the Kabul river Basin**



# CHAPTER FOUR

# HYDROLOGY MODELLING

This chapter involves the application of a physically based watershed model SWAT2012 in the Kabul River Basin to evaluate the influence of Topography, Land use, Soil and Climatic condition on stream flow. The effect of sub-division and hydrologic response units (HRU) assess based on streamflow. The application of the model involved calibration, sensitivity and uncertainty analysis. Figure 4.1 illustrates the conceptual steps that were carried out to analysis water availability.

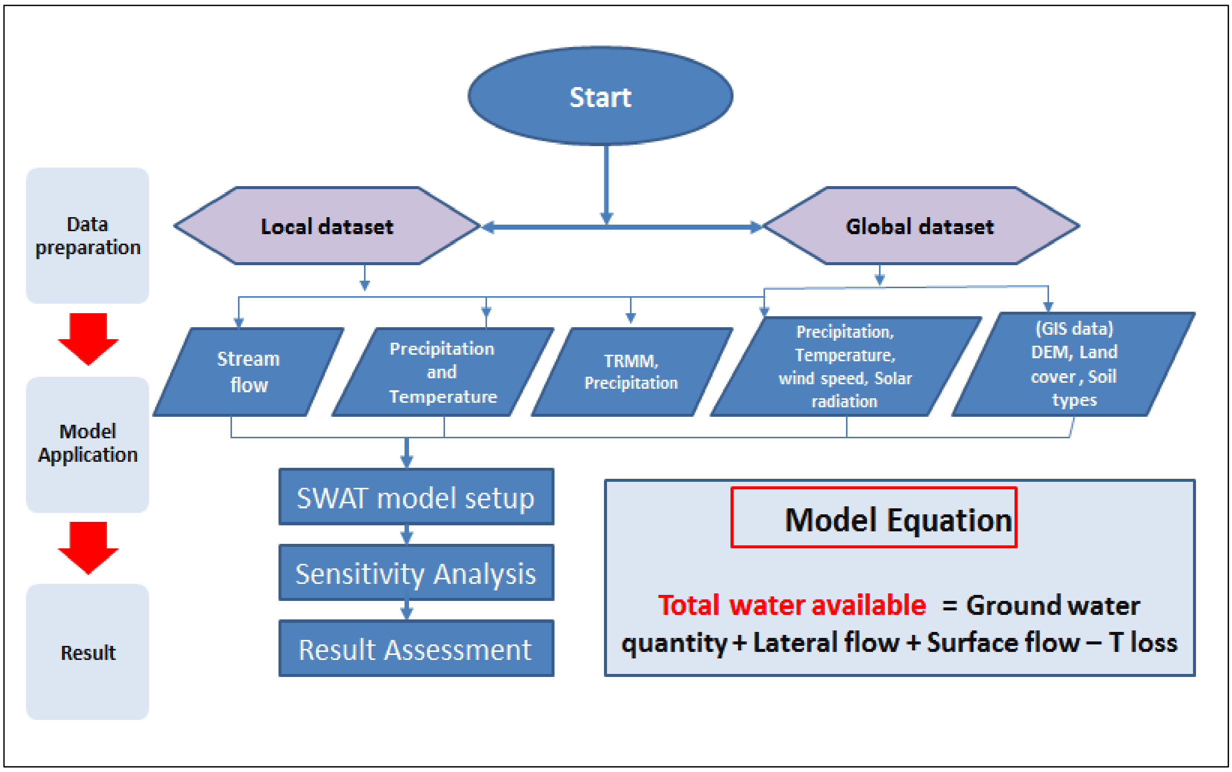



**Figure 4.1 Conceptual method for water availibiliy analysis using SWAT model.**

## 4.1. Soil and Water Assessment Tool (SWAT) background

SWAT is the acronym for Soil and Water Assessment Tool, a river basin scale model developed by Dr.Jeff Arnold for the USDA Agriculture Research Sercice [19] SWAT has the capability of different physical processes to be simulated in a watershed in figure 4.2 and Figure 21. For more detailed discussions on these processes and procedures employed by SWAT could be consulted on the SWAT theoretical Documentation, 2005 version and SWAT user manual 2012 version. SWAT was developed to predict he impact of land management practices on water, sediment, and agricultural chemical yields in large basins over a considerable period of time [20] It is a physically based model, i.e. it requires specific data about weatherm soil properties and topography, vegetation occurring in the watershed. Using these input data, SWAT will directly model the physical process associated with water movement, sediment movement, nutrient recycloig, etc. This approach has two benefits:

- To quantify the relative impact of alternative data (Stream gauge data )
- To quantify the relative impact of alternative data (change in climate, landuse, etc) on the water quantity, quality and other variables of interest.

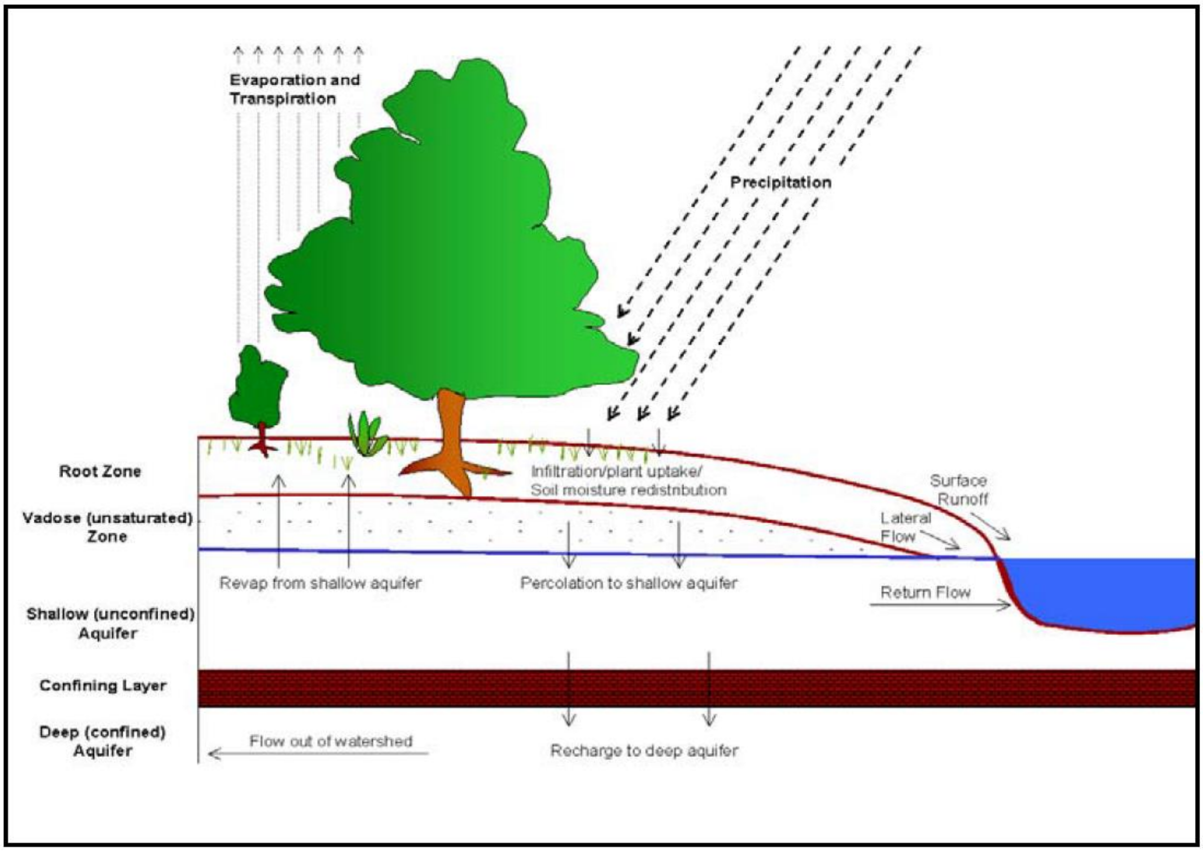



**Figure 4.2: Schematic representation of upland processes of hydrological cycle in SWAT**

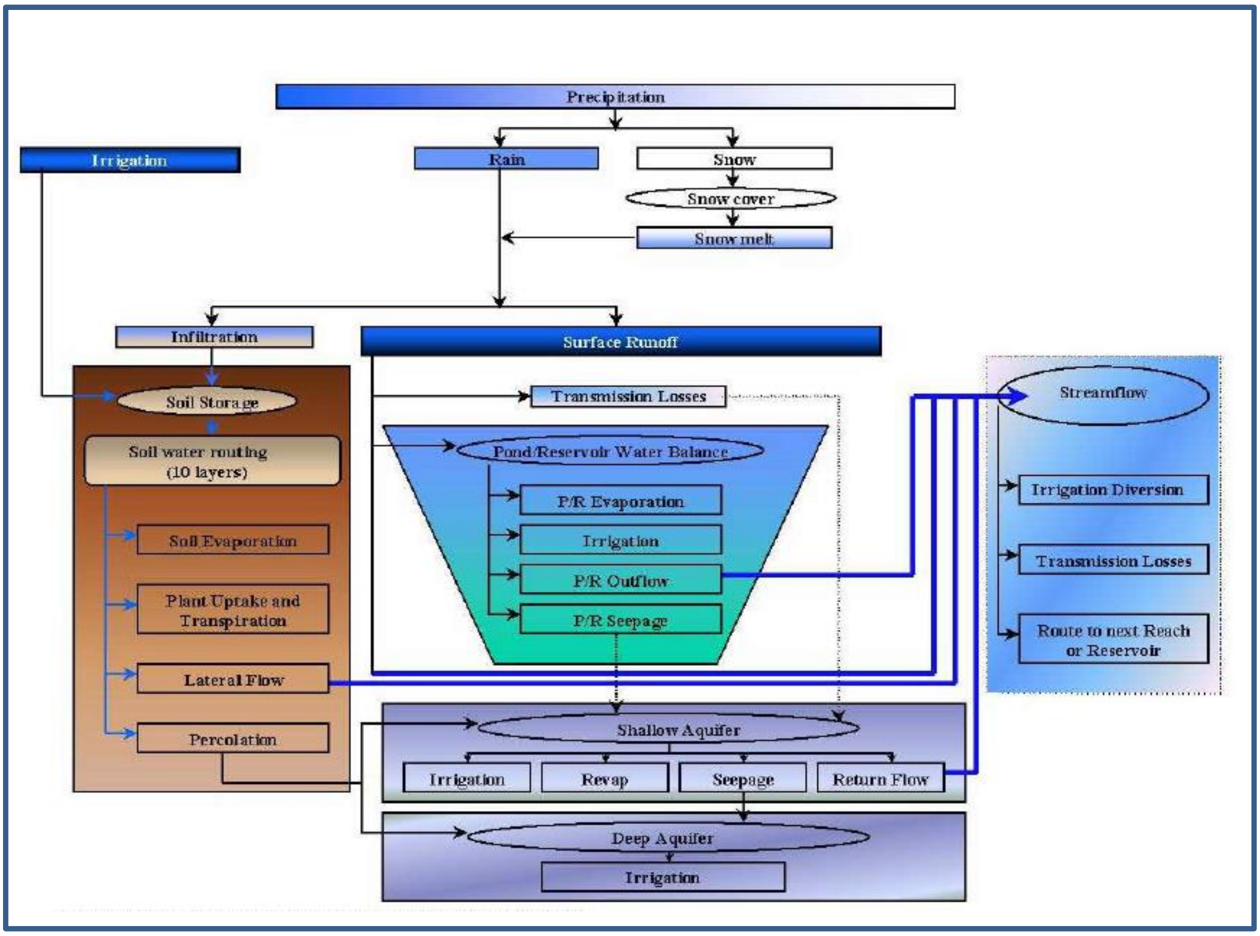



**Figure 4.3: Schematic of Patway available for water movement in SWAT.**

## 4.2. SWAT model

SWAT (Soil and Water Assessment Tool) model is a physically based hydrological/water quality model, developed by the United States Department of Agriculture [21] The model is a continuous-time, especially semi-distributed simulator for hydrological cycle and agricultural pollutant transport in the basin and watershed scale, and runs on annual, monthly and daily time steps. In SWAT, a watershed is divided into multiple sub-watersheds, which are than further subdivided into hydrologic response units(HRU) that consist of homogeneous land use and soil types and terrain characteristics. The hydrological cycle as simulated by SWAT is based on following water balance equation (SWAT theory)

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (2)$$

Where $SW_t$ is the final soil water content(mm $H_2O$), $t$ is the time (days), $R_{day}$ is the amount of precipitation on day $_i$ *(mm $H_2O$), $E_a$ i*s the amount of evapotranspiration on day i(mm$H_2O$), $W_{seep}$ is the amount of water entering the vadose zone from the soil profile on day i(mm$H_2O$) and $Q_{gw}$ is the amount of return flow on day (mm$H_2O$). the subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Snow melts for day is added to rainfall for day i in the computation of surface runoff and infiltration. Surface runoff is the favored flow path of most snow melt events. Infiltration is limited when the superficial soil profile layer is frozen through adjustments of the retention parameter in the soil conservation service (SCS) curve number procedure (SCS 1972) used to estimate the surface runoff. No lateral flow or percolation is allowed when the soil profile layer is frozen. The channel routing is estimated using the variable storage routing method (Williams, 1969); it does not require calibration and does not consider the ice influence on stream flow. Snow hydrology in SWAT is realized at the HRU scale. When the mean daily air temperature is less than a threshold temperature value (in the SFTMP parameter), the precipitation within the HRU is considered as snow and the liquid water equivalent of the snow precipitation is added to snow pack, the snow pack content increases with additional snowfall and decreases with snow melt. The mass balance for the snow pack is computed as follows:

$$SNO_t = SNO_o + \sum_{i=1}^{t} (pi - E_{subi} - SNOMLT_i) \tag{3}$$

Where $SNO_t$ and $SNO_o$ are the snow water equivalent at time t and at the initial time, respectively (mm of water); $P_i$ is the water equivalent of the snow precipitation on $day_i$ (mm of water ) all the variables are expressed as equivalent water depth (mm) over the total HRU area. The snowpack in a sub-basin is rarely uniformly distributed over the total area and a fraction of the sub-basin area can be without snow. In SWAT, the areal coverage of snow present in the basin is defined using an aerial depletion curve which described the seasonal growth and recession of the snow pack as function of the amount of snow present in the sub-basin [22] and is defined as :

$$SNOCOV_I = \frac{SNO_I}{SNOCOVMX} \left[ \frac{SNO_i}{SNOCOVMX} + \exp\left( cov1 - cov2 * \frac{SNO_i}{SNOCOVMX} \right) \right] \tag{4}$$

Where $SNOCOV_I$ is the fraction of HRU area covered by snow on $day_i$ ; SNOCOVMX is the minimum snow water content that corresponds to 100% snow cover (mm of water ); $cov_1$ and

$cov_2$ are the coefficients defining the shape of the curve. The values used for $cov_1$ and $cov_2$ are determined by solving equation (4) using two known points: (1) 95% SNOWCOVMX, specified by the SNO50COV parameter. Snowmelt is controlled by the air and snowpack temperature, the melting rate and the areal coverage of snow. A temperature index, $SNOMLT_i$ is used to determine the amount of snowmelt (in water equivalent; mm) on day i as defined below:

$$SNOMLT_I = b_{mlti} * SNOCOVi * \left(\frac{T_{snowi} + T_{\max i}}{2} - SMTMP\right) \quad (5)$$

Where $SNOCOV_i$ is the fraction of HRU area covered by snow on day i ; $T_{snowi}$ is the snowpack temperature on day i(°C);$T_{maxi}$ is the maximum air temperature on a given day i(°C); SMTMP is the base temperature above which snowmelt is allowed (°C) and $b_{mlti}$ is the melt factor accounts for the increase in the length of the day as the season progresses. A minimum (SMFMN) and mximum (SMFMX) melt factor occurring at the winter and summer solstices, respectively, control the seasonal variations on the day j of the year as defined below:

$$b_{mlt}j = [\left(\frac{SMFMX+SMFMN}{2} + \frac{SMFMX-SMFMN}{2}\right)\sin(\frac{2\pi}{365}(\text{J-81})] \quad (6)$$

Where, SMFMX and SMFMN are the maximum and minimum snowmelt factors, respectively, (mm of water $day^{-1}°C^{-1}$). The influence of the previous day's snowpack temperature ($T_{snowi-1}$) on the current day'S snowpack temperature ($T_{snowi}$) on the mean air temperature on day i($T_{airi}$) is achieved by a lag factor specified by the TIMP parameter which implicitly accounts for snowpack density and water content. The snowpack temperature is calculated as:

$$\mathrm{T_{snowi}} = [(1 - \mathrm{TIMP}) \times \mathrm{T_{snowi}}] + [\mathrm{TIMP} \times \mathrm{T_{airi}}] \quad (7)$$

Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. The surface runoff is calculated as follows:

$$\mathrm{Q}_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} - 0.8S)} \quad (8)$$

Where $Q_{surf}$ is the accumulated runoff or rainfall (mm), $R_{day}$ is the rainfall depth for the day (mm). The retention parameter is defined by equation. The retention parameter is defined by equation (8).

$$S = 25.4\left(\frac{100}{CN} - 10\right) \quad (9)$$

The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. SCS defines three antecedent moisture conditions: 1- dry (wilting point), 2- average moisture, and 3- wet( field capacity). The moisture condition 1 curve number is the lowest value that the daily curve numbers can assume in dry conditions. The curve number for moisture conditions 2 and 3 are calculated from equations 8 and 9.

$$CN_1 = CN_2 - \frac{20 \times (100 - CN_2)}{(100 - CN_2 + \exp[2.533 - 0.0636 \times (100 - CN_2)])} \quad (10)$$

$$CN_3 = CN_2 \times \exp[0.00673 \times (100 - CN_2)] \quad (11)$$

The $CN_1$ is the moisture condition 1 curve number, $CN_2$ is the moisture condition 2 curve number, and $CN_3$ is the moisture condition 3 curve number. Typical curve numbers for moisture condition 2 are listed in tables 2:1-1, 2:1-2, and 2:1-3 for various land covers and soil types[swat theory pp114], which are appropriated to slope less than 5%. To adjust the curve number for higher slopes than we use the (equation 11).

$$CN_{2s} = \frac{(CN_3 - CN_2)}{3} \times [1 - 2 \times \exp(-13.86.slp)] + CN_2 \quad (12)$$

Where the $CN_{2s}$ is the moisture condition 2 curve number adjusted for slope, $CN_3$ is the moisture condition 3 curve number for the default 5% slope, $CN_2$ is the moisture condition 2 curve number for the default 5% slope, and the slope is the average slope of the basin [23].

## 4.3. Model Input

SWAT is a comprehensive model that required a diversity of information and data in order to run.Specially distributed data (GIS input) needed for the Arc SWAT interface include the Digital Elevation Model (DEM), Soil Data, Land use, stream network layer, weather data such as precipitation, temperature, solar radiation, wind speed, relative humidity, river discharge were required for Hydrological modeling and calibration purposes.

### 4.3.1. Digital Elevation Model

Topography was defined by DEM that describes the elevation of entire the points and the area at the specific resolution. DEM with resolution of 30m*30m ($\sim 1km^2$) As show in figure 4.4 was downloaded from SRTM (Shuttle Radar Topography Mission) website on March 2014. The data sets are mosked and projected in UTM projection using GIS10.2. The DEM was used to delineate the watershed and to analyze the drainage patters of the land surface terrain. Subbasin parameters such as slope gradient, slope length, and stream network characteristics such as primary, secondary streams and rivers which were derived from the DEM.

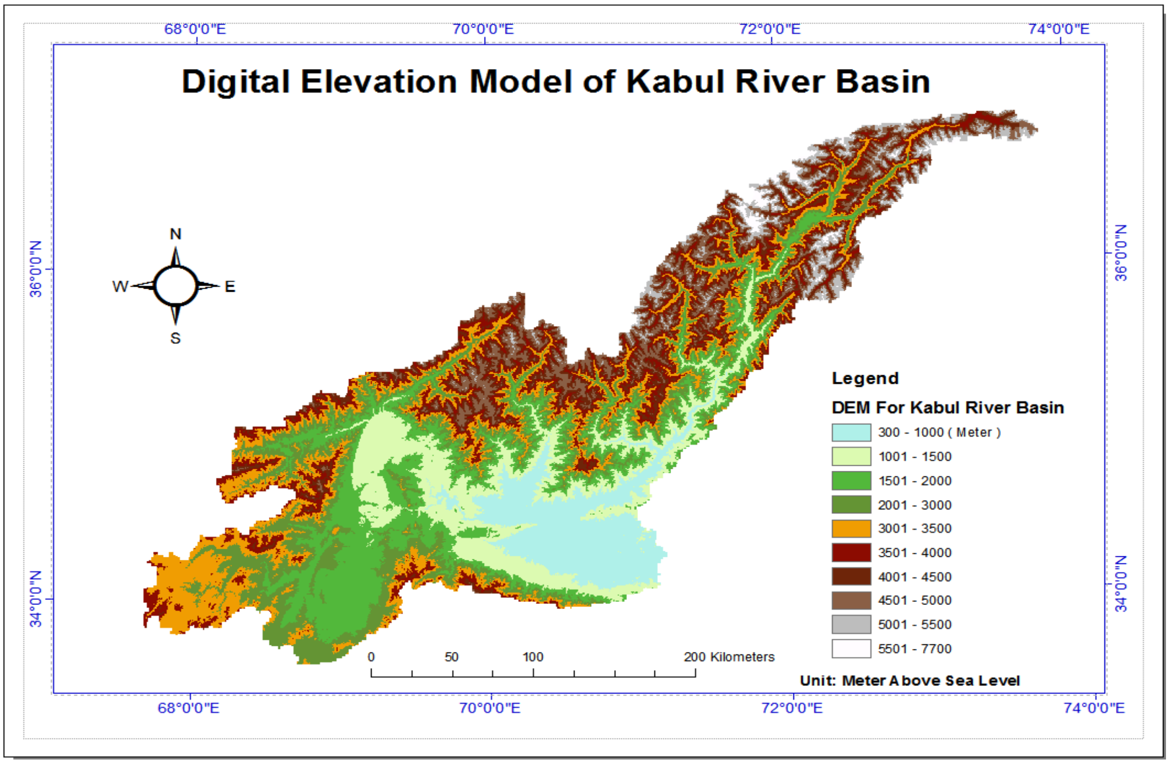



**Figure 4.4 Digital Evevatin Model of Kabul river Basin. Source : NASA**

### 4.3.2. Land cover/ land use(LC/LU) data

Land use/land cover is one of the most important factors that effects surface erosion, runoff and evapotranspiration in the watershed. The land cover datasets for the study area has been downloaded from Global Land Cover Facilities (GLCF). The dataset is derived from ($\sim 1km^2$) advanced very high resolution radiometer (AVHRR) and projected based on UTM projection using GIS10.2. The reclassification of the land use map was made to represent the land use according to the specific LULC types and the respective crop parameter for SWAT database (**Figure 23**). A lookup table that identifies the SWAT land use code for the different categories of the LULC was prepared so as to relate the grid values to SWAT Land use and land cover classes.

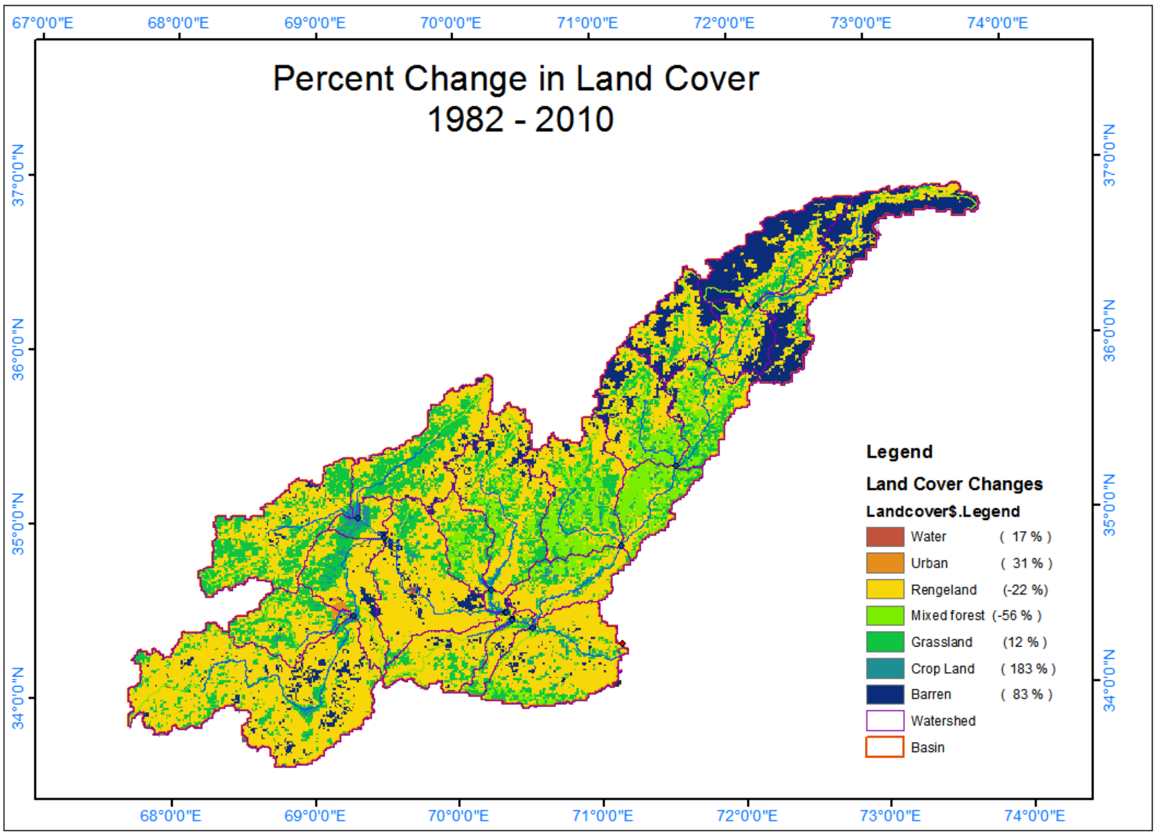



**Figure 4.5 Land cover changes in 28 years in the Kabul river basin**

**Table 4.1: Land cover/land use changes in the Kabul river basin. Land cover Baseline (sources: GLCF and LCI- 1982-2010).**

| Number | Land cover/ land use categories | Land cover / land use area (Thousand hectare) | | Percent of Changes (1982-1992 to 2000-2010) |
|---|---|---|---|---|
| | | (1982 – 1992) | (2000 – 2010) | |
| 1 | Water | 9.1 | 7.8 | -14.6 |
| 2 | Urban/ Built up | 11.3 | 14.6 | 29.2 |
| 3 | Rangeland | 3652.5 | 2848.6 | -22.0 |
| 4 | Mixed forest | 448.3 | 195.7 | -56.3 |
| 5 | Grassland | 1413.8 | 1586.6 | 12.2 |
| 6 | Cropland / Irrigated area | 94.2 | 264.1 | 183.8 |
| 7 | Barren | 891.0 | 1599.6 | 79.5 |

### 4.3.3. Soil classification

SWAT model requires different soil textural and physic-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. In this study, soil dataset obtained from FAO/UNESCO-ISWC (FAO/UNESCO-ISWC, 1998) with the resolution of 90m*90 meter and projected based on UTM, then applied in SWAT model in the stage of Hydrological Respond Unite (HRU). Definition of soil characteristics in shown in figure 4.6.

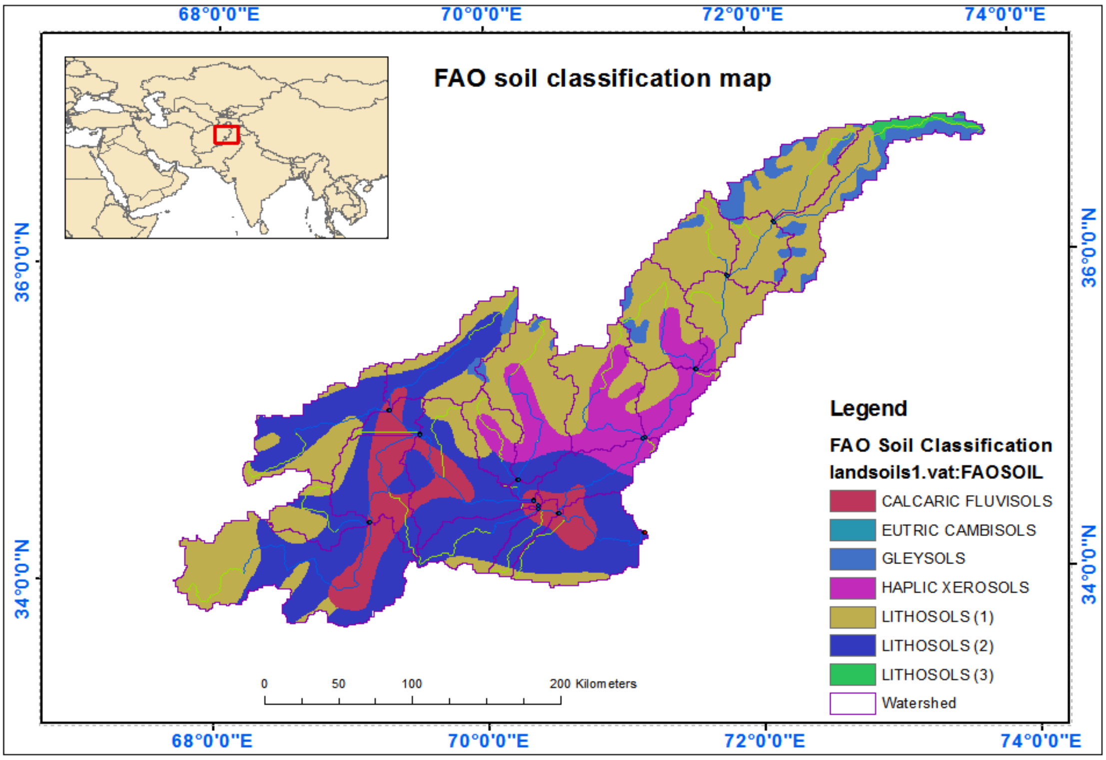



**Figure 4.6 Soil classification map of Kabul river basin**

**Table 4.2 Combination of FAO-Soil**

| FAOSOIL | Name | Area (% of basin) | Texture | Clay (%) | SILT (%) | SAND (%) |
|---|---|---|---|---|---|---|
| I-B-U-2c-3503 | LITHOSOLS (1) | 42.3 | Loam | 26 | 30 | 44 |
| I-X-c-3512 | LITHOSOLS (2) | 29.8 | Loam | 22 | 33 | 45 |
| Jc37-2a-3525 | CALCARIC FLUVISOLS | 10.7 | Loam | 18 | 35 | 47 |
| Be73-2c-3673 | EUTRIC CAMBISOLS | 0.0 | sandy _loam | 23 | 24 | 52 |
| I-X-2c-3731 | LITHOSOLS (3) | 1.1 | Loam | 22 | 33 | 45 |
| Xh18-bc-3870 | HAPLIC XEROSOLS | 10.7 | Silt_loam | 21 | 54 | 25 |
| GLACIER-6998 | GLEYSOLS | 5.4 | UWD | 5 | 25 | 70 |

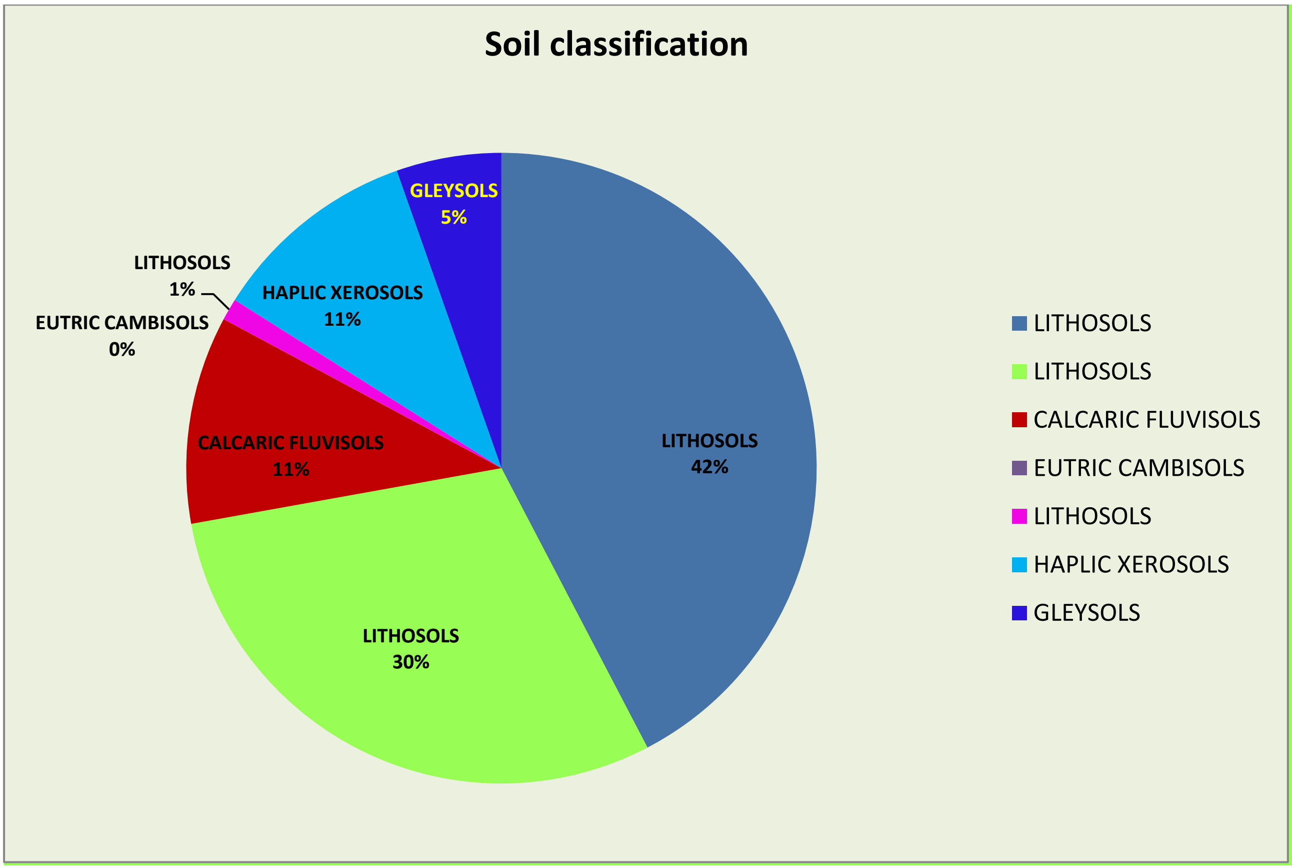



**Figure. 4.7 Soil classification pie chart based on percentage in the Kabul river basin.**

### 4.3.4. Meteorological Data

The model requires daily meteorological data that could either be read from a measured dataset or be generated by weather generator model with include precipitation, maximum and minimum air temperature, in the present study, 12 Precipitation points by period of (2002 – 2012) have been obtained from Tropical Rainfall Measuring Mission (TRMM) which is prepared by Japan and US and 64 temperature points records have been downloaded from National Centers for Environmental Prediction (NCEP) and applied in the model for present hydrology modelling in Kabul river basin, as shown in figure 4.8. The Hargreaves method which utilized maximum, minimum and mean temperature and solar radiation records employed for estimation of potential evapotranspiration (PET) for this specific study area. The typical quality of rainfall data was checked by cross correlation between the stations.

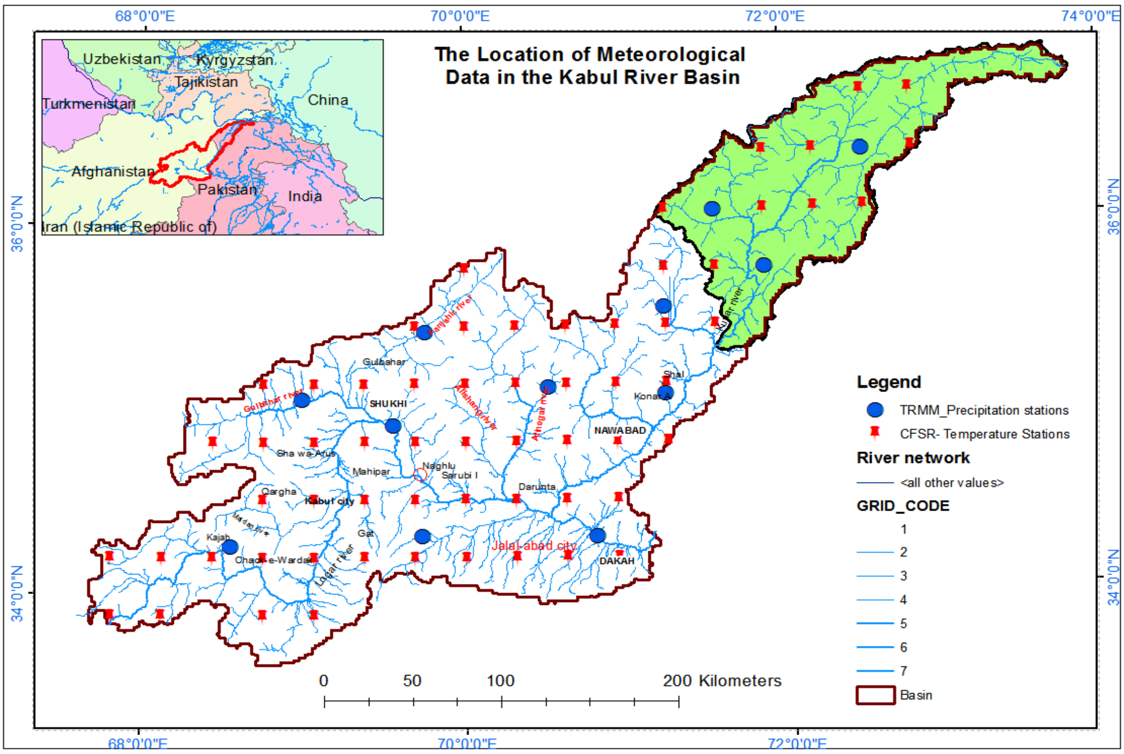



**Figure 4.8 Location of meteorological data sets from two sources: Precipitation from TRMM and Temperature from NCEP.**

#### 4.3.5. Stream runoff data

The hydrology of the watershed reflects the precipitation and temperature pattern within the basin. Daily river discharge data of 8 stream gauge stations were obtained from the Water Resources Department, Ministry of Energy and Water figure 4.9 The discharge data applied for performing sensitivity analysis, calibration of SWAT model. An automated base flow separation and recession analysis technique applied to separate the base flow, ground water flow and surface flow from the total daily and monthly stream flow records. This data and information then used in order to get SWAT correctly reflect basic observed water balance of the watershed.

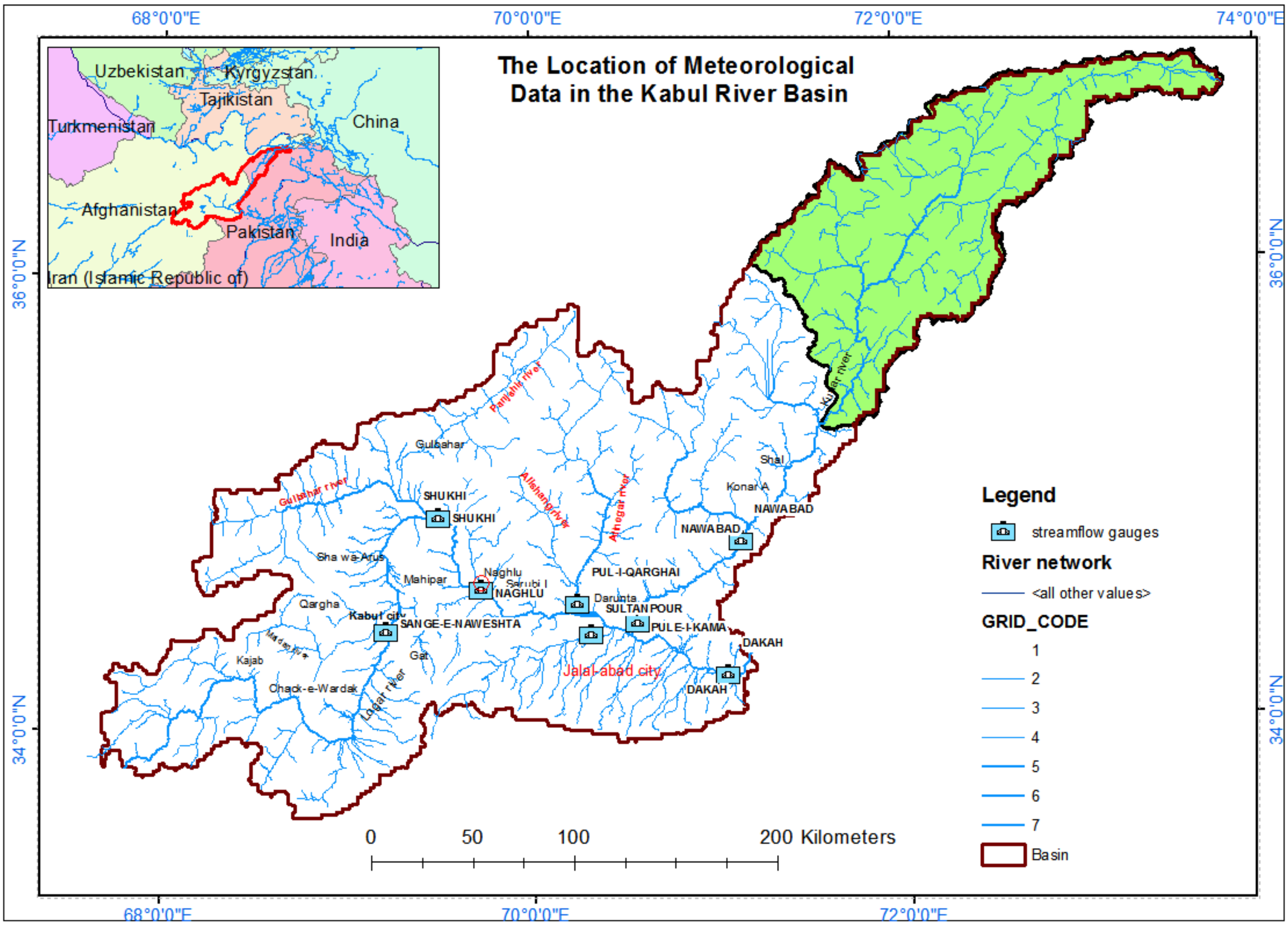



**Figure 4.9 Location of Stream run off stations in the Kabul river basin, data source: MoEW.**

## 4.4. Model setup

### 4.4.1 Watershed delineation

The first step in creating SWAT model input is watershed delineation from Digital Elevation Model (DEM). Inputs entered into the SWAT model were organized to have spetial characteristics. The most important step for creating watershed modeling and Hydrological response units (HRUs), DEM were projected into the UTM zone with N42, which are projection parameters for Afghanistan. Watershed partitioned into 23 sub-basins for modeling purposes as shown in figure 4.10 The watershed delineation process include five major steps, DEM setup, Stream definition, outlet and inlet definition, watershed outlets definition the threshold based steam definition options were applied to define the appropriate size of the sub-basins.

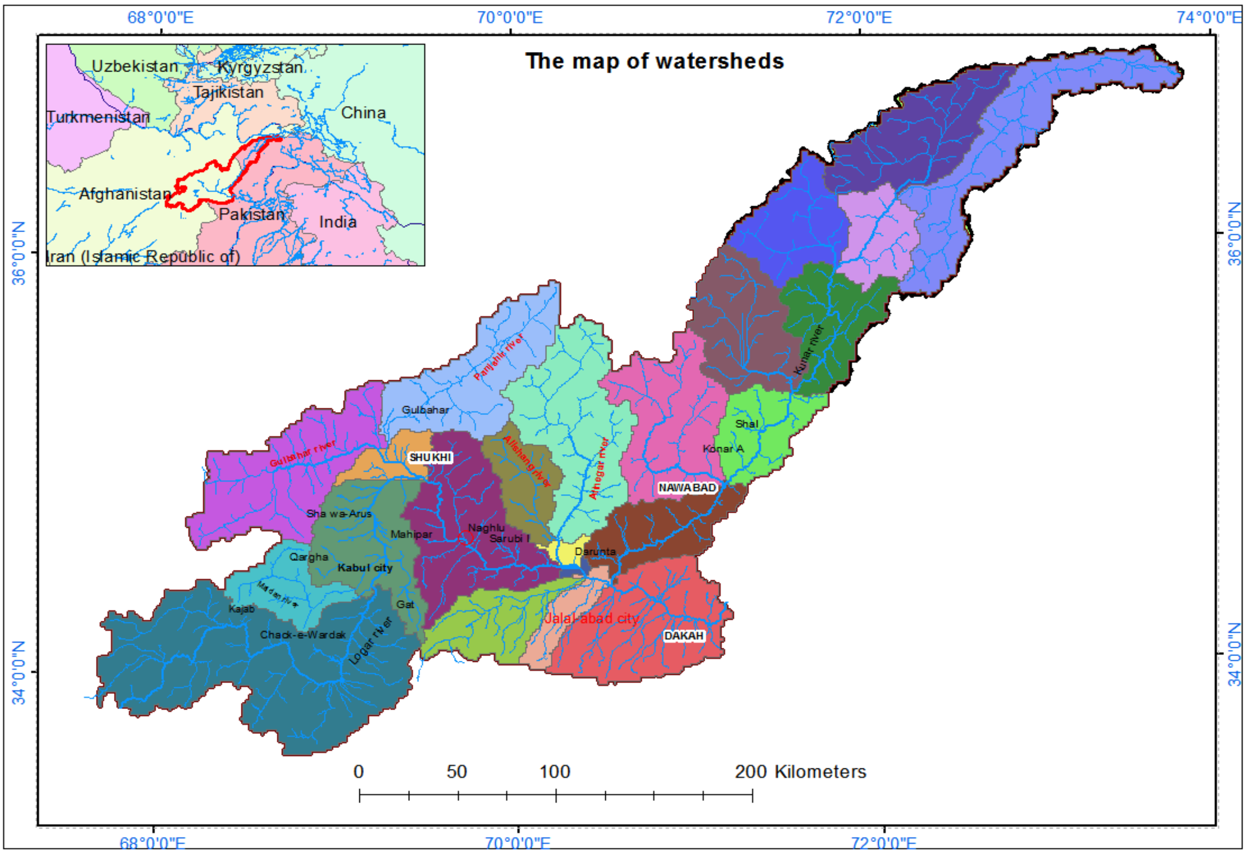



**Figure 4.10 Watershed delineation, 23 watersheds in the Kabul river basin, generated by SWAT Model.**

### 4.4.2. Hydrological Response Units (HRUs)

Subdividing the watershed into areas having unique land use, soil and slop combinations makes it possible to study the differences in evapotranspiration and other hydrology conditions for different land covers, soils and slopes. The land use, soil and slope datasets were projected based on UTM zone, N42 and imported to the SWAT model databases. To define the distributions of HRUs both single and multiple HRU definition options were tested. The multiple slope option which considers different slope classes, 15%, 30% and more than 30% for HRU definition) were selected. After overlying the land use, soil and slope datasets satisfactory the model generated 827 HRUs with a unique combination of land use, soil and slop and overlapped 100% with the watershed boundaries as shown in figure 4.11

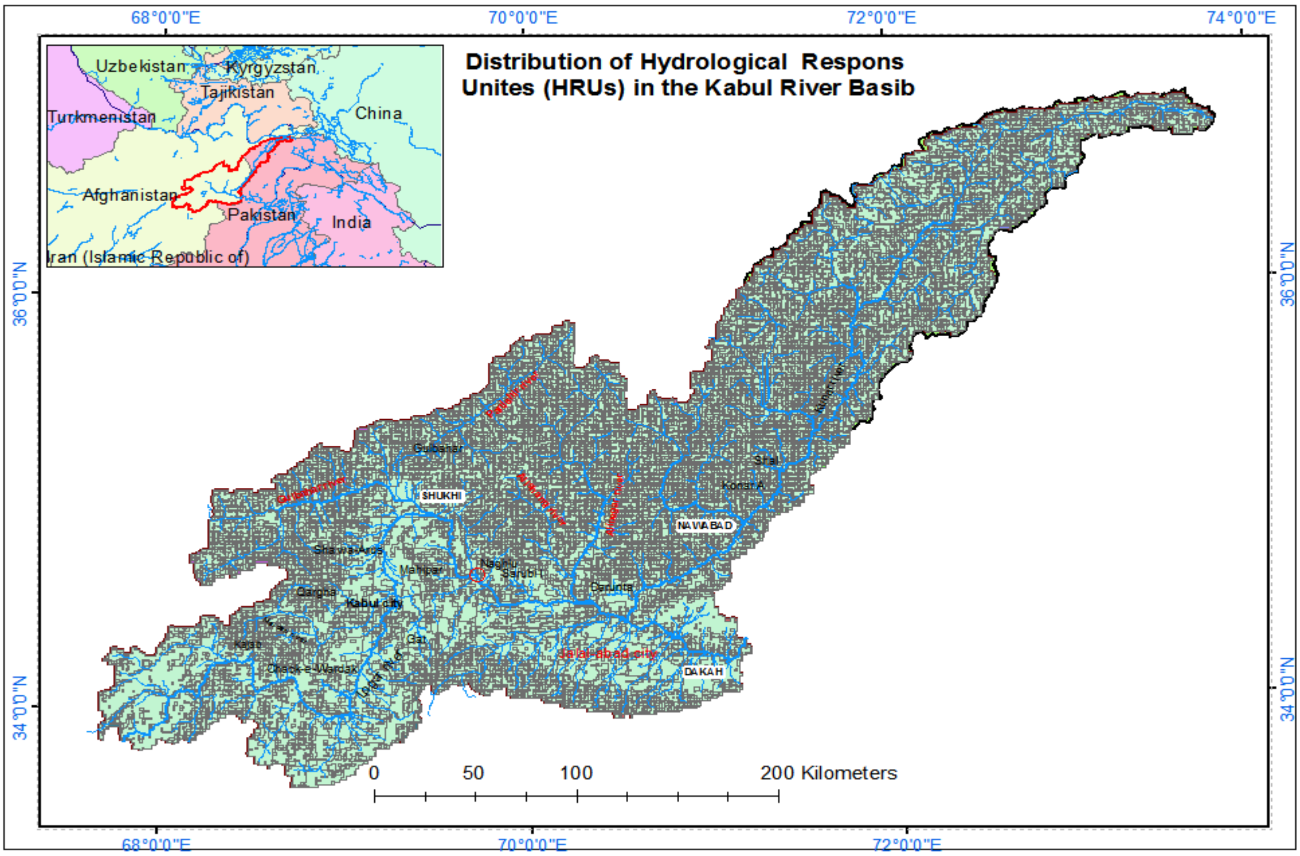



**Figure 4.11 827 HRU in the Kabul river basin.**

### 4.4.3. Defining climate database

One of the main sets of input for simulating the watershed in SWAT is climate data. Weather inputs consist of daily precipitation, maximum and minimum. All these datasets records for the period of 2002 – 2012 and 6 years of warm up or equilibration period applied to get the hydrological cycle fully operational. The write input table menu contains items that all building database files containing the information needed to generate default input for SWAT. The write command become enabled after weather data were successfully loaded. These commands were enabled in sequence and need to processed only once for a project. Before SWAT run, the initial watershed input values have been defined. These values were set properly based on the watershed delineation, land use, soil and slope characterization. There are two ways to build the initial values: activate the write all commands or the individual write commands on the write input table menu. Finally, the other key aspects of the SWAT simulation performed for the watershed are listed below:

1- Output time step: daily and monthly
2- Simulation period: 11 years (2002-2012)
3- Rainfall distribution: skewed normal.
4- Runoff generation: CN method.

## 4.5. Model output

### 4.5.1. Primary output

The primary result showed that, the model had a sensitivity with several elevation zones, precipitation in the form of snow, temperature based snow melting and snowmelt runoff. For simplification, assumed that, all the components of SWAT model are constant that were calculated from the water balance equation. In this cause the interaction of the model with the snow is same as rain, without consideration of snow melt base temperature and snow melt maximum and minimum factors properly, the primary output compared with observed runoff in the figure 4.12 and 4.13.

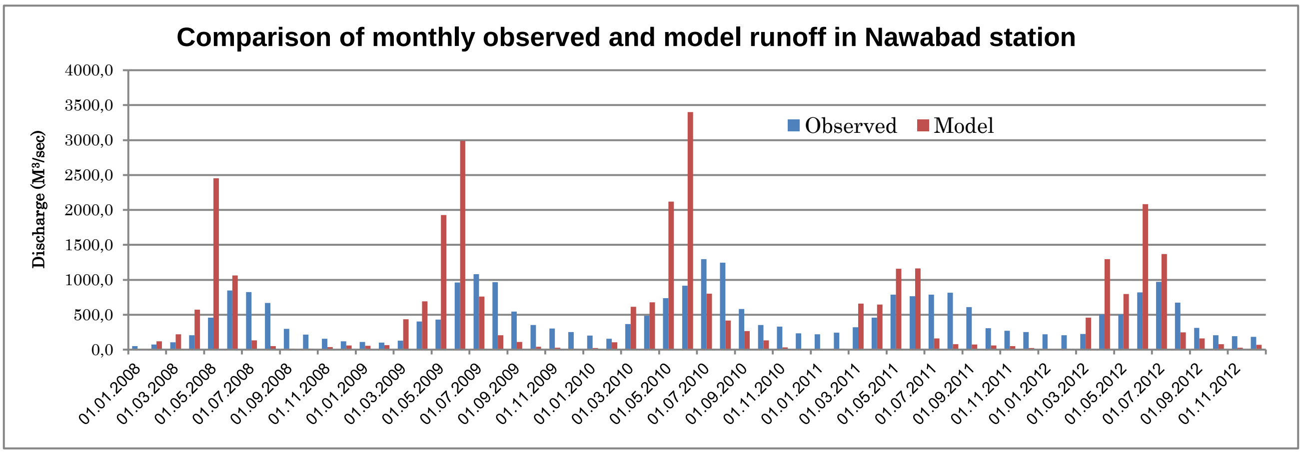



**Figure 4.12 Comparison of monthly observed and model runoff in Nawabad station.**

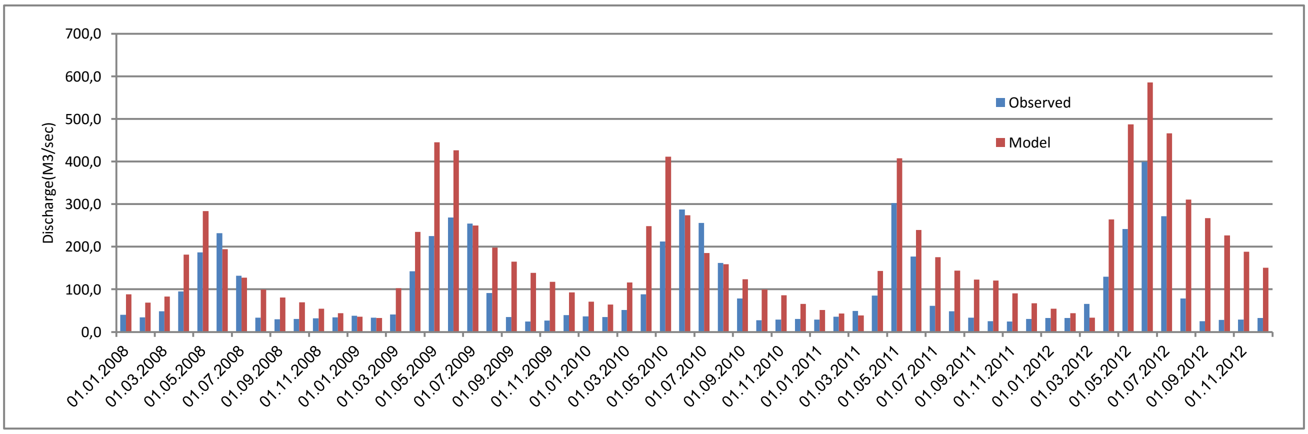



**Figure 4.13 Monthly observed and model runoff in Shukhi station**.

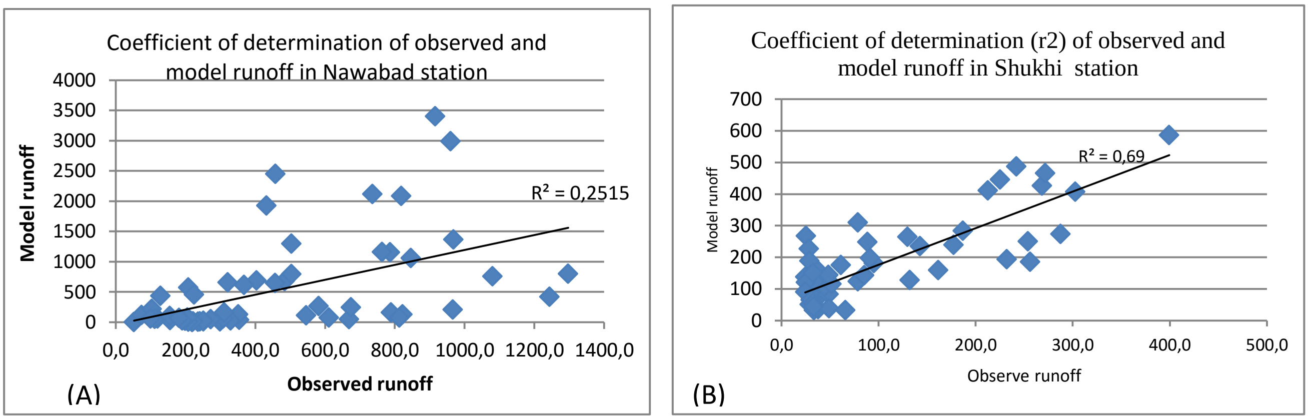
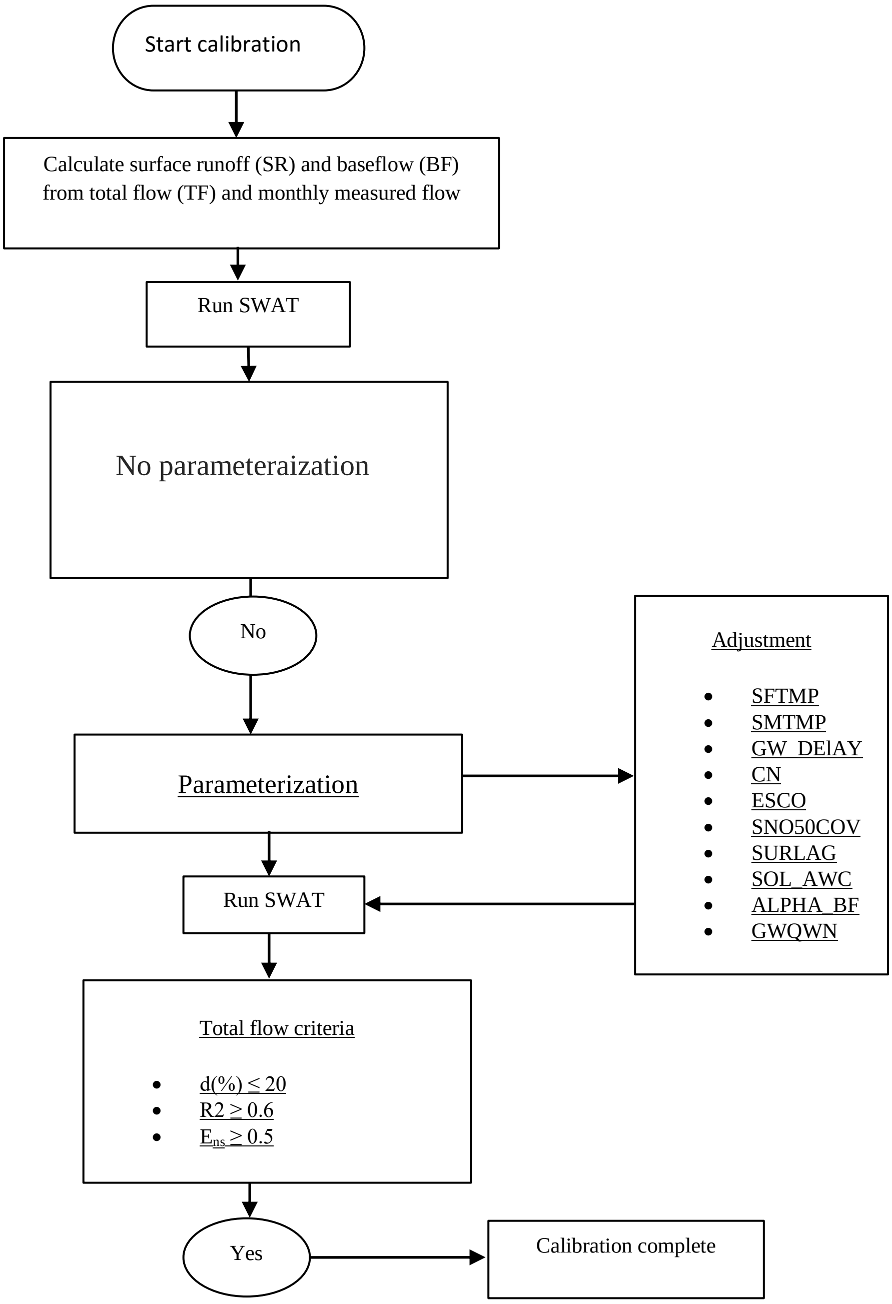



**Figure 4.14 Regression coefficient of monthly observed and simulated stream flows at (A) Nawabad, (B) Shukhi river gauging stations, during 2008-2012**

## 4.6. SWAT Calibration

SWAT input parameters are process based and must be held within a realistic uncertainty rang. The first step in the calibration process in SWAT is the determination of the most sensitive parameters for a given watershed or sub-watershed. The SWAT user must determine which variables to adjust based on expert judgment or no sensitivity analysis. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters), [24] .it is necessary to identify key parameters and the parameter precision required for calibration. In a practical sense, this first step helps determine the predominant processes for the component of interest. Two types of sensitivity analysis are generally performed widely in the SWAT model: local, by changing values one at a time, and globally, by allowing all parameter values to change. In this study, I have applied local sensitivity analysis. Sensitivity of one parameter often depends on the value of other related parameters; hence, the problem with one-at-a-time analysis is that the correct values of the other parameters that are fixed. Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. Calibration can be accomplished manually or using auto-calibration tools in the SWAT model as shown in figure 4.15




LEGEND

**D**: percent difference between measured and simulated average monthly values

$\mathbf{R^2}$: Coefficient of determination.

$\mathbf{E_{ns}}$: Nash_Sutcliffe efficiency coefficient.

**CN**: SCS curve number for moisture condition II.

**SFTMP**: Snowfall temperature

**SMTMP**: Snowmelt base temperature

**GW_DELAY**: Ground water delay time.

**SOL_AWC**:  Available soil water content.

**ESCO**: Evaporation compensation factor.

**Figure 4.15  SWAT manual calibration flowchart ( SWAT: Model used**

## Calibrated Model Parameters for Kabul river basin

Table 4.3 Summary of the 14 most sensitive parameters: description, default value, range and optimal value for entire Kabul river.

| Group | Parameter | Description | Rank | Range | Optimal values for Nawabad catchment | Optimal value for Shukhi Catchment | Optimal value for Kabul river basin |
|---|---|---|---|---|---|---|---|
| Infiltration | CN2 | SCS runoff curve number | 1 | (0-100)% | 85% | 65% | +75% |
| Evaporation | ESCO | Soil evaporation compensation factor | 2 | 0-1 | 0.85 | 0.95 | 0.70 |
| Snowmelt | TIMP | Snowpack temperature lag | 3 | 0-1 | 0.81 | 0.6 | 0.8 |
| Snowmelt | SMTMP | Snowmelt base temperature(°C) | 4 | -5 to +5 | 3.2 | 5 | 3 |
| Snowmelt | SMFMN | Minimum melt factor (mm°C/day) | 5 | 0 – 10 | 5.5 | 4.5 | 4.5 |
| Groundwater | GW_DELAY | Groundwater delay time (days) | 6 | 0 to 500 | 180 | 200 | 300 |
| Snowmelt | SMFMX | Maximum melt factor (mm°C/day) | 7 | 0 to 10 | 5.5 | 7 | 6 |
| Snowfall accumulation | SFTMP | Snowfall temperature threshold (°C) | 8 | -5 to +5 | 4.5 | 4 | 3 |
| Snowfall accumulation | SNO50COV | Areal snow coverage threshold at 50% | 9 | 0-1 | 0.44 | 0.65 | 0.4 |
| Basin | SURLAG | Surface runoff lag time coefficient | 10 | 1 – 24 | 8 | 6 | 12 |
| Soil | SOL_AWC | Available water capacity at soil | 11 | 0-1 | 0.13 | 0.25 | 0.15 |
| Snowfall accumulation | SNOCOVMX | Areal Snow coverage threshold at 100% | 12 | 0 to 500 | 45 | 20 | 20 |
| Groundwater | ALPHA_BF | Baseflow factor (days) | 13 | 0-1 | 0.21 | 0.40 | 0.25 |
| Groundwater | GWQWN | Threshold water depth in the shallow aquifer for return flow to occur (mm) | 14 | 0-5000 | 80 | 100 | 150 |

## 4.7. Model performance evaluation

The regression coefficient ($r^2$) describes the proportion of the total variance in the observed data that can be explained by the model [25]. The closer the value of $r^2$ to 1, the higher is the agreement between the simulated and the measured flow and is calculated as follow:

$$R^2 = \frac{(\sum[x_i - x_{av}][y_i - y_{av}])^2}{\sum[x_i - x_{av}]^2 \sum[y_i - y_{av}]^2} \tag{12}$$

Where: $x_i$ is measured value, $x_{av}$ is average measured value, $y_i$ is simulated value, $y_{av}$ is average simulated values, the same holds true for Eqs.(12) and (13).

Nash Sutcliff Efficiency ($E_{NSE}$) indicates the degree of fitness of observed and simulated data and given by the following formula.

$$E_{NSE} = 1 - \frac{\sum[x_i - y_i]^2}{\sum[x_i - y_i]^2} \tag{13}$$

The value of $E_{NSE}$ ranges from 1 (perfect) to negative infinity. If the measured value is the same as predictions, $E_{NSE}$ is 1. If the $E_{NSE}$ is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe, 1970).

The percent difference (D) measures the average difference between the simulated and measured values for a given quantity over a specified  period were calculated as flows:

$$D = 100\left(\frac{\sum y_i - \sum x_i}{\sum x_i}\right) \tag{14}$$

A value close to 0 % is best for D. However, higher values for D are acceptable if the accuracy in which the observed data gathered is relatively poor.

**Table 4.4. General reported ratings for Root Coefficient of determination ($R^2$), Nash-Dutcliffe efficiency (EMS) and Differentiate**

| Formula | Value | Rating |
|---|---|---|
| $R^2 = \frac{(\sum[x_i - x_{av}][y_i - y_{av}])^2}{\sum[x_i - x_{av}]^2 \sum[y_i - y_{av}]^2}$ | $> 0.8$<br>$0.65 \leq R^2 \leq 0.8$<br>$0.50 \leq R^2 \leq 0.65$<br>$R^2 \leq 0.50$ | Very good<br>Very Good<br>Satisfactory<br>poor |
| $E_{NSE} = 1 - \frac{\sum[x_i - y_i]^2}{\sum[x_i - y_i]^2}$ | $E_{NSE} = 1$<br>$0.65 \leq E_{NSE} \leq 0.85$<br>$0.50 \leq E_{NSE} \leq 0.65$<br>$E_{NSE} \leq 0.50$ | Excellent<br>Very good<br>Satisfactory<br>Poor |
| $D = 100\left(\frac{\sum y_i - \sum x_i}{\sum x_i}\right)$ | $D, zero$<br>D, close to Zero<br>High variation | Excellent<br>Very good<br>good |

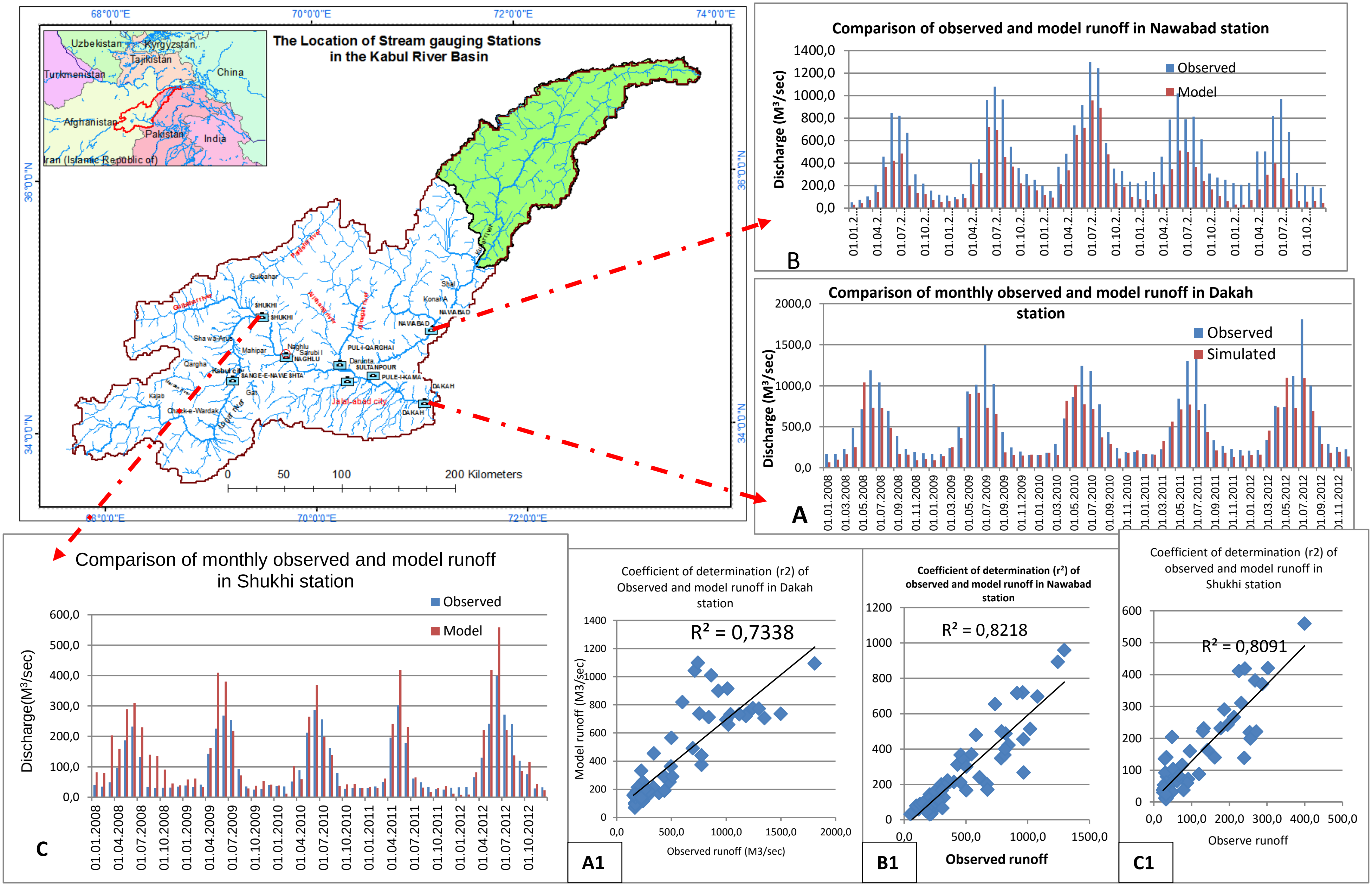



Figure 4.16 Comparison of calibrated model output and observed monthly runoff at stations Dakah (A), Nawabad (B) and Shukhi (C). and $R^2$ for, Dakah (A1), Nawabad (B1), Shukhi (C1, during the period of (2008- 2012)

## 4.8. Hydrology modeling summary

The SWAT model has been run for eleven years (2002-2012) and six years selected as warm up. The year 2008 was a dry year (below average precipitation), while 2009, 2010, 2011 were normal years with average precipitation, however the year 2012 known wet year (above average of precipitation). Manual calibration has been applied on three river gauging stations Figure 4.14, the result of calibration evaluated satisfactory as the characterized in Figure 4.15 in general three different types of output are being generated by the SWAT model due to differences in meteorological data, topographical characteristics, soil types and land use. Output of generated by SWAT can be large depending on the selected output options. One can select output to be written per day, month or year. Output files can include results for the entire basin, for each sub-basin or for each HRU. In addition, stream flow is provided for each sub-basin. Figure 4.17**,** show the hydrology modeled summary and the average flows of the simulated period. The yearly average precipitation for the study area estimated 516 mm/year and the actual Evapotranspiration is 254 mm. The potential the Evapotranspiration is higher is as high as 1219 mm/year.

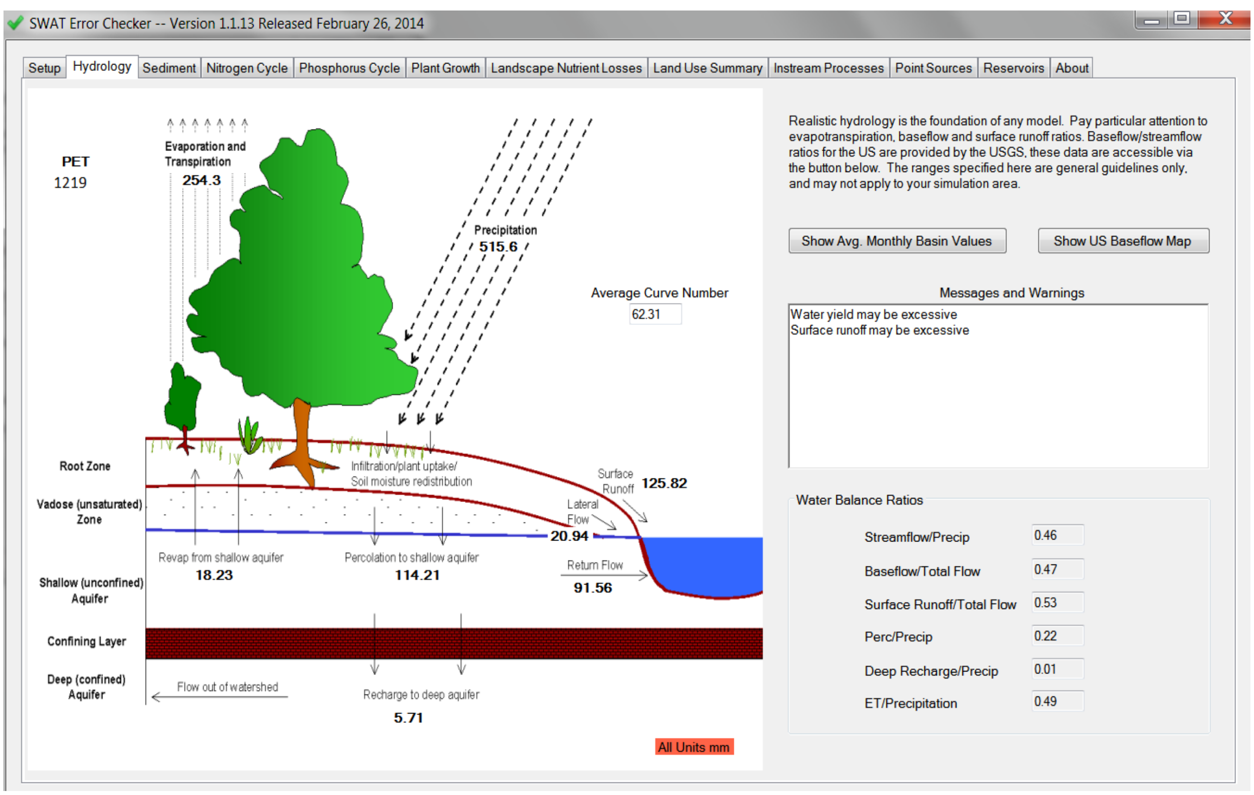



**Figure 4.17 The hydrology modeled summary and hydrology components in the Kabul river basin**.

## 4.9. Flow Duration Curves and indices Hydrology Alteration

A flow duration curve illustrates the percentage of time, or probability, that flow in a stream will equal or exceed a particular value. Flow duration curve analysis is a method involving the frequency of historical flow data over a specified period. Typically, low flows are exceeded a majority of the time, while high flows, such as those resulting in floods, are exceeded infrequently.

### 4.9.1 Create Flow Duration Curves

Flow data are used to generate a flow duration curve. Creating a flow duration curve involves four basic steps.

- Acquire stream flow data
- Arrange data (in descending order)
- Rank flow data
- Obtain frequency of occurrence (or exceedance probabilities)

Frequency of occurrence is obtained using the following formula:

$$F = 100 \times \frac{R}{N + 1}$$

Where, F is the frequency of occurrence (expressed as % of time a particular flow value is equaled or exceeded). R is ranked number, N is the number of observations. It is mentionable SWAT 2012 have been applied to simulate stream flow at Dakah in the Kabul river basin. In the present study, monthly stream flow for the period of (2008 – 2012) selected for Dakah, Shukhi and Nawabad stations. SWAT model can appropriately simulate stream flow in a watershed for use in a duration curve analysis.

### 4.9.2 Flow Duration curve intervals and Zones

The flow duration curve analysis identifies intervals, which can be used as a general indicator of hydrologic conditions (i.e. Wet versus, dry and severity). Flow duration curve intervals can be grouped into several broad categories, or zones. These zones provide additional insight about conditions and patterns associated with the impairment. A common way to look at the duration curve is by dividing it into five zones, as illustrated in (figure 1.1) in Dakah station, representing High flows (0- 30 %), moist conditions (30-45%), mid rang flows (45-100%).

# CHAPTER FIVE

# CLIMATE SCENARIOS AND WATER STRESS ANALYSIS

This chapter concerns the input data sets such as local and global including four scenarios climate outputs and the application of the Water Assessment Tool (SWAT) model for CCMs analysis in the middle of the twenty – first century under three emission scenarios, A2, A1B and B1. Four GCMs, such as MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3 have been selected and the other hand, assessment of water stress under population growth in the middle of the twenty – first century.

## 5.1. Data sets and methods

### 5.1.1 Observed climate data

Observed weather data such as (precipitation and temperature) data sets for the Kabul river basin were obtained from Department of Water Resources (DWR), Ministry of Energy and Water and Ministry of Agriculture, Irrigation and Livestock, Kabul, Afghanistan for the period of 2008 - 2012 (detail description on data quality explained in chapter two). Eight precipitation and temperature gauging stations selected as reliable data with were located within the plain areas of the basin as shown in the figure 6, chapter two and four stations from MoEW, Four stations from MAIL compared with TRMM precipitation point records for the purpose of data quality assessment for detail information see chapter three. Evaluation of the sufficiency of record length and quality discussed in the chapter two and three. According to the monthly and yearly analysis. 64 temperature stations downloaded from CFSR for detail information see chapter two. The overall analysis of different precipitation data sets shows that TRMM data set is reliable as baseline data for hydrology modeling and impact assessment of climate change.

### 5.1.2. Stream flow gauging stations

The hydrology of the catchment reflects the precipitation and temperature pattern within the basin. Daily river discharge data of 8 stream gauge stations were obtained from the Water Resources Department, Ministry of Energy and Water figure 4.9 chapter 4. The discharge data applied for performing sensitivity analysis, calibration in SWAT model. An automated base flow separation and recession analysis technique applied to separate the base flow, ground water flow and surface flow from the total daily and monthly streamflow records. This data and information then used as baseline data for runoff modeling.

### 5.1.3. Global Circulation Model selection

Global climate models (GCMs) are a class of computer-drivn models for weather forecasting, understanding climate and projecting climate change. A global climate model or general circulation model aims to describe climate behavior by integrating a variety of fluid-dynamical, chemical, or even biological equations that are either driven directly from physical laws (e.g Newton's low) or constructed by more empirical means (science-daily). The GCMs output used in this chapter were prepared to investigate the impact and uncertainties of climate change on the Hydrology of the Kabul River Basin (KRB). A set of four criteria was used to select representative GCMs for the KRB. (1) Availability of daily precipitation and temperature, (2) positive correlation coefficient of monthly average observed and GCMs output, (3) heterogeneity of model source such as country or sponsor institution (4) applicabe to apply in the SWAT model. A peirod of 1950- 2000 is used as historic and the future period 2046 2064 were downloaded from for GCMs as listed in the table 5.1.

**Table 5.1 List of GCMs used for this study with daily mean precipitation, maximum and minimum temperature data availability for A1B, A2 and B1 SRES scenarios.**

| No | CMIP3 ID | Organization Group | Country |
|---|---|---|---|
| 1 | MIROC 3.2 (Med) | Center for Climate System Research (The University of Tokyo), National Institute For Environmental Research, Studies, and Frontier Research Center for Global Change (JAMSTEC) | Japan |
| 2 | CGCM 3.1 (T47) | Canadian Centre for Climate Modeling and Analysis | Canada |
| 3 | GFDL-CM2.0 | US Department of Commerc /NOAA/ Geophysical Fluid Dynamics | USA |
| 4 | CNRM-CM3 | Meteo-France /Centre National de Recherches Meteorologiques | France |

### 5.1.4. Digital Elevation Model

Topography was defined by DEM that describes the elevation of entire the points and the area at the specific resolution. DEM with resolution of 30m*30m ($\sim$1k$m^2$) as show in Fig 2.1 chapter 2, was downloaded from SRTM (Shuttle Radar Topography Mission) website on March 2014. The data sets are mosaicked and projected in UTM projection using GIS10.2. The DEM was applied in the SWAT model to delineate the watersheds and to analyze the drainage patters of the land surface terrain. Subbasin parameters such as slope gradient, slope length, and stream network characteristics such as primary, secondary streams and rivers which were derived from the DEM.

### 5.1.5. Land cover data set

The 2001- 2010 Land cover dataset had downloaded from MODIS-based global land cover dataset Global Land Cover Facility with high resolution(0.5) km. All land use and land cover classes were aggregated into seven major categories according to their hydrologic properties. These include rangeland, grassland, mixed forest, barren, cropland, settlement and water. All the categories identified based on legend attached to it in the folder. After performing mosaic, and projection in UTM projection using GIS. As shown in figure 2.3, chapter 2. The data set was applied in the SWAT model.

### 5.1.6. Soil properties

The SWAT model requires different soil textural and physic-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. In this study, soil dataset obtained from FAO/UNESCO-ISWC (FAO/UNESCO-ISWC, 1998) with the resolution of 90m*90 meter and projected based on UTM, then applied in SWAT model. The soil data set shown in figure 2.4, chapter 2.

## 5.2. Climate Change Scenarios

The intergovernmental panel on Climate Change (IPCC) developed long-term emissions scenarios in 1990 and 1992 these scenarios have been widely used in the analysis of possible climate change (IPCC AR3). These changes in understanding relate to, e.g. the carbon intensity of energy supply, the income gap between developed and developing countries, and to sulfur emissions. The latest IPCC assessment report (IPCC AR4) stated that Earth's average temperature is unequivocally warming. The report documented that anthropogenic factors (due to human activity) are responsible for most of the current global warming. The primary anthropogenic source is the emission of greenhouse gases such as carbon dioxide, which is mainly produced by the burning of fossil fuels. A world range of emission scenarios was developed by the IPCC in a Special Report on Emission Scenarios (SRES), the main scenario storylines are as follows:

- **A1** Storyline describes a world of rapid economic growth and rapid introduction of new and more efficient technology.
- **A2** Storyline describes a very heterogeneous world with an emphasis on family values and local traditions.
- **B1** storyline describes a world of dematerialization and introduction of clean technologies.
- **B2** Storyline describes a world with an emphasis on local solutions to economic and environmental sustainability. The SRES team defined four narrative storylines. Environmental sustainability. The SRES team defined four narrative storylines shown in 5.1

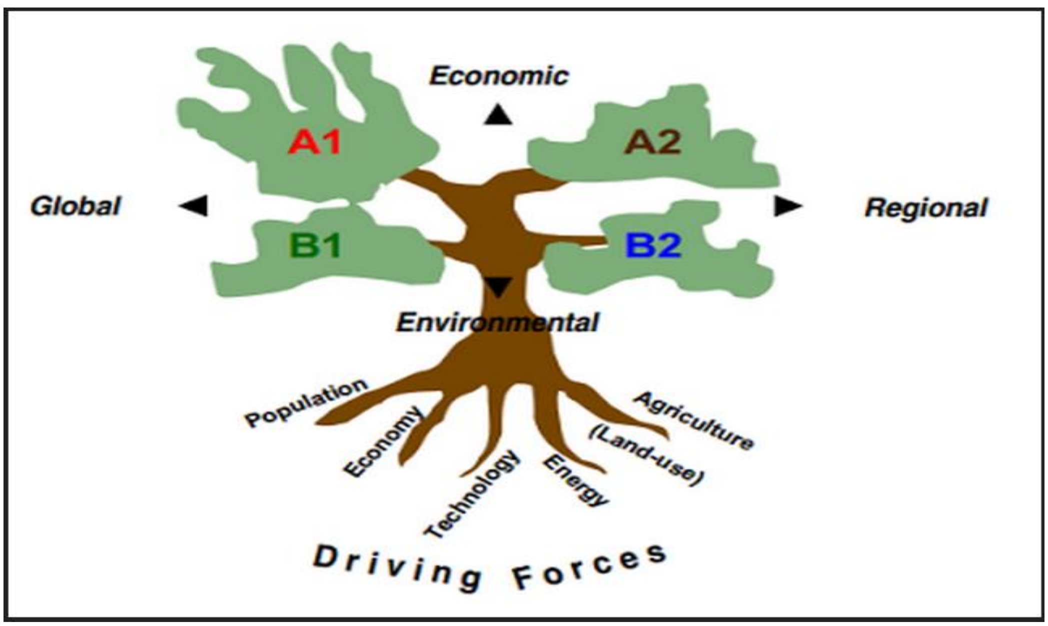



**Figure 5.1 labelled A1, A2, B1 and B2, describing the relationship between the forces driving greenhouse gas and aerosol emissions and their evaluation during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways(IPCC, data simulation.**

## 5.3. Methods

This study has combined two components as shown in figure 5.2. The first component involved assessment of climate scenarios based on Global Circulation Models (GCMs) output using SWAT model. The second component includes water stress assessment based on projected population in the Kabul river basin.

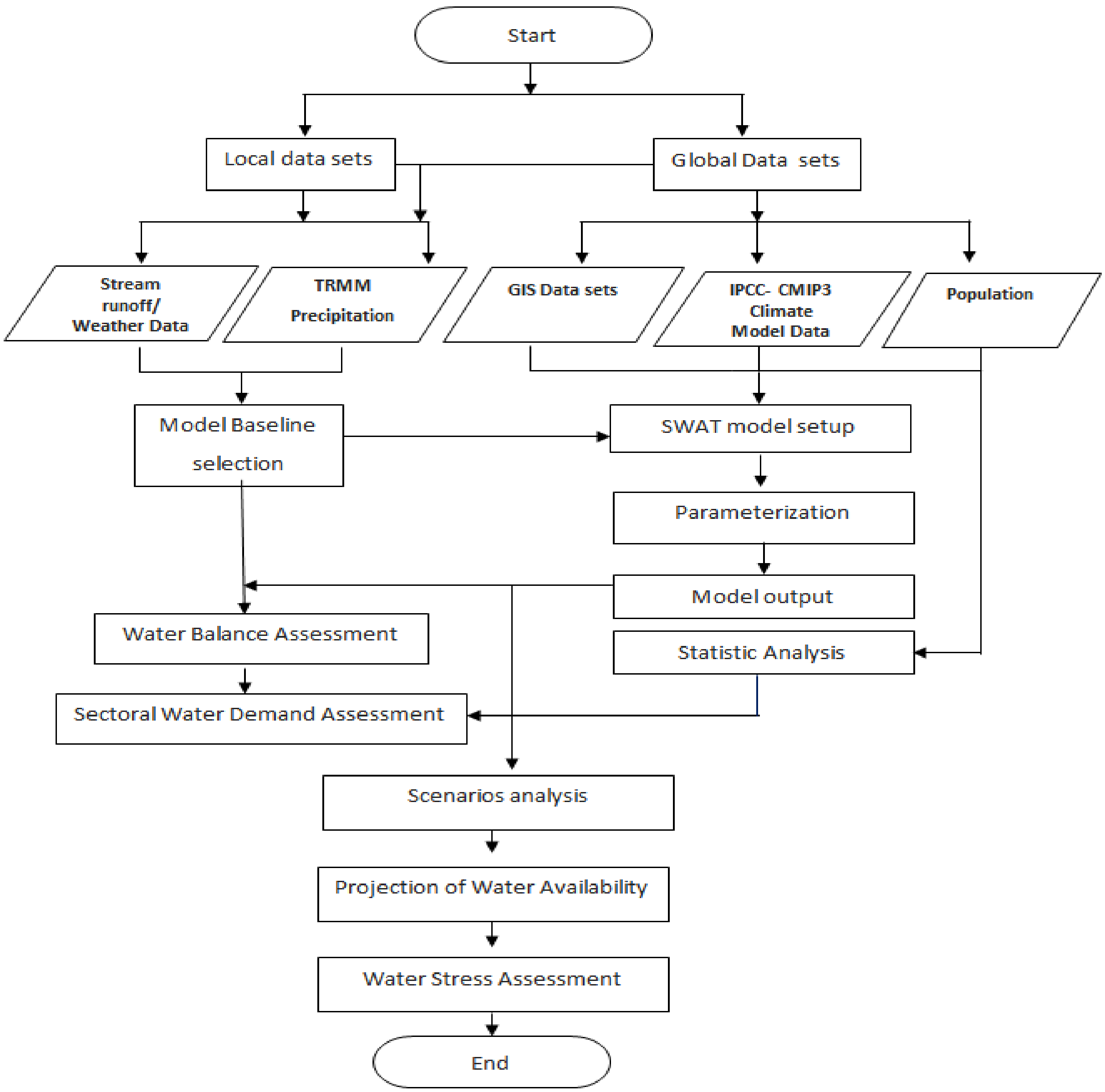



**Figure 5.2 Methodology for Climate Change analysis and Water stress Assessment in the Kabul river basin**

## 5.4. SWAT Model setup

The first step in creating SWAT model input is watershed delineation from Digital Elevation Model (DEM). Inputs entered into the SWAT model were organized to have spetial characteristics. The most important step for creating watershed modeling and Hydrological response units (HRUs), DEM were projected into the UTM zone with N42, which are projection parameters for Afghanistan. Watershed partitioned into 23 sub-basins for modeling purposes as shown in figure 4.10, chapter 4. The watershed delineation process includes five major steps, DEM setup, Stream definition, outlet and inlet definition, watershed outlets definition the threshold based steam definition options were applied to define the appropriate size of the sub-basins.

### 5.4.2. Watershed delineation

Dividing the watershed into areas having a unique land use, soil and slop combinations makes it possible to study the differences in evapotranspiration and other hydrology conditions for different land covers, soils and slopes. The land use, soil and slope datasets were projected based on UTM zone, N42 and imported to the SWAT model databases. To define the distributions of HRUs both single and multiple HRU definition options were tested. The multiple slope option which considers different slope classes, 15%, 30% and more than 30% for HRU definition) was selected. After overlying the land use, soil and slope datasets satisfactory the model generated 827 HRUs with a unique combination of land use, soil and slop and overlapped 100% with the watershed boundaries as shown in figure 4.11, chapter 4.

### 5.4.3. Defining climate database

One of the main sets of input for simulating the watershed in SWAT is climate data. GCMs inputs consist of daily precipitation, maximum and minimum temperature. The climate data which were applied in the model are for mid twenty- first century (2046-2064). 6 years of warm up or equilibration period applied to get the hydrological cycle fully operational. The write input tables menu contains items that all building database files containing the information needed to generate default input for SWAT. Finally, the other key aspects of the SWAT simulation performed for the watershed are listed below:

1- Output time step: daily and monthly
2- Simulation period: 11 years (2002-2012)
3- Rainfall distribution: skewed normal.
4- Runoff generation: CN method.

## 5.5. Model parameterization

SWAT input calibration are process based and must be held within a realistic uncertainty rang [44] The first step in the calibration process in SWAT is the determination of the most sensitive parameters for a given watershed or sub-watershed. The SWAT user must identify which parameters are variable to adjust based on expert judgment or no sensitivity analysis. The adjustment of parameter, depends on many aspects of watershed and its climate condition as well. In the present study, I have identified a group of parameters which are very sensitive for the hydrology components of the study are. These parameters explained in the chapter 4, table 4.3.

## 5.6. SWAT Model Output

The SWAT model has been run based on four GCMs outputs for historic data (1961 – 2000 ) and future data (2046 – 2064) under three scenarios, A2, A1B and B1 with 6 years of warm up. Manual calibration (Parameterization) has been applied to the model. The result of calibration evaluated satisfactory according to $R^2$. The output of generated by SWAT are differentiated based on model input data. SWAT model based on The GCMs outputs run monthly. Output files can include results of the entire basin. For each sub basin or for each HRUs as well. In addition, (Surface Runoff+ ground water quantity + Lateral Flow – Total losses) can count as watershed Available water resources.

## 5.7. Population Growth Analysis

More than 35 years of war in Afghanistan not only have resulted in widespread deforestation, land degradation, breakdown of water resources infrastructure and destruction of irrigation scheme also resulted in destroying of family planning and resulted widespread population growth in the whole country specially in the Kabul river basin. For the purpose of water stress assessment, population growth analysis in the Kabul river basin is very important, Its significance must be analyzed in relation to other factors affecting sustainability. However, rapid population growth can place strain on river basin's capacity for handling a wide range of issues of economic, social and environmental significance, particularly when rapid population growth occurs in conjunction with poverty and lack of access to resources, or with unsustainable patterns of production and consumption, or ecologically vulnerable zones. The percent population growth rate changes from one period to another and calculated from the below formula:

$$P_{rate} = \frac{(V_{present} - V_{past})}{V_{past}} \times 100 \quad (19)$$

Where, $P_{rate}$ is percent rate, $V_{present}$ is present value, $V_{past}$ is past population value.

Exponential growth, such as population growth, is calculated using a compound interest formula to project population in the Kabul river basin in 2045.

$$P_{future} = P_{present} \times (1 + i)^n \quad (20)$$

Where, $P_{future}$ is population in the future, $P_{present}$ is population in the present, i is growth rate, n is number is year for population projection.

**Table 5.2 projected population change in the Kabul river basin (million), 2000 – 2045**

| years | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 |
|---|---|---|---|---|---|---|---|---|---|---|
| Urban population | 3.5 | 5.1 | 6.0 | 7.2 | 8.1 | 8.9 | 9.6 | 10.4 | 10.9 | 11.7 |
| Rural population | 4.6 | 5.2 | 5.3 | 5.5 | 6.2 | 6.8 | 7.3 | 7.9 | 8.3 | 8.5 |
| Total population | 8.0 | 10.3 | 11.4 | 12.7 | 14.2 | 15.7 | 16.9 | 18.2 | 19.2 | 20.2 |

Not: Distribution of population in the urban and rural area in the Kabul river basin by Million.

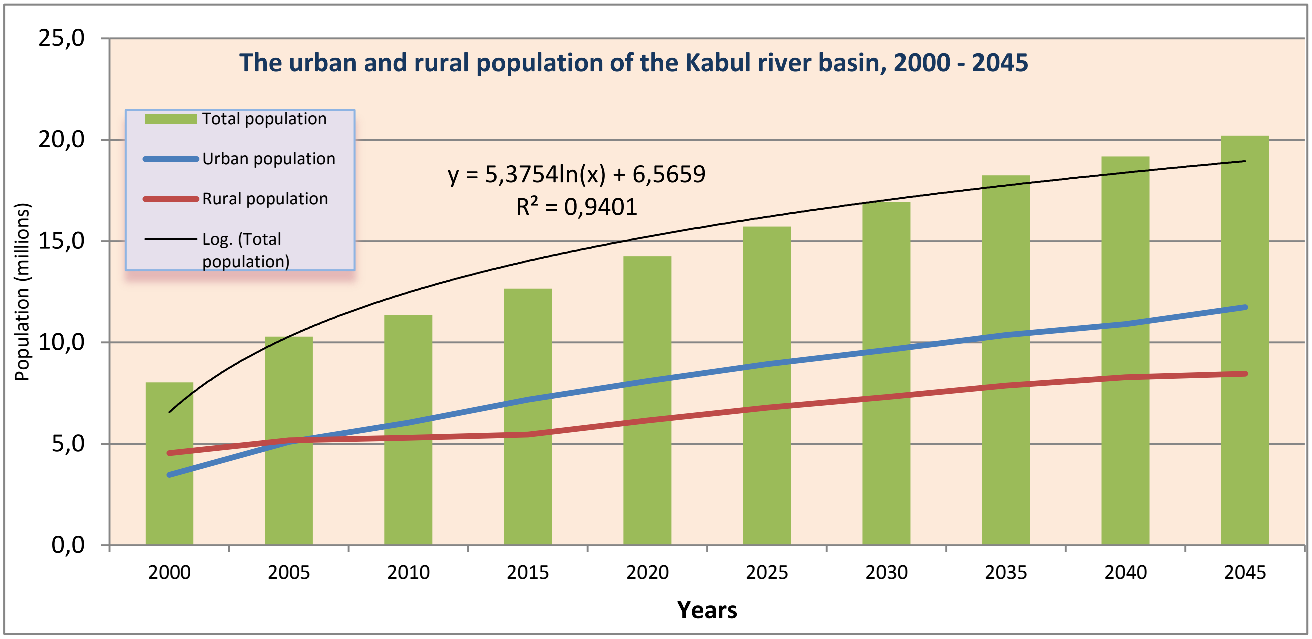



**Figure 5.3: population projection in Kabul river basin**

The result of raster zonal statistical analysis using GIS and formula (19) and (20) shows that the population of Basin increased at a rate of approximately 4.6% every year, it could be the result of refugee returning beside high birth rate. T.J.Mack in his report on Water availability in the Kabul river basin argued that population of Kabul city increased at rate of about 4 percent per year during 2002 to 2007. It is mentionable that, the government has the strategy of public awareness through the school, mass media, so in log term, it could possible increase awareness in Kabul basin, so, in calculation, I assumed 2.4 percent for the years of (2020-2035) and 1.5% from (2035 to 2045).

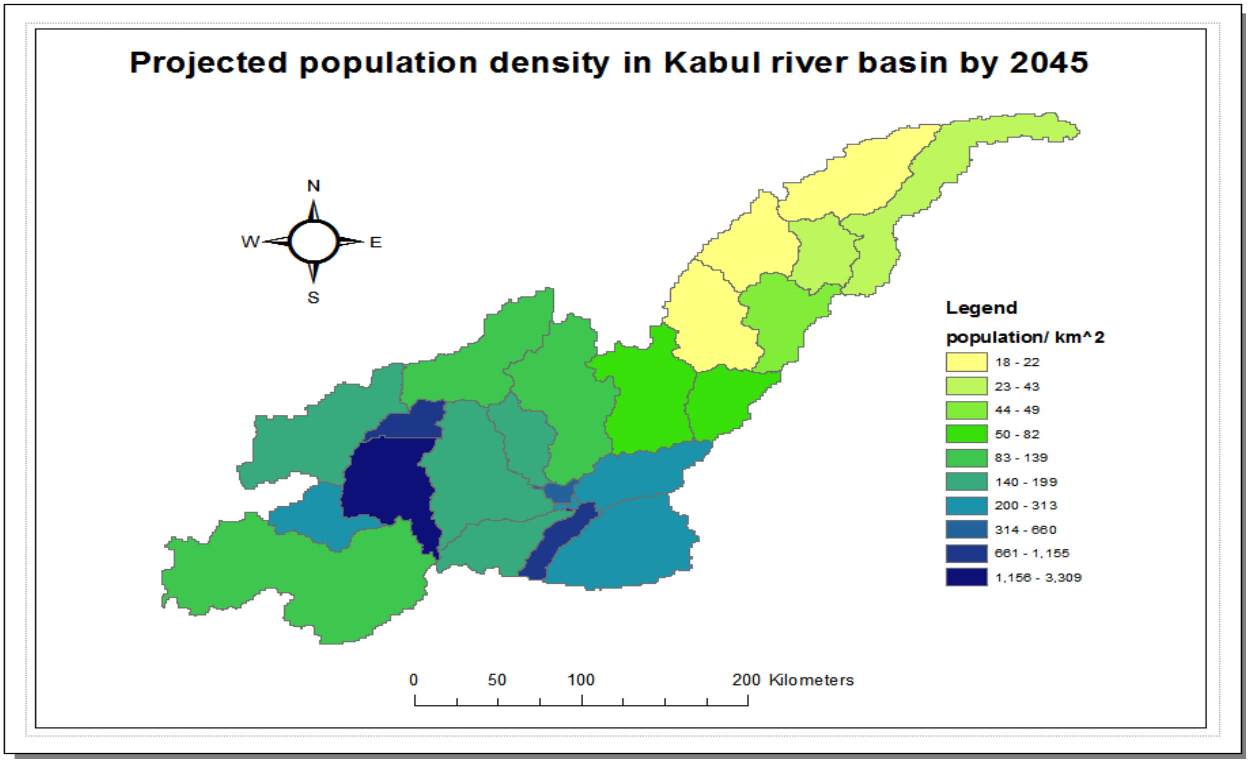



**Figure 5.4 Population density map of Kabul river basin by 2045**

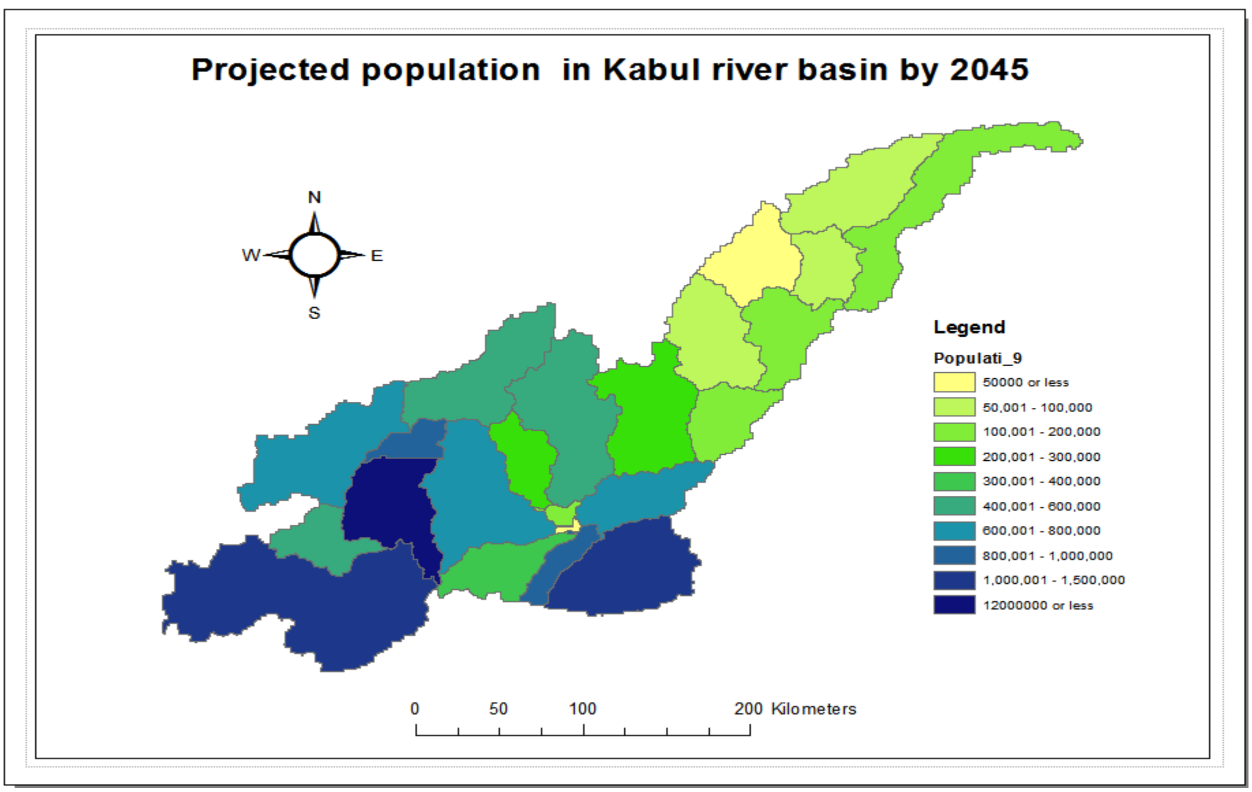



**Figure 5.5 Projected population based on the watershed boundary in the Kabul river basin by 204.**

## 5.8. Indicators for water stress assessment

One of the most pressing global security problems in the future is likely to be water scarcity [44]. A situation where there is insufficient water to satisfy normal human requirements. The best known indicator of national water scarcity is per capita renewable water, where threshold values of 500, 1000 and 1700 $m^3$/person/year are used to distinguish between different levels of water stress [45], Also, A country is defined as experiencing water stress when annual water supply drop below 1700 $m^3$ per person, the country is defined as water scarcity. Based on the FAO criterion, countries or regions are considered to be facing absolute water scarcity if renewable water resources are < 500 $m^3$ per capita, chronic water stress if renewable water resources are between 500 and 1000 $m^3$ per capita, and regular water stress between 1000 and 1700 $m^3$ per capita (Table 5.3). This simple approach measures water stress, according to a population that can reasonably live with a certain unit of water resources. This indicator is widely used because it can be easily calculated for every country, region and watershed in the world and for every year.

**Table 5.3 consideration of the water stress level based on FAO criterion (2012)**

| Annual renewable freshwater (m3/ person/year | Level of water stress |
|---|---|
| <500 | Absolute water stress |
| 500 – 1000 | Chronic water shortage |
| 1000 - 1700 | Regular water stress |
| <1700 | Occasional or local water stress |

Present estimation shows that, currently people in the Kabul upstream and midstream suffers from water scarcity. This number is expected to increase substantially as population increases and as standards of living (and therefore consumption) in the middle of twenty-first century. Climate change is expected to have an impact on precipitation 18% decrease in the entire basin. The possible impacts of Climate change on water resources, projected for the mid to late century according to James R. Mihelcic and Julie Beth Zimmerman ( Environmental Engineering) [46]. as shown in the table 5.4.

**Table 5.4 Expected impacts of climate change on water resources**

| **Example of possible impacts of climate change on water resources, projected for the mid to late century** | | |
|---|---|---|
| Phenomenon and direction of trend | Livelihood of future trends based on projections for the 21st century | Major impacts(s) |
| Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days a nights | Virtually certain | Effects on water resources relying on snow melt; effects on some water supplies |
| Warm spells/ heat waves; frequency increases over most land areas | Very likely | Increase water demand; war quality problem, for example, algal blooms |
| Heavy precipitation events, frequency increases over most areas | Very likely | Adverse effects on quality of surface water and groundwater; contamination of water supply; water scarcity may be relieved |
| Increase in area affected by drought | Likely | More widespread water stress |
| Increase in intense tropical cyclone activity | Likely | Power outages, causing disruption of public water supply |

# CHAPTER SIX

# SECTORAL WATER DEMAND ESTIMATION

## 6.1. Integrated Water Resources Management

The competition for available water resources in much of the developing countries are growing rapidly due to ever-increasing and conflicting demands from agriculture, industry, urban water supply and energy production. The demand is fueled by factors such as population growth, urbanization growth, dietary changes and increasing consumption accompanying economic growth and industrialization [26]. Climate changes are expected to further increase the stress on water resources in arid and semi-arid regions. The traditional fragmented approach is no longer viable and a more holistic and coordinated approach to water management is essential. The new water law concentrated on stakeholder participation in water management in the Kabul river basin and sub-river basins. Based on new water sector policy and water resources sub-sector, Integrated Water Resources Management (IWRM) is carried out through the river basin approach. The objective of IWRM is to decentralize the activities gradually to river basins and sub basins [27] and considerable use of water resources for food production, electricity generation, fishery and biodiversity. Recently river basin and sub-basin institutions are faced with a complex task. The river flows in the Kabul and its tributaries are not only highly seasonal (72% of annual flow occurs in five months, May-September. As shown in figure 6.1

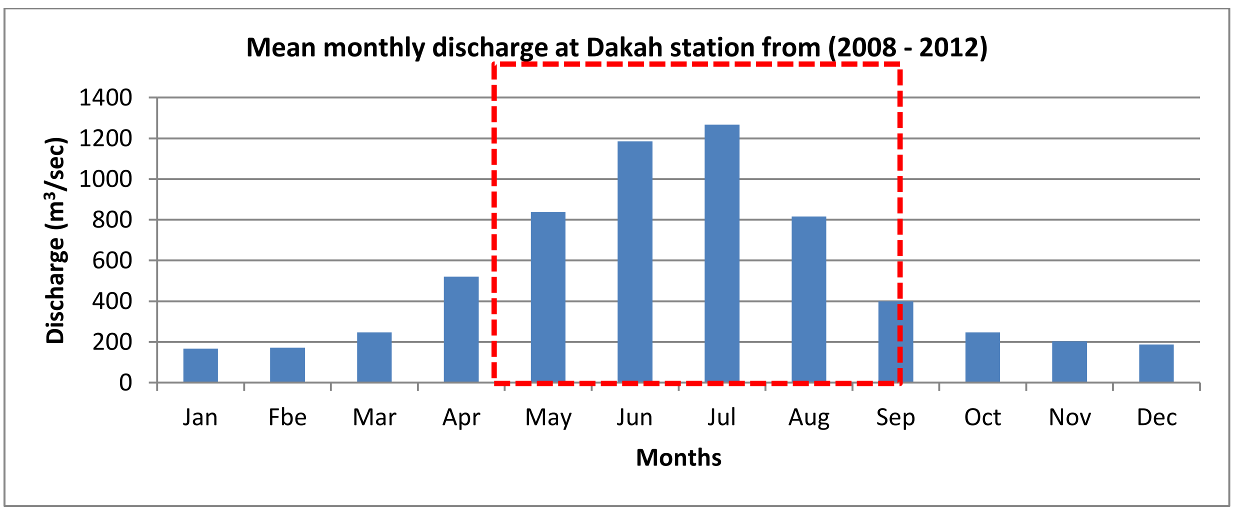



**Figure 6.1: The mean monthly discharge of Dakah station on Kabul river**

Although winter precipitation is diminutive, the crops such as wheat and rice are grown in the late of winter and early in the spring seasons for historical reasons, so the summer peak flows mush be stored to irrigate winter and spring crops. Wheat and Rice are key to food security in Afghanistan. Therefore, winter and spring irrigation take precedence over the summer for crops like sugarcane, cotton and rice in downstream in water management.

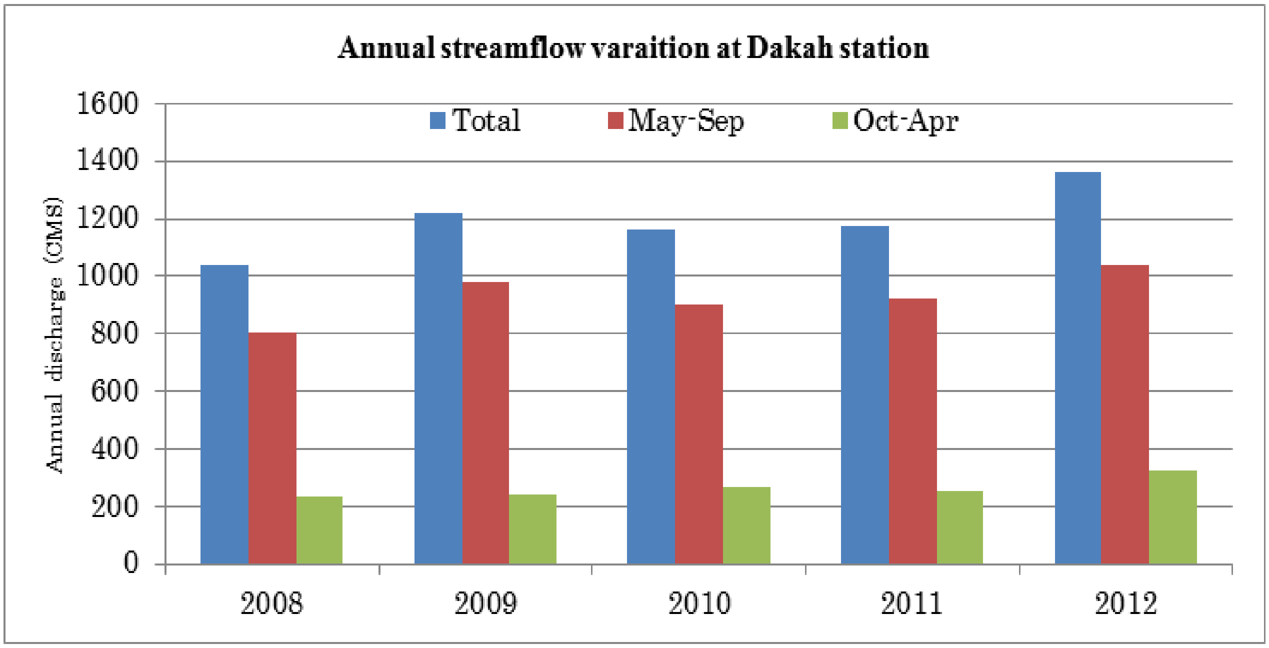



**Figure 6.2 Annual stream flow variation in cubic meter per second at Dakah station, on the outlet of Kabul river basin.**

## 6.2. Hydraulic assets in the Kabul river basin

There are several hydraulic infrastructures such as dams and reservoirs across the streams in the Kabul river basin. A number of these assets constructed for electricity power generation, water supply and irrigation purposes [28]. Further to the general situation the basin features some key hydraulic infrastructures that include hydropower as well as irrigation schemes (partly multipurpose). A list of existing hydraulic assets in the Kabul river basin is shown in the Table 6.1.

Table 6.1 Existing hydraulic infrastructures in the Kabul river basin.

| Scheme | Longitude | Latitude | River | Purpose | Date of construction | $P_a$(MW) | Q(MCM/yr) | S(MCM) | Area Irrigated |
|---|---|---|---|---|---|---|---|---|---|
| **Mahipar** | 69.2621 | 34.6182 | Kabul | Hydropower | 1966 | 53 | 485 | ROR | NA |
| **Naghlu** | 69.71716 | 34.641031 | Kabul | Hydropower | 1967 | 75 | 3560 | 496 | NA |
| **Darunta** | 70.362961 | 34.484302 | Kabul | Hydropower and Irrigation | 1967 | 7.5 | 5920 | 40 | 23075 |
| **Sarubi** | 69.775618 | 34.586526 | Kabul | Hydropower | 1957 | 20 | 3560 | 6.5 | NA |
| **Chake-e-Wardak** | 68.578404 | 34.106699 | Logar | Hydropower and Irrigation | 1938 | 1.7 | 235 | 22 | 3597 |

**Note**: $P_a$ – Actual power generation, Q- Average annual streamflow, S- storage capacity, Area irrigated by Hectare.

As shown in the table 6.1 These dams due to limited storage capacity cannot supply adequate water for irrigation in spring season. These dams can together store only 12 days of total annual flows of all rivers, including the Kunar river, 59 days excluding Kunar river. For comparison, the Colorado river basin has nearly 1000 days of built storage [29]. As shown in the figure 6.3

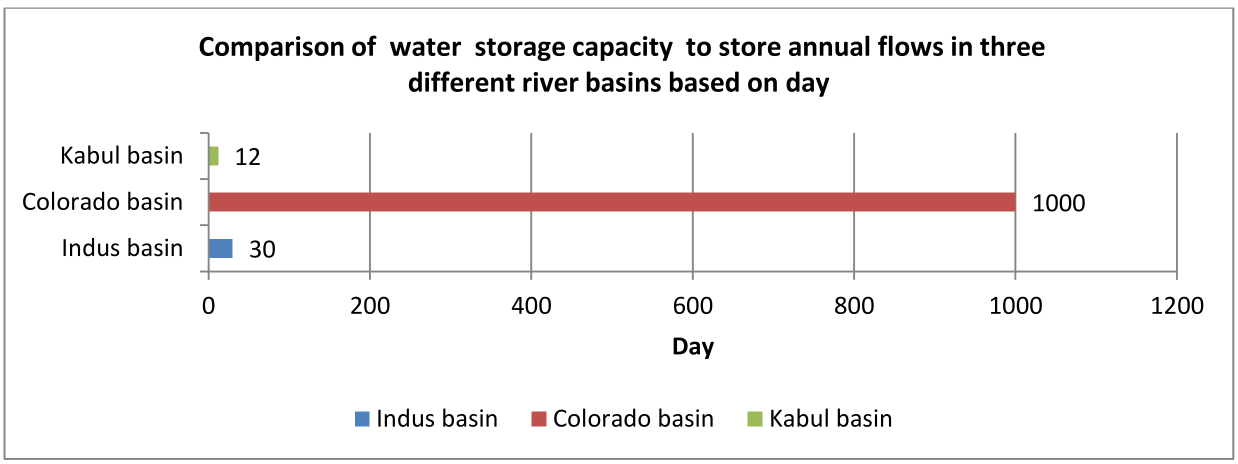



**Figure 6.3. Constructed dam's capacity for storing annual flows in the three different river basins based on the day.**

Low built storage capacity forces Kabul river basin and sub-basins authorities to keep reservoir levels low in the April, May and June months for happening floods in downstream. However the majority of these dams constructed for the purpose of electricity generation and irrigation. Dam is cornerstone in the development of and management of water resources development of a river basin. There are a number of existing, ongoing and proposed dams in the Kabul river basin as shown in the figure 6.4

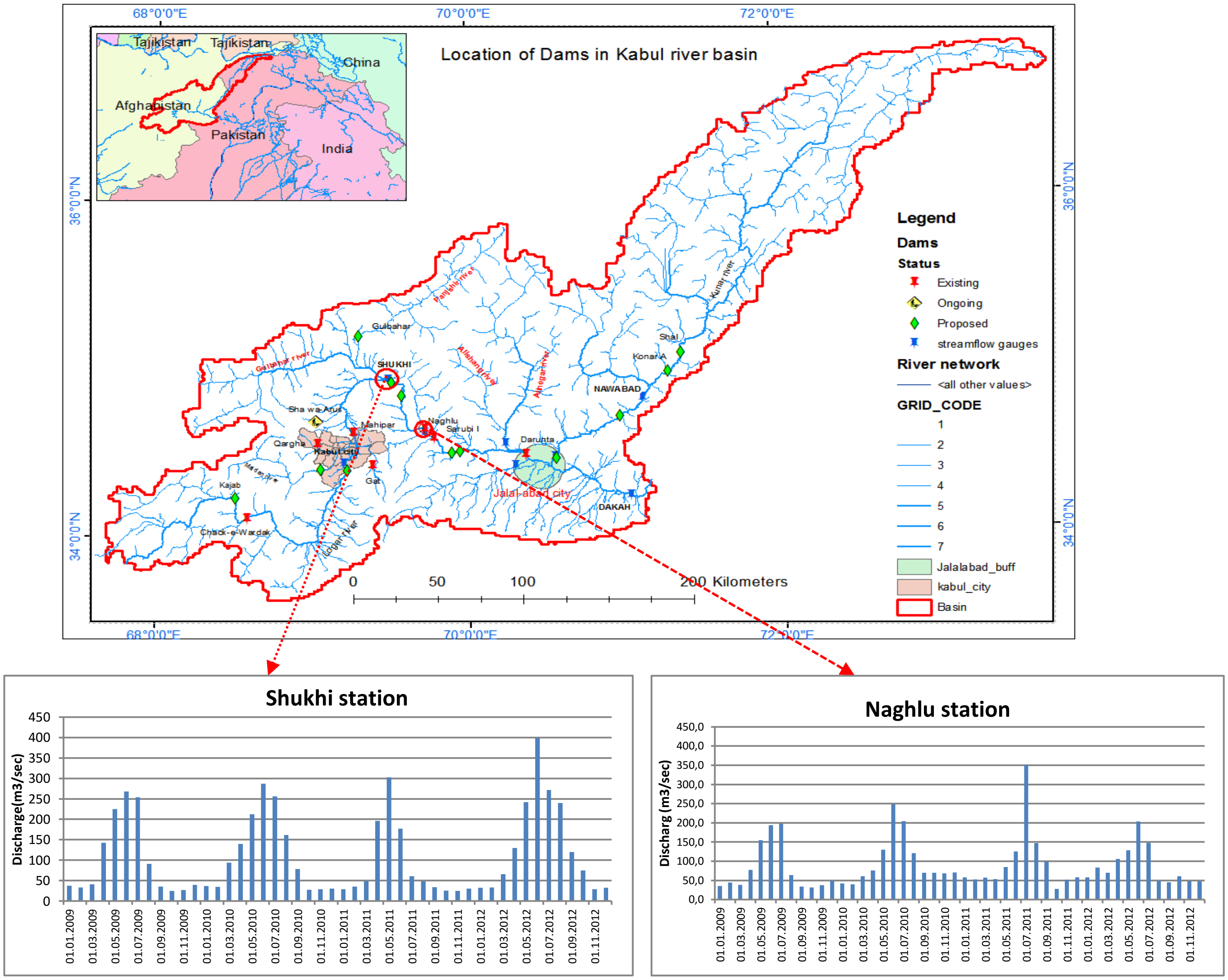



**Figure 6.4 Location of constructed, ongoing and projected dams in the Kabul river basin, also this figure shows comparison of monthly runoff records in Shukh and Naghlu stations.**

Naghlu and Darunta dams can be effectively used to regulate stream peak and flooding in downstream to the dam by temporarily storing the river peak in the months of April, May and Jun and releasing water in the months of August, September and October. However, these two dams have very limited storage capacity, 496 and 40 million cubic meters respectively. The most effective method of stream peak control is accomplished by an integrated water management plan for regulating the storage and discharges of each of the main dams located in the river basin. each dam is operated by a specific water control plan for routing floods and stream peak through the basin without damage[CIGB, http://www.icold-cigb.org/GB/Dams/role_of_dams.asp].


**Figure 6.5 Location of Shukhi stream gauge station, Naghlu and Darunta Dams across the Kabul river. Map source:Global Energy Conservation.**

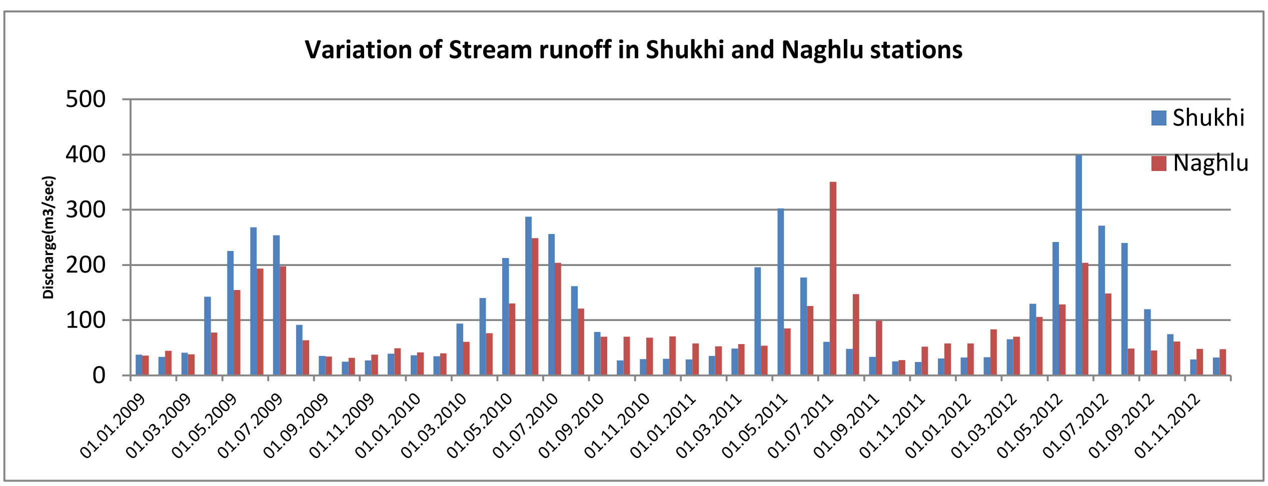



**Figure 6.6 variation of stream runoff in two stream gauging stations, first Shukh station, which is located in upstream and Naghlu stream gauging station which is located in the downhill after Naghlu storage to measure the stream runoff after passing the dam.**

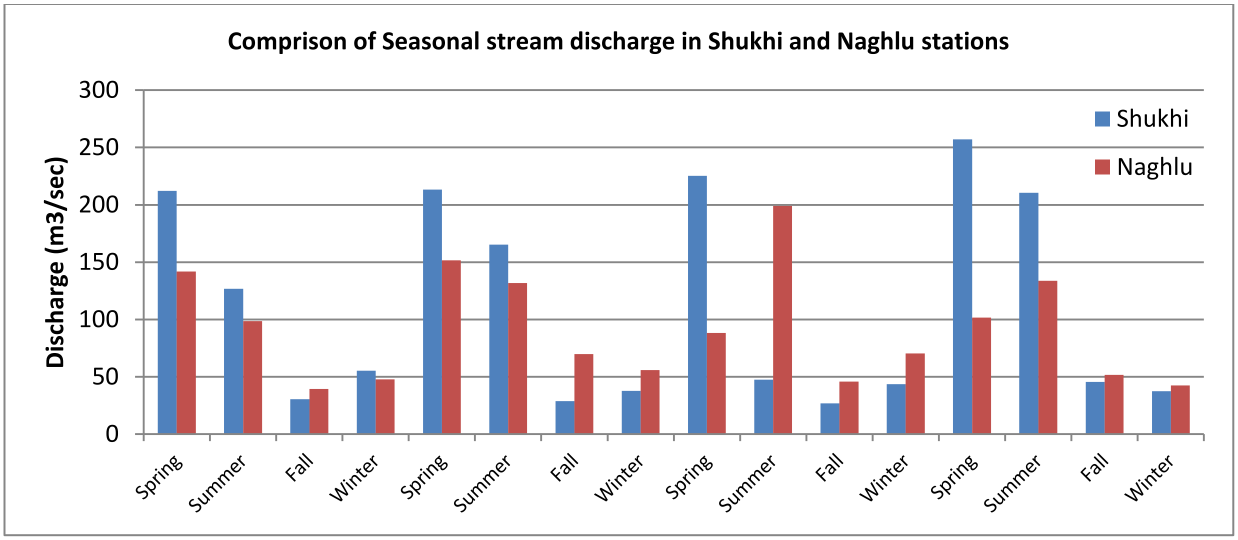



**Figure 6.7: the comparison of seasonal stream flow in Shukh and Naghlu stations from 2009 to 2012 measured in cubic meter per second. figure demonstrates that Naghlu dam playing key role for regulating stream from Summer to Fall and Winter. By limited storage capacity can control stream peak and regulate water to stream and irrigation canals in the fall and winter seasons.**

## 6.3. Evaluation of Monthly and yearly water availability

I have obtained daily and monthly river discharge data from the ministry of Energy and Water (MoEW), Department of Water Resources (DWR), water yearly book for the period of (2008-2012) at eight stations (see table 10, stations located across the streams). In this chapter, I have analyzed monthly stream runoff at five stations which records almost all surface water available in the basin as shown in the figure 54. Widespread groundwater pumping augments the surface supply of water. The irrigation canals in the midstream and downstream are mostly constructed traditionally, causing large seepage losses. However, these losses are more than fully recovered by over million tube wells pumping groundwater across Parwan, Kabul, Nangarhar provinces for the purpose of household water consumption and Agriculture irrigation. Although the exact amounts of groundwater extraction and recharge are little known, it is estimated (SWAT2012) approximately 5.5 billion cubic meters of groundwater is available annually in the Kabul river basin to augment surface water supply. This amount of groundwater is made available in the model for all the basin all the year. They end up pumping water mostly in the winter months (November-February).

**Table 6.2 location of stream gauge recorders in the Kabul river basin**

| No | Name of station | Latitude | Longitude | Daily Records | Length or records | |
|---|---|---|---|---|---|---|
| | | | | River runoff | Begin_Date | End_Date |
| 1 | Shukhi | 34.93333 | 69.48333 | ✓ | 01/01/2008 | 30/12/2012 |
| 2 | Sange-e-Naweshta | 34.43333 | 69.20000 | ✓ | 01/01/2008 | 30/12/2012 |
| 3 | Naghlu | 34.61667 | 69.71667 | ✓ | 01/01/2008 | 30/12/2012 |
| 4 | Pul-i-Qarghai | 34.55000 | 70.23333 | ✓ | 01/01/2008 | 30/12/2012 |
| 5 | Sultanpour | 34.41667 | 70.30000 | ✓ | 01/01/2008 | 30/12/2012 |
| 6 | Nawabad | 34.81667 | 71.11667 | ✓ | 01/01/2008 | 30/12/2012 |
| 7 | Pule-i-Kama | 34.46667 | 70.55000 | ✓ | 01/01/2008 | 30/12/2012 |
| 8 | Dakah | 34.23333 | 71.03333 | ✓ | 01/01/2008 | 30/12/2012 |

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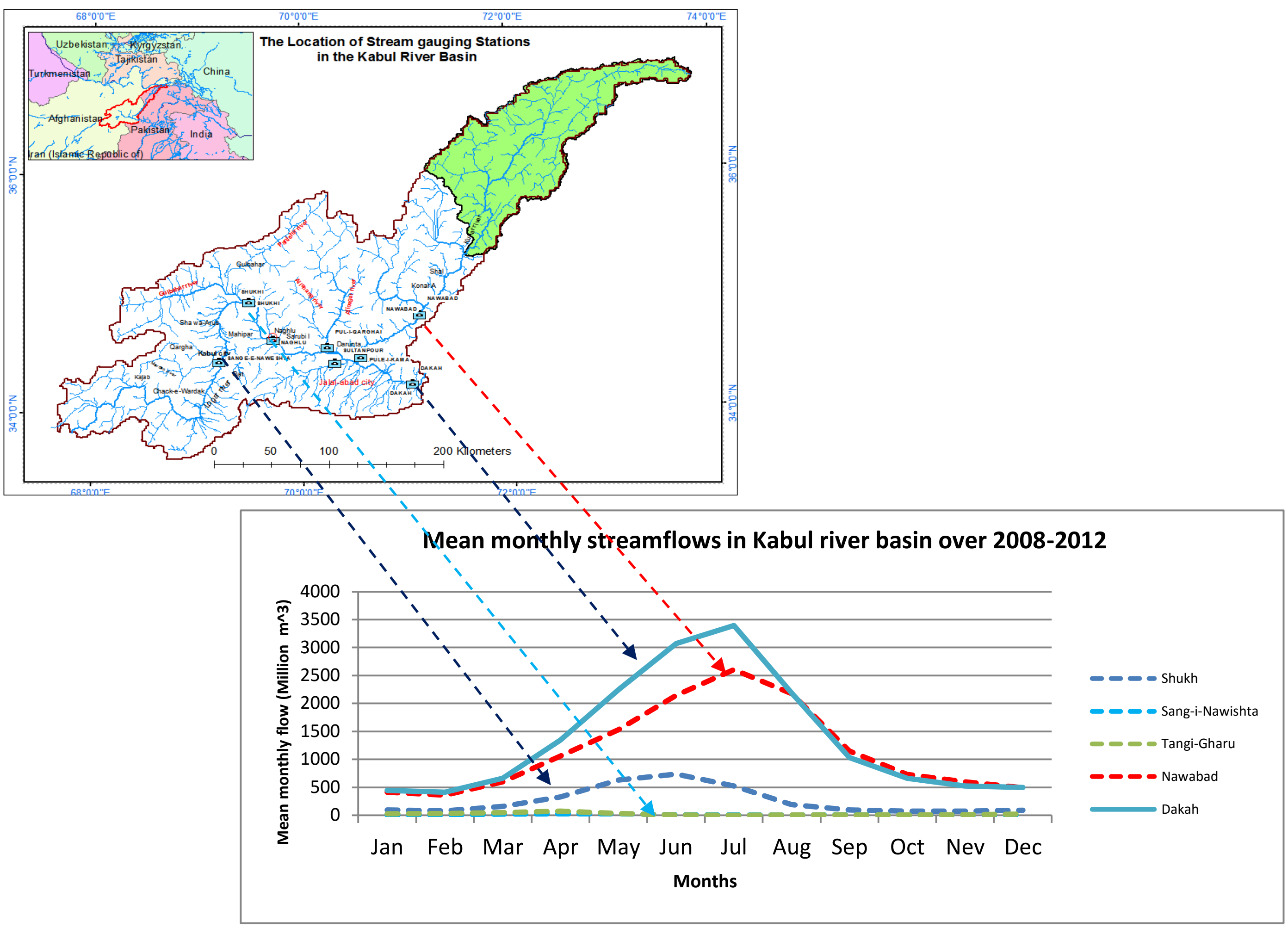


**Figure 6.8 location of stream gauges and monthly runoff records in the Kabul river basin.**

## 6.4. Sectoral water demands

Although the major irrigation schemes collapsed during the civil war [30], agriculture still is the main water consumer according to AQUASTAT survey report [31] and in accordance with the study at hand and land cover analysis using remote sensing and SWAT model. Agriculture, development, population growth and urbanization are important socioeconomic trends in the Kabul river basin. Future projections about the local economy and demography are vital for the water demand assessment and will be explored in terms of development scenarios. It is also important to consider the certain reserve flows are required to sustain environmental functions and environmental services associated with the rivers. There is no data nor are any estimates available on environmental water demands in the Kabul upstream, midstream and downstream basin, but demand assumption would distort the picture. In this study, therefore, attempts to provide first cautious estimates of reserve flow requirements in the basin, referring to case studies in the basin and their respective research findings. Historically, groundwater extraction has been largely limited to, water from shallow unconfined aquifers abstracted using kariz and traditional wells from which water is drawn using animal power. More recently, deeper confined aquifers are being developed for domestic and municipal water supply in the urban and rural areas using deep-wells (AQUASSTAT-2012).

### 6.4.1. Agriculture water demand

Agriculture in the Kabul river basin is generally limited to, land along the river valleys with access to the river for irrigation [32]. The broad plain stretching southward from the Ghorband and Panjshir rivers, the lover logar valley, areas adjacent to Kabul and the wide valley of the Kabul river, east of Jalalabad as shown in the figure 6.9. These areas represent the greatest potential in the Kabul river basin for intensive cultivation of high value crops. If water supply is reliable throughout the summer season, irrigated agriculture is intensive. Intermitted irrigation is practiced where access to water is more uncertain. The existing and potential of irrigated areas within the Kabul river basin estimated 264100 hectares based on

HRU analysis. From the total irrigated area 62000 hectare intensive irrigated area with two crops per year and 205300

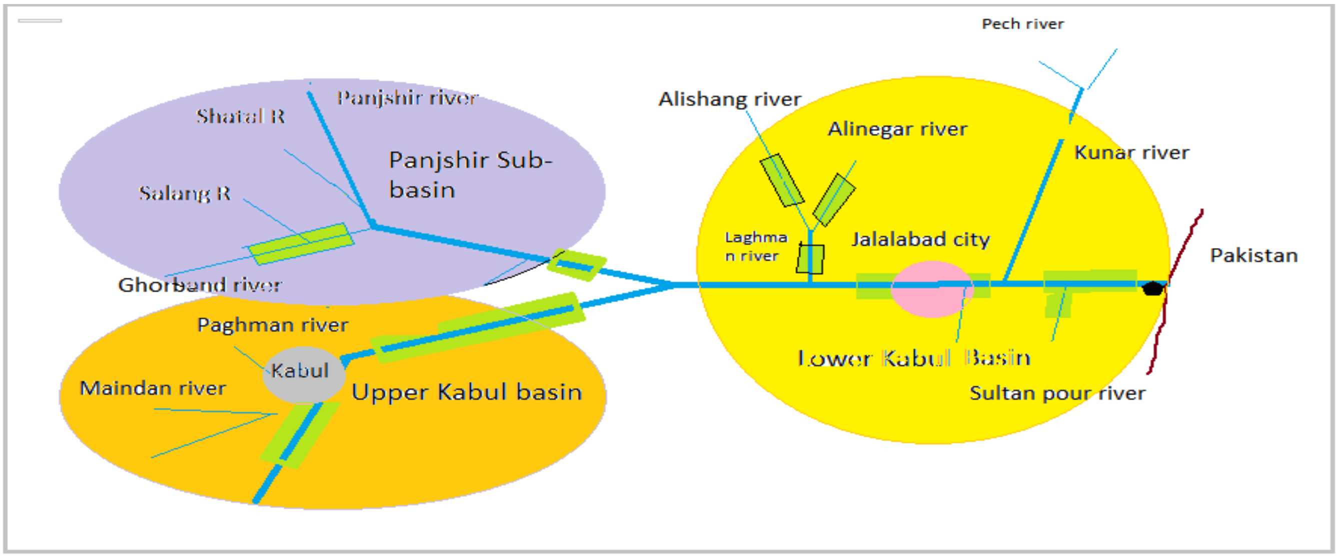


**Figure 6.9 Schematic diagram of the Kabul sub-basins. The location of croplands along the river valleys shown by green polygons.**

| Table 6.3 Cultivated surface area of wet farming agricultural crops (hectare) | | | | | | |
|---|---|---|---|---|---|---|
| | Agriculture area by (Hectare) | | | | | |
| Sub basins | Wheat | Barley | Vegetable | Fruit trees | Other crops | Total area |
| Logar-Upper Kabul sub basin | 73900 | 11300 | 10600 | 7430 | 1700 | 104930 |
| Panjshir Sub basin | 46700 | 7000 | 2200 | 11810 | 1500 | 69210 |
| Lower Kabul sub-basin | 81300 | 3500 | 5490 | 3570 | 5100 | 98960 |
| **Total area for specific crop by hectare** | 201900 | 22800 | 18290 | 12810 | 8300 | 264100 |
| **Agriculture area by percentage** | 3.2 | 0.3 | 0.3 | 0.4 | 0. 1 | 4.3 |

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**Figure 6.10 Irrigated land in panjshir valley**

**Figure 6.11 Irrigated land khogyani district (Nanagarhar)**

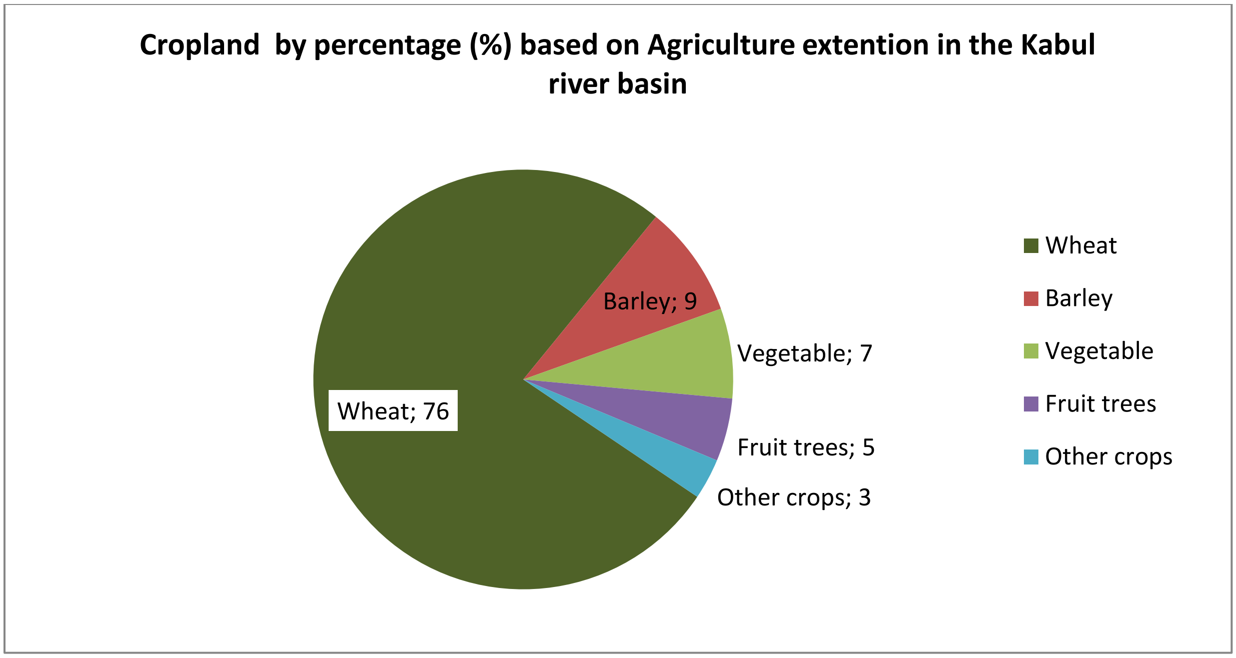


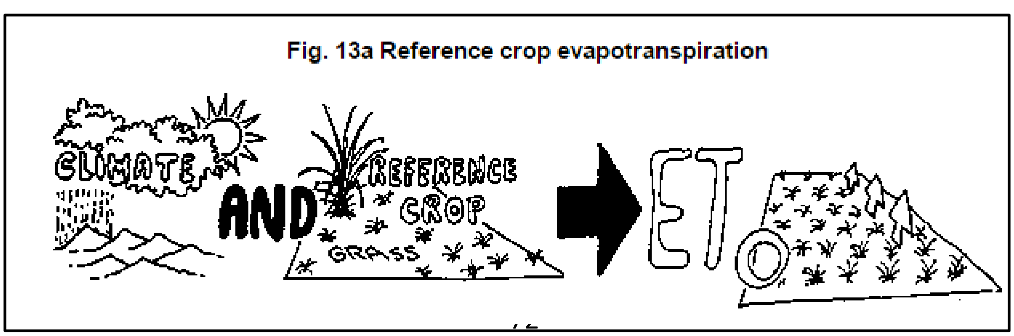

**Figure 6.12 :Cropland by percentage(%) based on agriculture extension in the Kabul river basin.**

### 6.4.2. Calculation of seasonal and monthly irrigation water demand

To estimate monthly or seasonal water demand for the agriculture sector, crop water need or crop water requirement is crucial. To estimate crop water need, [33] educational manual, Crop water need, chapter (3) applied. Crop water need always refers to a crop grown under optimal conditions for example: uniform crop, actively growing, completely shading the ground, free of diseases and favorable soil conditions. Reference crop evapotranspiration ($ET_o$), using Blaney-Criddle Method calculated as follow:

$$ET_o = p(0.48Tmean + 8) \qquad 15$$

Where $ET_o$ is reference crop evapotranspiration, p is mean daily percentage of annual daytime hours for different latitudes, which is obtained from the (www.fao.org/docrop/s2022eot.htm). Tmean calculated from the minimum and maximum daily temperature.



The relationship between the reference grass crop and the crop actually grown is given by the **crop factor**, Kc as shown in the following formula:

$$ET_o \times K_c = ET\ crop \qquad 16$$

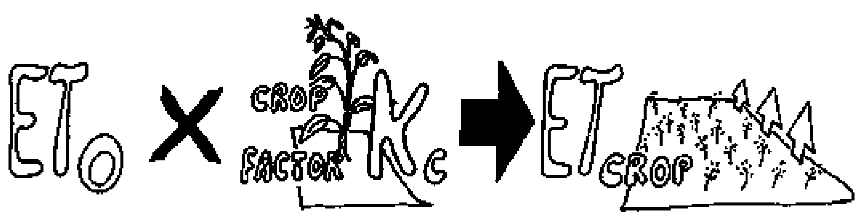
ET crop = crop evapotranspiration or crop water need (mm/day)

Kc = Crop factor

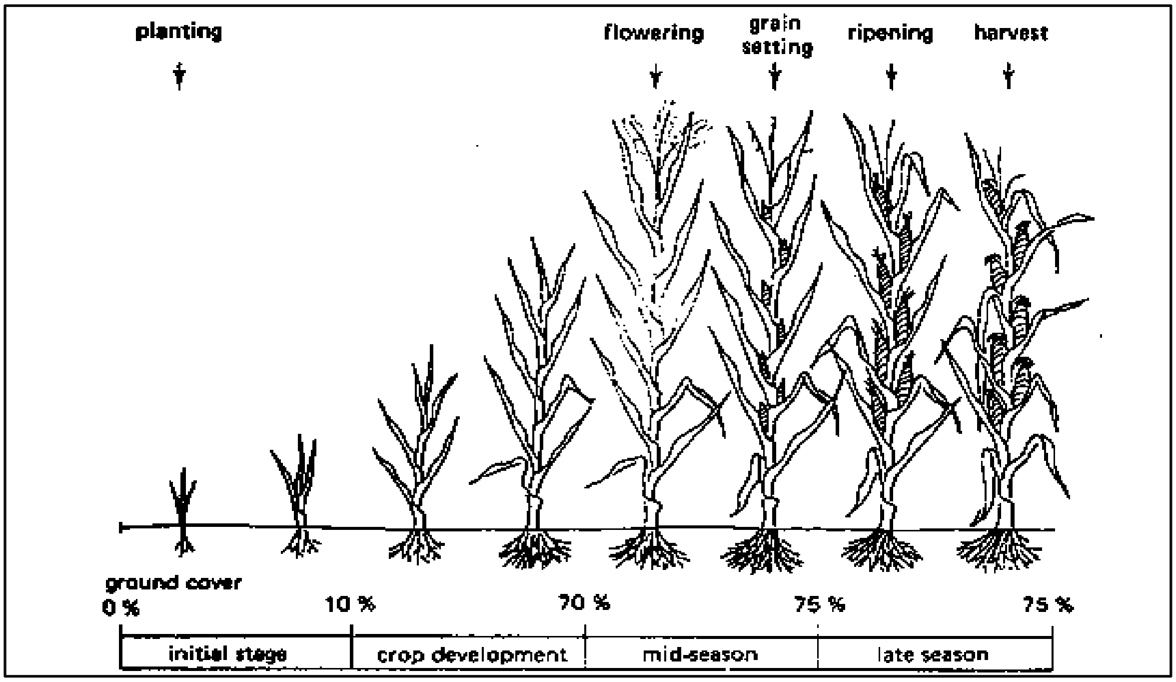
ETo = reference evapotranspiration (mm/day).

The crop factor, Kc , mainly depends on: the type of crop, growth stage of the crop and the climes condition such as ( Humid, Sub-humid, semi-arid, Desert/Arid).

Fig. 13b Crop evapotranspiration or crop water need




Kc is depends of type of crop, fully developed maize, with its large leaf area will be able to transpire, and thus use, more water than the reference grass crop: Kc, maize is higher than 1. Cucumber, also fully developed, will use less water than the reference grass crop: Kc, cucumber is less than 1 (FAO, crop water need). The total growing period of crop is divided into 4 growth stages fighter 6.13.

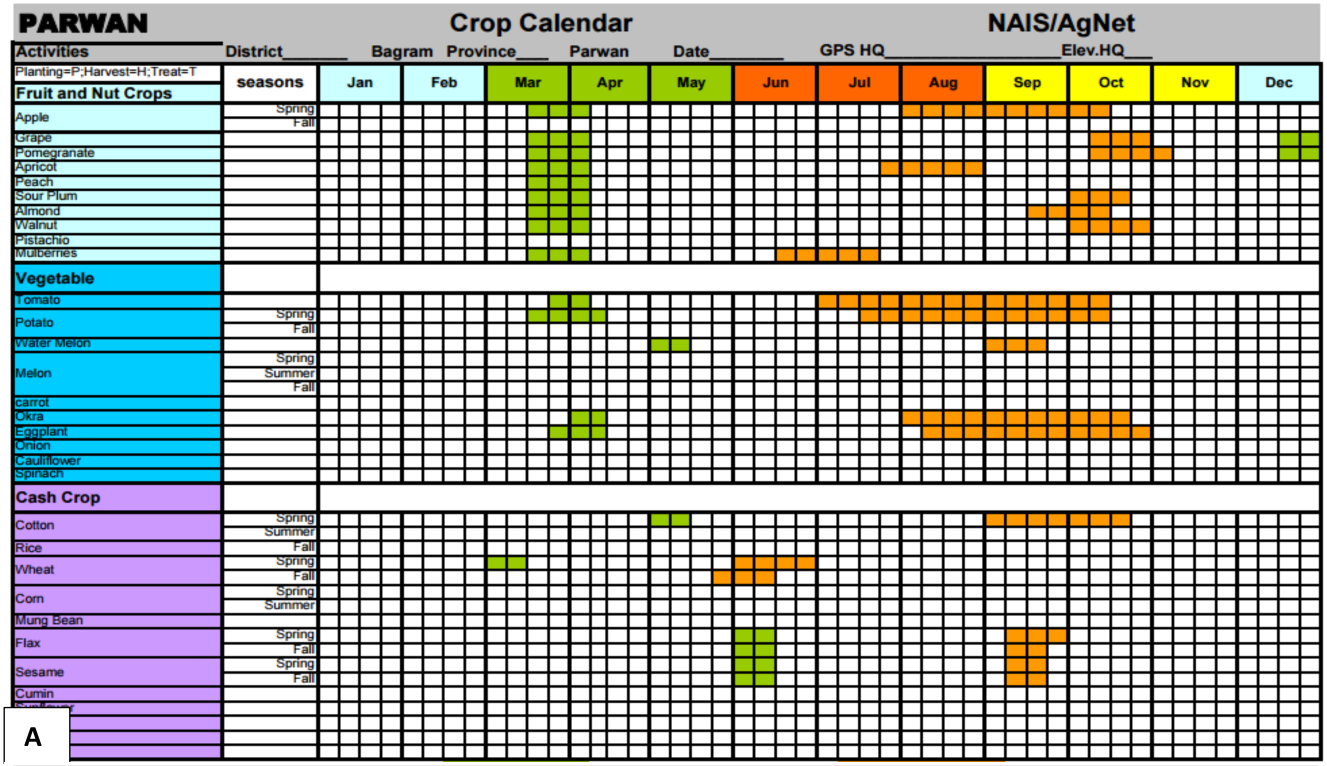



**6.13: this figure shows crop growth stages. this figure taken from FAO chapter 3:crop water needs.**

Accordingly, to calculate crop water need as millimeter of irrigation water need per crop per month for each sub-basin shown in (table 4). Averaged over the years 2008-2012, runoff estimated monthly as shown in figure 27 reflect river regime and irrigation requirement only. The crop, I have considered wheat, barely, rice, sugarcane, cotton, million, potato, vegetables, maize and fruit trees. Table 6.3 and figure 6.12 show the spatial distribution of crops based on hectare and percentage. So I have used the unit area irrigation requirements and the cultivated areas of crops in the base period of 2010 as constant, and applied them against the flows of 2008-2012. I have calculated irrigation water demands by taking the cultivated areas under each crop in each sub-basin and multiplying them by the irrigation requirement per crop per unit area per month. In other words, for each crop in each upper Kabul and whole the catchment as well.

Volume of irrigation water need = (Area cultivated) x (Irrigation need in mm/ha)……..17

Sowing and harvesting crop calendars for each sub basin,obtained from ucdavis, Afghan agriculture,website(http://afghanag.ucdavis.edu/country-info/Province-agriculture-profiles/wardak). Using this calendar, I have distributed the total irrigation requirement of the crop through the planting and growing months and seasons. Figure $6.14_{a,b,c}$ shows the four season's crop calendar


PARWAN
Crop Calendar
NAIS/AgNet
Activities
District_____ Bagram Province____ Parwan Date________ GPS HQ________________Elev.HQ___
Planting=P;Harvest=H;Treat=T
Fruit and Nut Crops
seasons
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Apple
Spring
Fall
Grape
Pomegranate
Apricot
Peach
Sour Plum
Almond
Walnut
Pistachio
Mulberries
Vegetable
Tomato
Potato
Spring
Fall
Water Melon
Melon
Spring
Summer
Fall
carrot
Okra
Eggplant
Onion
Cauliflower
Spinach
Cash Crop
Cotton
Spring
Summer
Fall
Rice
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Corn
Spring
Summer
Mung Bean
Flax
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Sesame
Spring
Fall
Cumin

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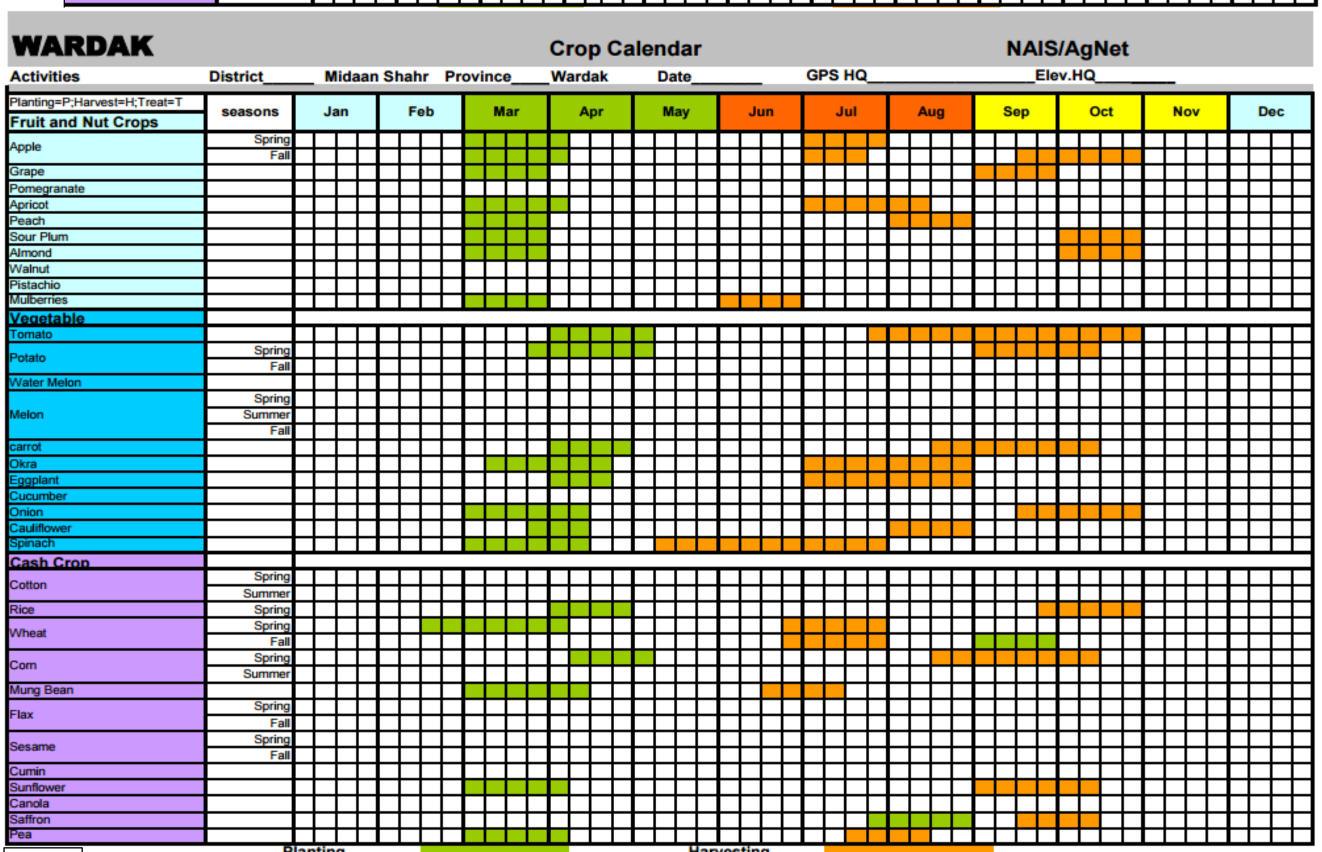
WARDAK
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Planting=P;Harvest=H;Treat=T
Fruit and Nut Crops
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Nov
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Apple
Spring
Fall
Grape
Pomegranate
Apricot
Peach
Sour Plum
Almond
Walnut
Pistachio
Mulberries
Vegetable
Tomato
Potato
Spring
Fall
Water Melon
Melon
Spring
Summer
Fall
carrot
Okra
Eggplant
Cucumber
Onion
Cauliflower
Spinach
Cash Crop
Cotton
Spring
Summer
Rice
Spring
Wheat
Spring
Fall
Corn
Spring
Summer
Mung Bean
Flax
Spring
Fall
Sesame
Spring
Fall
Cumin
Sunflower
Canola
Saffron
Pea
Planting
Harvesting

B

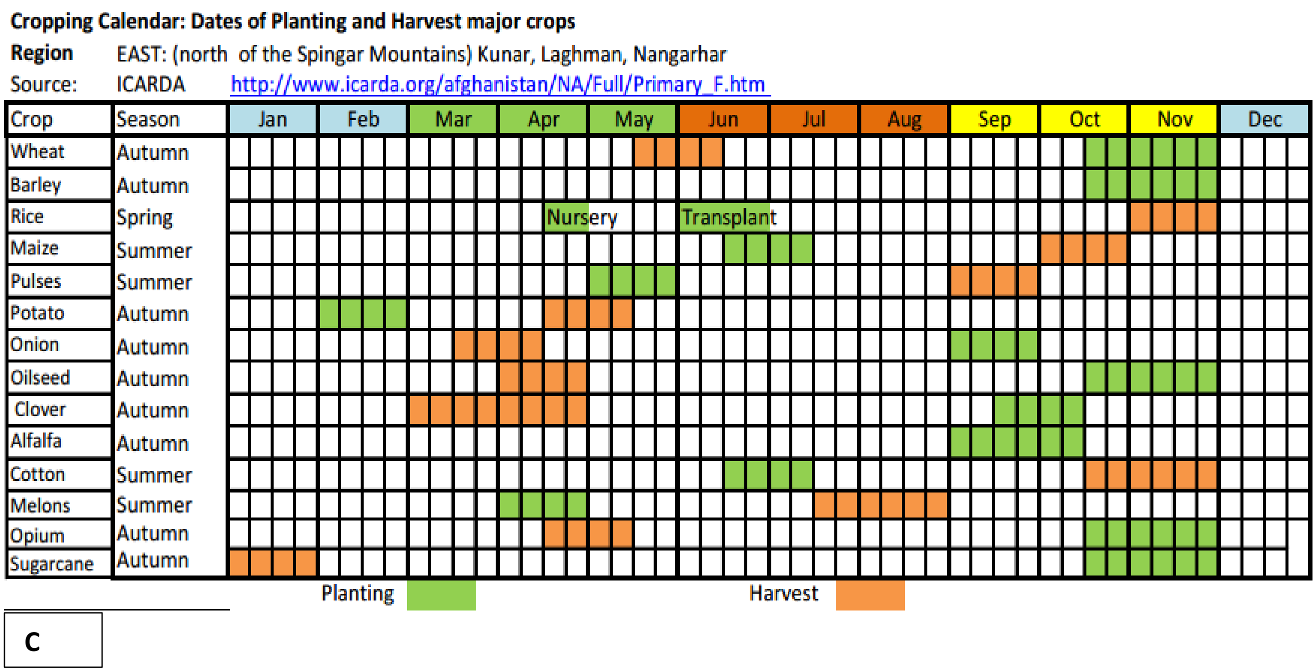



**Figure 6.14: official crop calendars for (A , B) Upper Kabul sub basin, (C) Lower Kabul sub basin . Source: ICARDA**

Crop water need (ET crop) is determined to supply water by various ways, such as by rainfall, by irrigation and combination of irrigation and rainfall (FAO, irrigation water need). In cases where all the water needed for optimal growth of the crop is provided by rainfall, irrigation is not required and the irrigation water need equals to zero. Most cases, however, part of the crop water need is supplied by rainfall and the remaining part by irrigation. In such cases the irrigation water need (IN) is the difference between the crop water need and calculated based on the below formula:.

$$\text{Irrigation water need} = \text{Crop evapotranspiration} - \text{Precipitation} \qquad 18$$

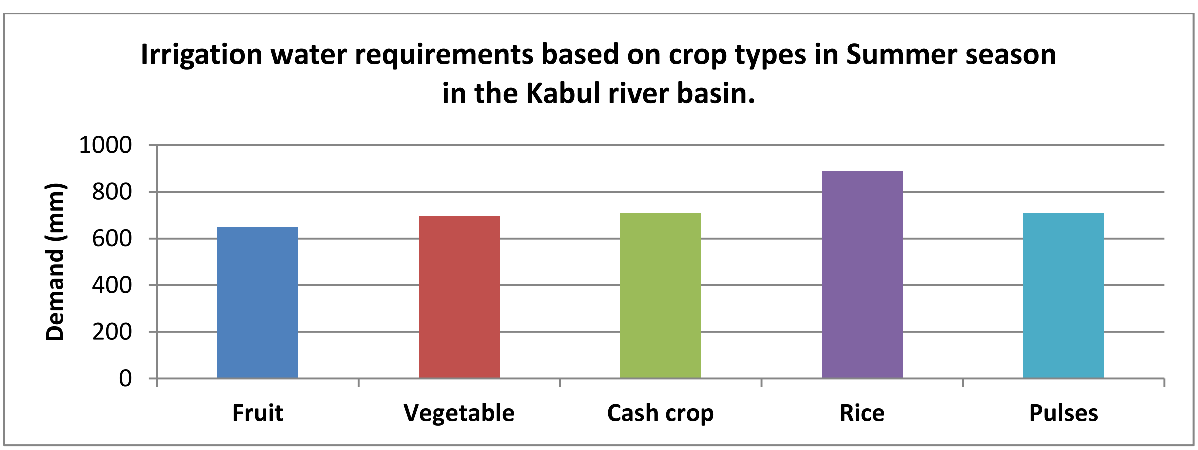



**Figure 6.15 Irrigation water needs based on crop types in summer season.**

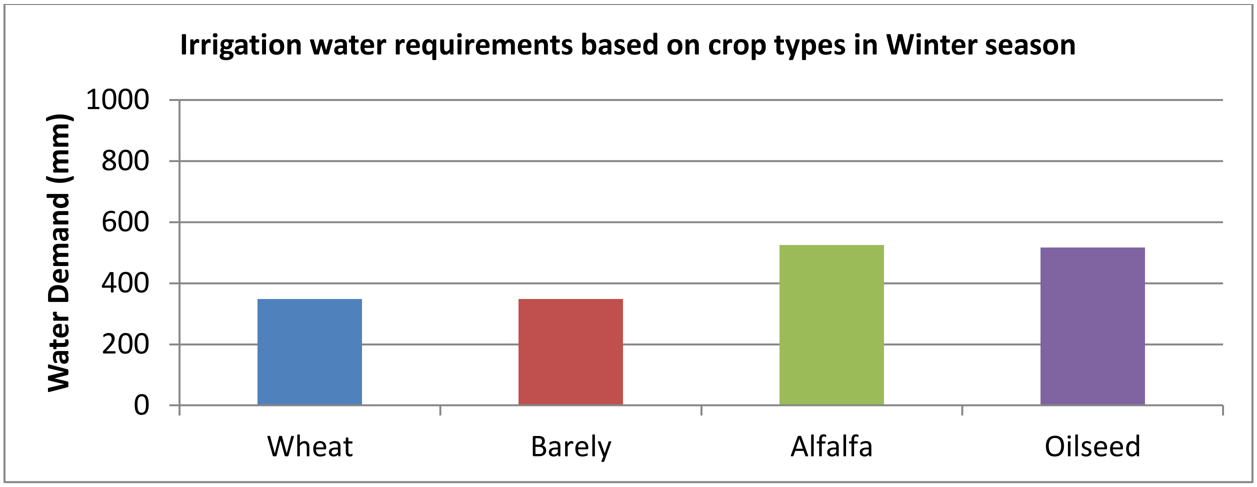



**Figure 6.16 Irrigation water need based on crop types in winter season**

Combining all the calculation on irrigated areas, crop water need and irrigation water requirement for optimal growth and monthly water available on the river basin, assessment performed based on two scenarios. The scenarios described in figure 6.17 and 6.18.

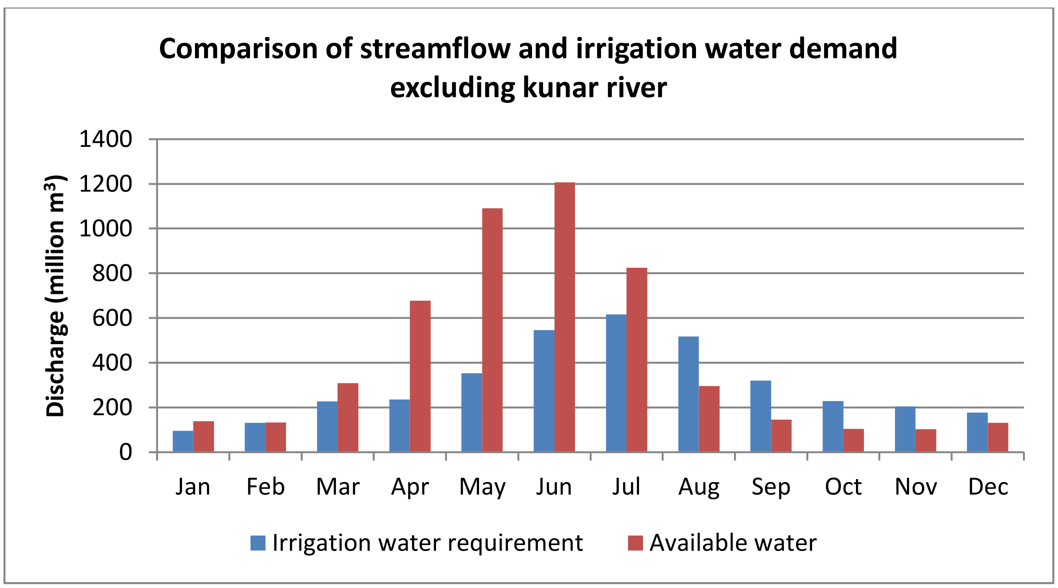



**Figure 6.17 Monthly water demand against the unmanaged flows of all the rivers in the Kabul river system{Panjshir, Logar+Maidan, (Alishang and Alinegar) Laghman, surkhrod } excluding kunar river. Water demand exists throughout the year with farming done in every season.but water supply from rivrs is highly seasonal, leading to the need for water management**.

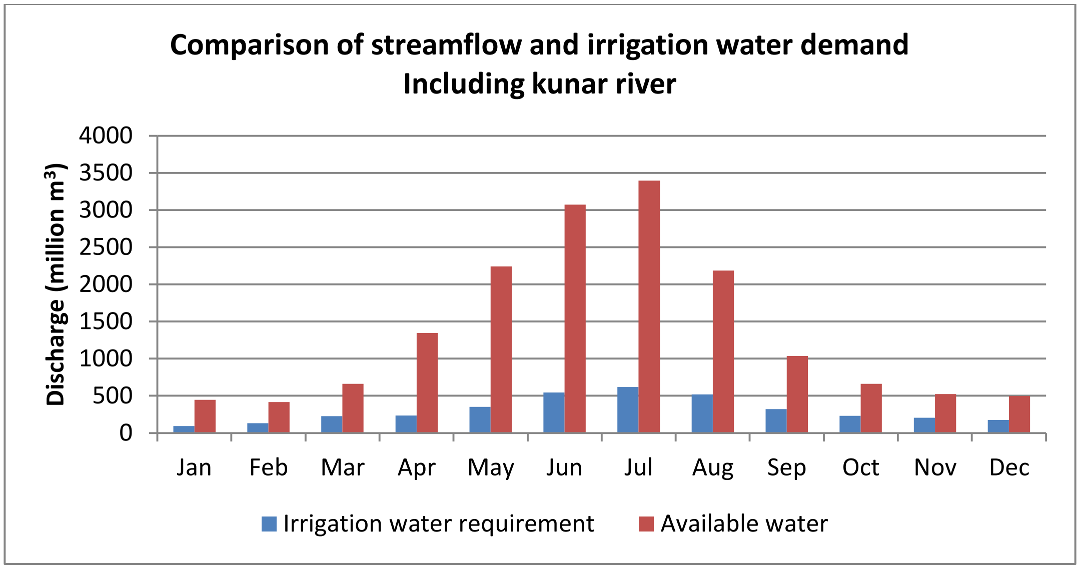



**Figure 6.18 Monthly water demand against the unmanaged flows in whole the Kabul river basin.**

### 6.4.3. Domestic Demand

About 39% (12.5 million) of the Afghanistan population live in the Kabul river basin (Land scan raster analysis). The basin embraces 23 watersheds in 10 provinces in the east. At least for entire provinces, groundwater availability is directly dependent on infiltrations along the Panjshir, Logar and Kabul rivers. The upper Kabul sub basin uncounted small area, but with big city like Kabul it has the highest population number in the basin [34] Being located in west of the river basin, where human activities are significantly concentrated. Its water supply quantity is heavily depending on ground water which is fed by upstream such as Paghman, Logar and Kabul rivers. Population growth and recent droughts have placed new stresses on the city's limited water resources and have caused many wells to become contaminated, dry, or inoperable in recent years. The number of population extracted based on watershed not based on provincial boundary because of water availability or water resources available and number of residences in the watersheds, upstream, mid-stream and downstream to be differentiated here are the urban and the rural population. They differ fundamentally in their access to water. In terms of quantities and qualities. Domestic water in big citis such as Kabul, Jalalabad supplies primarily by groundwater and secondarily by surface water obtained from the Qargha and Darunta reservoirs. In rural area domestic water generally is supplied by shallow well or directly from the streams and rivers with poor quality. The per person rate of water use in the study area is not known and likely differs considerably from rural to urban areas. Estimated per person water use rates reported for Kabul include 80 L/d [36]. 50 L/ d [35] 60 L/d in winter to 110 L/d in summer [37], Estimated per person water use in rural area is thought to be lower than urban areas. In this study attempted to assume 80 litters for urban areas and 65 litters for rural areas, which is very close to the above estimates and this assumption seems fair estimate for average consumptions. By these means, a total domestic water demand of 961000 $m^3$ per day is determined, translating into 351 million cubic meters per year. Table 6.4 lists the basin and sub basins as well as rural and urban details for this calculation.

**Table 6.4: Population based on 2015 and associated water demands for sub-basins**

| River Basin | Sub basins | Area ($km^2$) | Populatin by 2015 | | Water demand ($m^3$/year) | | |
|---|---|---|---|---|---|---|---|
| | | | Urban | Rural | Urban | Rural | Total |
| Kabul | Upper Kabul | 13932 | 6,426,725 | 1,050,983 | 187,660,364 | 24,934,567 | 212,594,931 |
| | Panjshir Sub basin | 8735 | | 1,484,959 | | 35,230,652 | 35,230,652 |
| | Upper Kunar | 13966 | | 383,086 | | 9,088,715 | 9,088,715 |
| | Lower Kunar | 10910 | | 694,652 | | 16,480,619 | 16,480,619 |
| | Lower Kabul | 17660 | 536091 | 2,597,563 | 15,653,857 | 61627182 | 77,281,039 |
| | Total | 65202 | 6,962,816 | 6,211,243 | 203,314,221 | 147,361,736 | 350,675,957 |
| | Percentage | 100% | 52.80% | 47.20% | 58% | 42% | 100% |

As shown in Table 6.4, about 53 % of the population in the basin classified as urban area with high density of population, whereas 47% of the population (including capital of provinces and cities) identified as rural for the objective of domestic water demand estimation. There is a clear trend of urbanization though, as illustrated in figure 6.19, below. The increase in population due to returning immigrants from neighboring countries such as Pakistan, Iran and turned from rural to urban for employing between 2001 to 2015 is 65%, corresponding to an annual increase of 4 %. So it is projected that the average per capita water demands are raising too, just based on a change in lifestyle and water supplies.

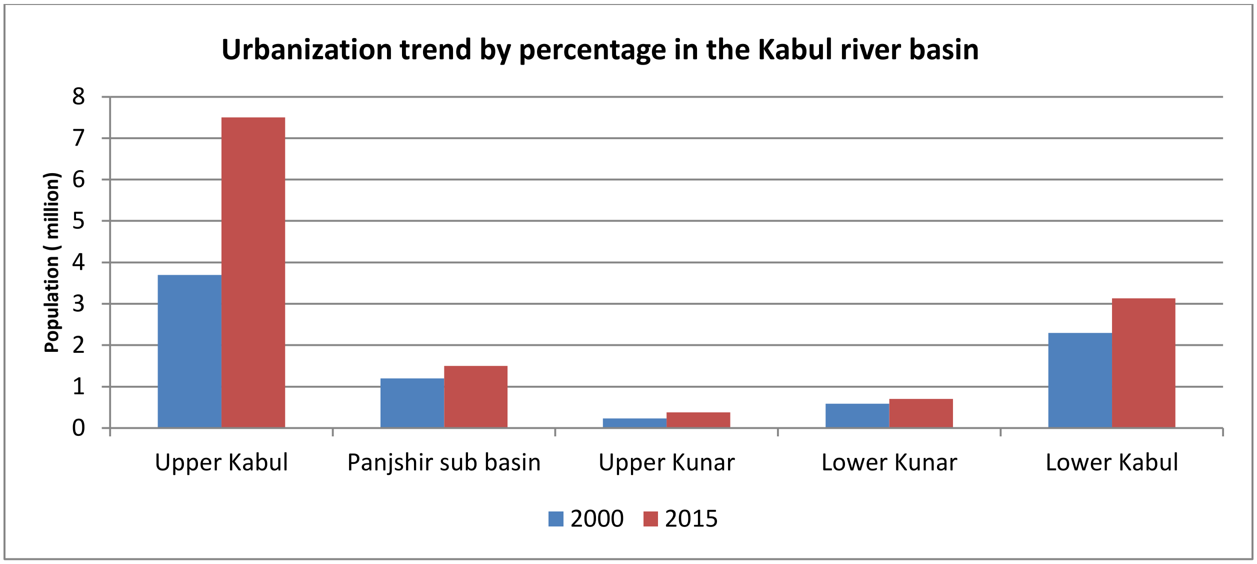



**Figure 6.19 Urbanization trend in the Kabul river basin**

Concerning the exact locations of water demands, settled population can be illustrated, as done in figure 6.20 and 6.21 below. The settlements trend to be concentrated along the river and / or where are good ground water resources. The below figure demonstrates estimates of population densities in the different watersheds and sub basins for the year 2015.

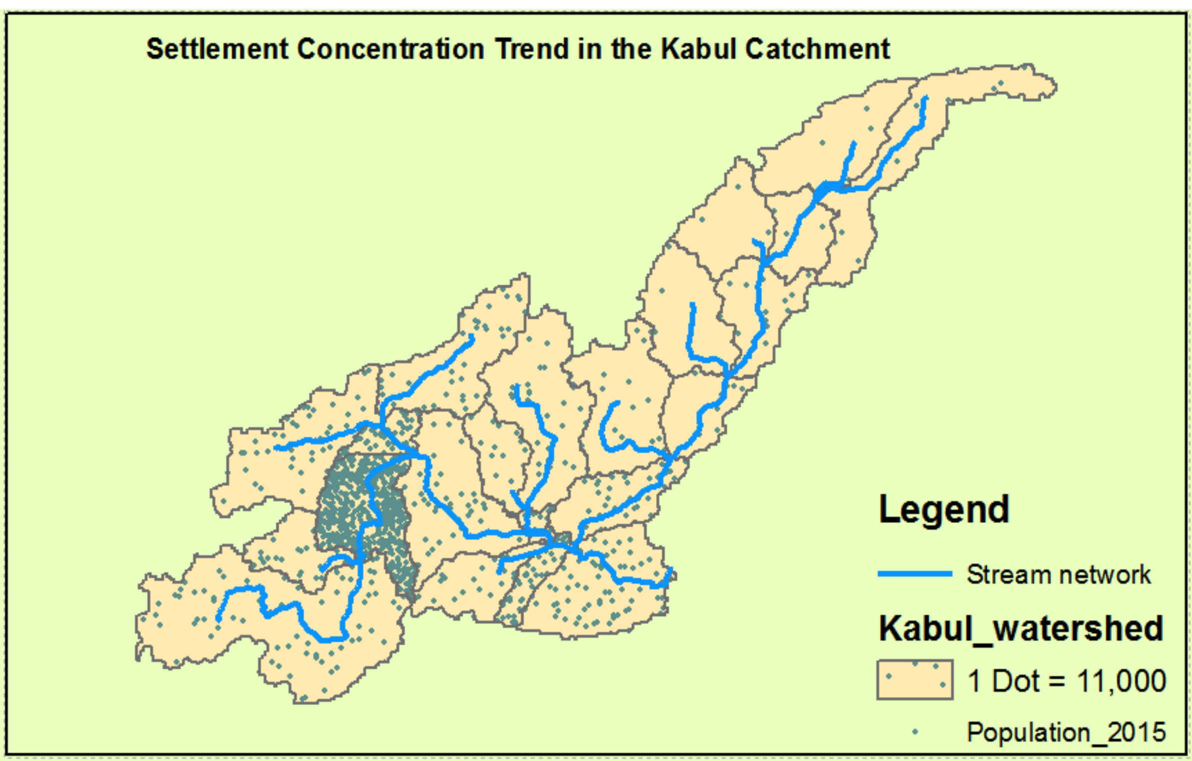



**Figure 6.20 settlement concentration the in the floodplain area and across the river network.**

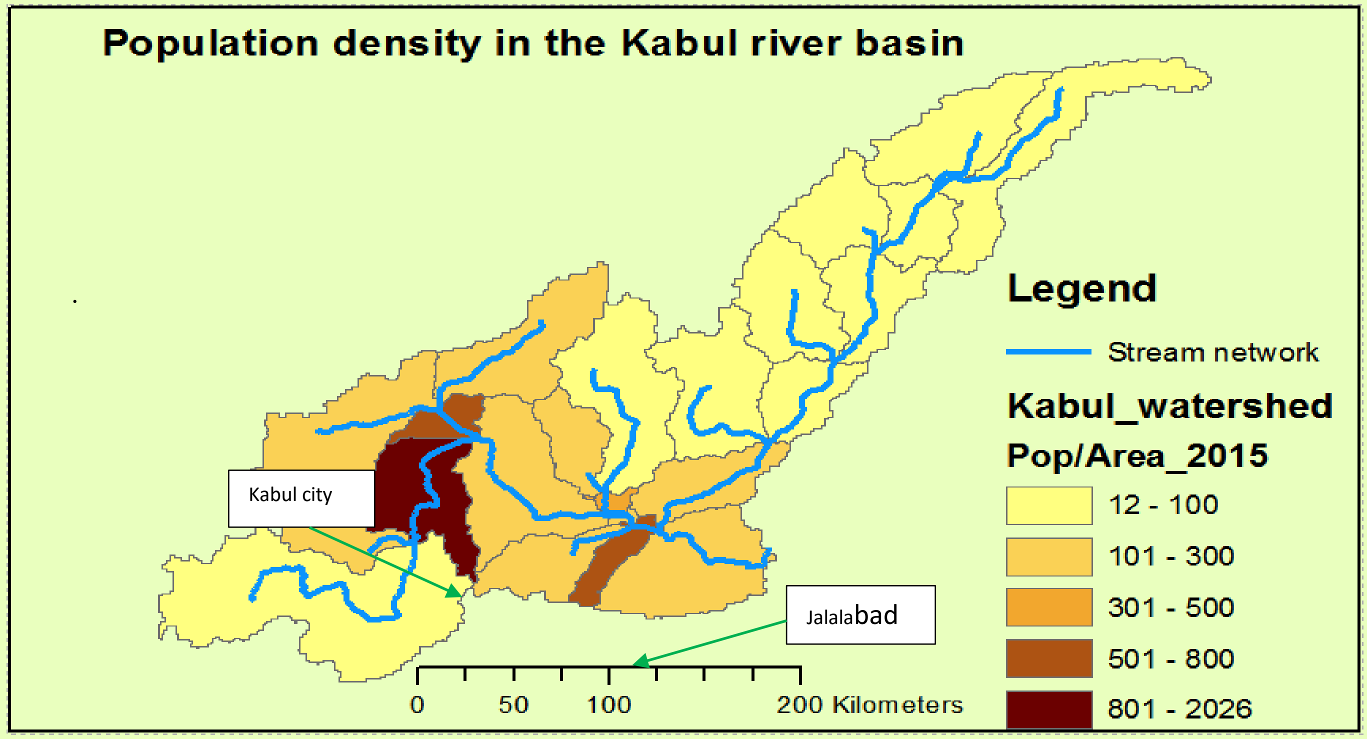



**Figure 6.21 Population density in the watersheds and sub basins, Kabul basin**

### 6.4.4. Environmental flow demand

In order to maintain aquatic ecosystems, Environmental Flow Assessment (EFA) is necessary. In other words, a flow regime in the river, capable of sustaining a complex set of aquatic habitats and ecosystem process are referred to as environmental flow [38]. There are many techniques for environmental flow demand estimation, the difficulty to estimates Environmental flow demand in the Panjshir, Logar, Kunar and Kabul rivers lies in the lack of understanding the relationship between river flow and the multiple components of river ecology and the scarcity of data concerned to these relationships. For example, required river flow conditions are available for fish species or other creatures in a given river basin and this information is very specific and not applied under different circumstances. Different types of flow with different amount of discharge are spread through dry and wet seasons. This fact plays very important role in the interaction of river flow with the surrounded ecosystem (Diban project). An environmental Flow Assessment (EFA) could reveal the precise water needs for sustaining specific ecosystem functions at desirable qualities [39]. Regarding estimation of environmental flow downstream, there is no methodology developed for the Kabul river basin which is subjected to various climatic meteorological and geologic conditions. In the present study Building block methodology (BBM) has been adopted. According this method, an environmental flow regime is then constructed (month by month basis) through separate consideration of different components of the flow regime. Each component of flow being specified in terms of magnitude, time of year, duration and rate of rise and fall of flood flows A recent (EFA) for the Mara river between Kenya and Tanzania yielded a minimal reserve flow of 30% for season considered as high flow, 20%, the season considered as an average flow period, 15% considered as low or lean or dry flow season respectively .Assuming a comparably high flow, average flow and low flow for the Kabul river basin is accepted. For the sake of not neglecting this sector, an annual environmental demand of 3.65 billion cubic meters for the Kabul River is determined. In order to perform Kabul river basin EFA with robust estimates based on the actual aquatic and riparian ecology, the water quality, hydraulics, hydrology and geomorphology are necessary in the Kabul river basin.

**Table 6.5 Flow requirement to sustain the river system ecology based on Building Block Methodology for the period of 2008 to 2009 in the Kabul river system.**

| Months | Discharge (m3/sec) | Percentage based on BB methodology (%) | Flow requirement (m3/sec) |
|---|---|---|---|
| Jan | 166 | 15 | 25 |
| Fbe | 171 | 15 | 26 |
| Mar | 247 | 15 | 37 |
| Apr | 520 | 20 | 104 |
| May | 837 | 20 | 167 |
| Jun | 1186 | 30 | 356 |
| Jul | 1268 | 30 | 380 |
| Aug | 817 | 20 | 163 |
| Sep | 399 | 15 | 60 |
| Oct | 247 | 15 | 37 |
| Nov | 203 | 15 | 30 |
| Dec | 186 | 15 | 28 |

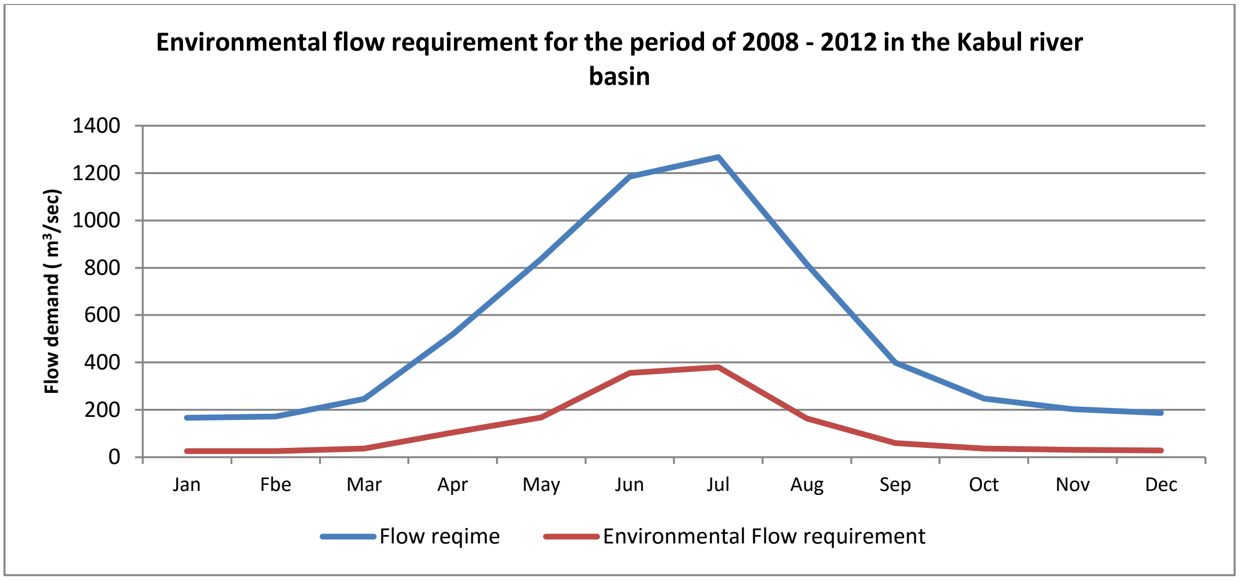



**Figure 6.22 Environmental Flow requirement for the Kabul river system.**

### 6.4.5. Industrial water demand

Manufacturing, mining, food processing, electricity and gas supply and other industries consumed a big portion of water resources in the other countries [40]. Unfortunately, detailed Information and data on industry and mining water use is not available in the Kabul river basin. Mining and industries estimated to consume 43 million cubic meters in the year [41] Based on benchmark parameters, it is estimated that the Aynak mine will require fresh water consumption 0.225 $m^3$/Sec for phase one and 0.723 $m^3$/Sec for phase two extractions [42].The government of Afghanistan plans to open industrial park, which promote new manufacturing businesses in the packaging and food production. The agro-industry planned to improve through livestock rehabilitation in the upstream and downstream of the Kabul river basin. Therefore, for improving the Agra-industries, mining process and other small industries fresh water is needed to manage properly and recycle it appropriately.

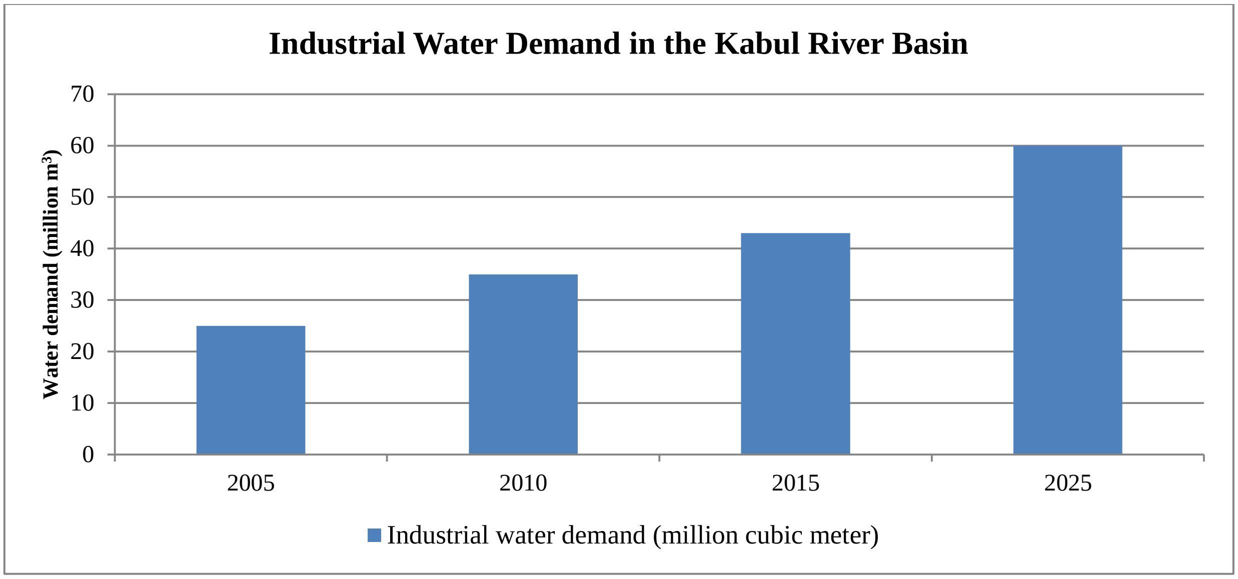



**Figure 6.23 Industrial water demand estimation in the Kabul river basin. Source: (Scoping strategic options for development of the Kabul river basin, World Bank)**

# CHAPTER SEVEN

# RESULT AND DISCUSSION

In this chapter, the results of the precipitation consistency analysis of three data sources using dynamic and normal ratio methods on the Kabul river will be discussed in section 7.1. The hydrology modeling and hydrology components using Soil and Water Assessment Tool (SWAT 2012) model will be analyzed in section 7.2. Flow duration and hydrology alteration will present in section 7.3. The results of climate change impacts and analysis of GCC scenarios in the Kabul river basin are presented in the section 7.4. For this study , three climate change scenarios were analyzed and for each climate change scenarios four Global Climate Models such as MIROC 3.2 (Med) ,CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3 were presented in the section 7.5. The water stress analyzed in the section 7.6. River basin managerial approach and sectoral water demand and water availability will be discussed in the section 7.7

## 7.1. Precipitation consistency analysis

Although with the shorter time series, based on observed available meteorological data for the period of (2008- 2012) were used to evaluate the consistency of three different data sources from Ministry of Energy and Water (MoEW), Ministry of Agriculture, Irrigation and Livestock (MAIL) and non-observed data Tropical Rainfall Measuring Mission (TRMM) compared monthly and yearly are compared in the chapter three in the figures 3.2, 3.3 and 3.4 respectively. The primary result shown that, in these three data sources, MAIL and TRMM annual precipitation records have close similarity. For the second time annual precipitation records from MAIL and TRMM compared from 2004 to 2010 in four plots, respectively, the result of the annual precipitation comparison and evaluated based on Difference index (D %) showed that, there is acceptable consistency between two data sets in the period of (2004 – 2010) records as shown in figure 7.1 and Table 7.1 and then applied the TRMM data source hydrology modeling in the Kabul river basin using SWAT model.

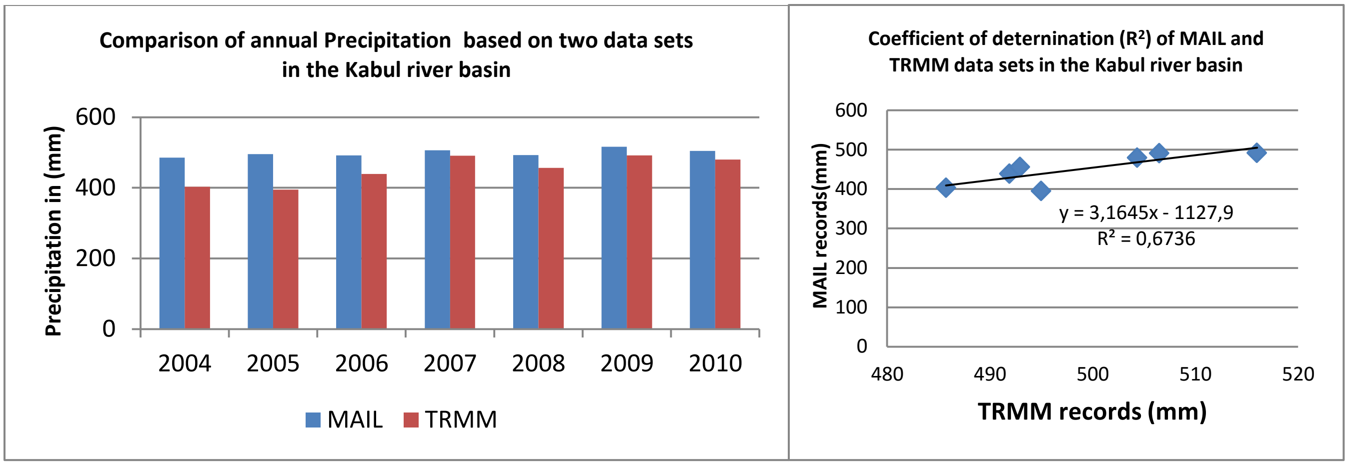



**Figure 7.1 Comparison of annual precipitation based on two data sets analysis.**

**Table 7.1 The result of precipitation analysis based on percentage**

| Years | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|
| MAIL | 486 | 495 | 492 | 507 | 493 | 516 | 504 |
| TRMM | 403 | 395 | 439 | 491 | 456 | 492 | 480 |
| Difference in % | **21** % | **25** % | **12** % | **3** % | **8** % | **5** % | **5**% |

## 7.2. The hydrology modelling

The SWAT model is a parametric model requiring a formal calibration procedure to optimize the parameter values using observed stream runoff. Parameters have physical meanings in the field, allowing parameters to be set using these databases for land use /land cover, soil type, topography, and climate statistics. The model simulation was executed for 11 years. The first five years were selected as warm up period. Stream flow is the most important element of calibrated in this model. After the successful run of SWAT model, average monthly hydrological components in the basin shown in the Table 7.2 .

**Table 7.2 Average monthly hydrology components of the Kabul river basin using SWAT model.**

| Month | Rainfall | Snowfall | Surf (Q) | Lat (Q) | Yield | ET | PET | Yield (T/HA) |
|---|---|---|---|---|---|---|---|---|
| Jan | 53.4 | 49.4 | 1.0 | 0.1 | 8.5 | 3.6 | 14.0 | 0.2 |
| Feb | 55.4 | 50.5 | 1.6 | 0.2 | 8.0 | 6.6 | 16.6 | 0.7 |
| Mar | 47.6 | 33.6 | 13.4 | 1.0 | 20.4 | 15.2 | 39.6 | 12.0 |
| Apr | 74.7 | 32.6 | 22.3 | 2.2 | 31.0 | 25.3 | 62.1 | 46.1 |
| May | 49.6 | 10.5 | 48.3 | 4.7 | 51.0 | 35.9 | 109.3 | 90.1 |
| Jun | 40.0 | 3.5 | 35.7 | 4.8 | 39.0 | 34.9 | 138.5 | 88.4 |
| Jul | 32.3 | 0.0 | 1.1 | 2.7 | 24.0 | 33.2 | 145.3 | 1.1 |
| Aug | 32.8 | 0.0 | 0.3 | 1.7 | 19.0 | 30.5 | 139.5 | 0.2 |
| Sep | 33.3 | 1.6 | 0.3 | 1.5 | 13.0 | 25.7 | 114.2 | 0.3 |
| Oct | 33.9 | 7.6 | 0.8 | 1.2 | 12.0 | 21.1 | 81.0 | 1.2 |
| Nov | 41.7 | 21.2 | 1.0 | 0.7 | 10.2 | 15.1 | 42.0 | 0.8 |
| Dec | 22.2 | 20.3 | 0.1 | 0.2 | 8.5 | 7.4 | 26.0 | 0.1 |

In accordance with (C.H.Green, 2005) , the SWAT 's runoff simulation data were tested against measured runoff data. The annually averaged simulated stream discharge (244 mm) is 86% of the measured average value (284 mm) Tabl2 7.3

**Table 7.3 Comparison of measured and simulated annual stream discharge for the Kabul river basin for the period of (2008 – 2012)**

| Years | Precipitation (mm) | Measured Streamflow (mm) | Simulated Streamflow (mm) |
|---|---|---|---|
| 2008 | 453.86 | 228.74 | 219.65 |
| 2009 | 560.12 | 265.50 | 273.39 |
| 2010 | 629.41 | 256.27 | 329.34 |
| 2011 | 484.14 | 257.11 | 187.05 |
| 2012 | 450.42 | 414.65 | 211.12 |
| **Total** | 2577.95 | 1422.27 | 1220.55 |
| **Average** | 515.59 | 284.45 | 244.11 |

The SWAT model simulated water yield or ( available water resources ) based on the following formula: Model Equation

**Annual water yield (Water resource available) = Precipitation - ET ± Total losses.**

**Table 7.4 Simulated hydrologic budget for the Kabul river basin from 2008 to 2012 using SWAT**

| Years | Precipitation (mm) | Water yield (mm) | Evapotranspiration (mm) | ± Losses |
|---|---|---|---|---|
| 2008 | 453.86 | 219.65 | 231 | 3.21 |
| 2009 | 560.12 | 273.39 | 289 | -2.27 |
| 2010 | 629.41 | 329.34 | 296 | 4.07 |
| 2011 | 484.14 | 187.05 | 294 | 3.09 |
| 2012 | 450.42 | 211.12 | 234 | 5.3 |

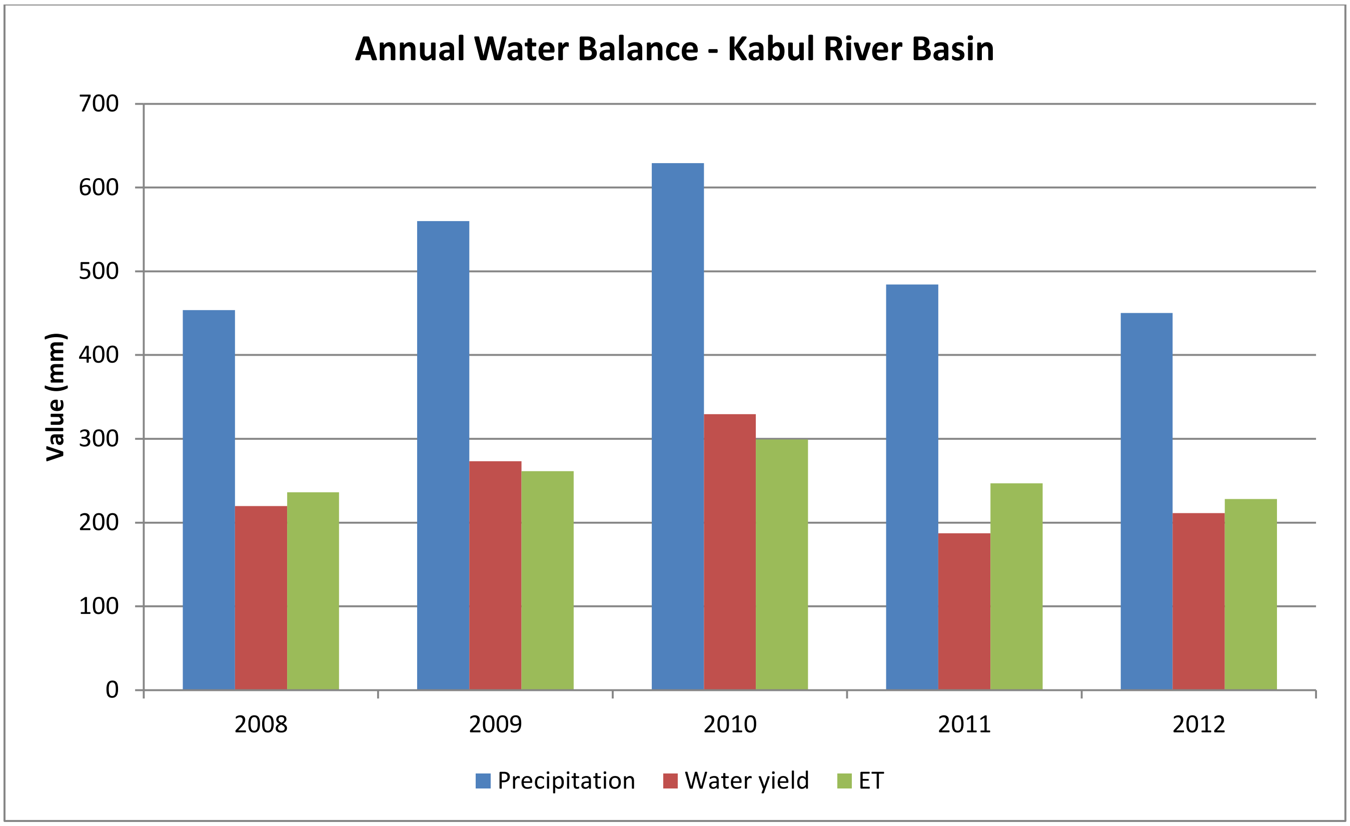



**Figure 7.2 Annual water balance- in the Kabul river basin**

## 7.3. Flow duration and hydrology alteration

A basic flow duration curve measures flow regime in the rivers, such as high flows to low flows to indicate or determine flooding and drought in the stream based on monthly flow. The result of mean monthly flow in the three stations illustrated in figure 7.3. The X-axis represents he percentage of time (Known as duration or frequency of occurrence) that a particular flow value is equaled or exceeded. The Y-axis represents the quantity of flow at a given time by cubic meters per second,associated with the duration, flow duration intervals are expressed as percentage of exceedance with zero corresponding to the highest  stream discharge in the record and 100 to the lowest such as drought condition.

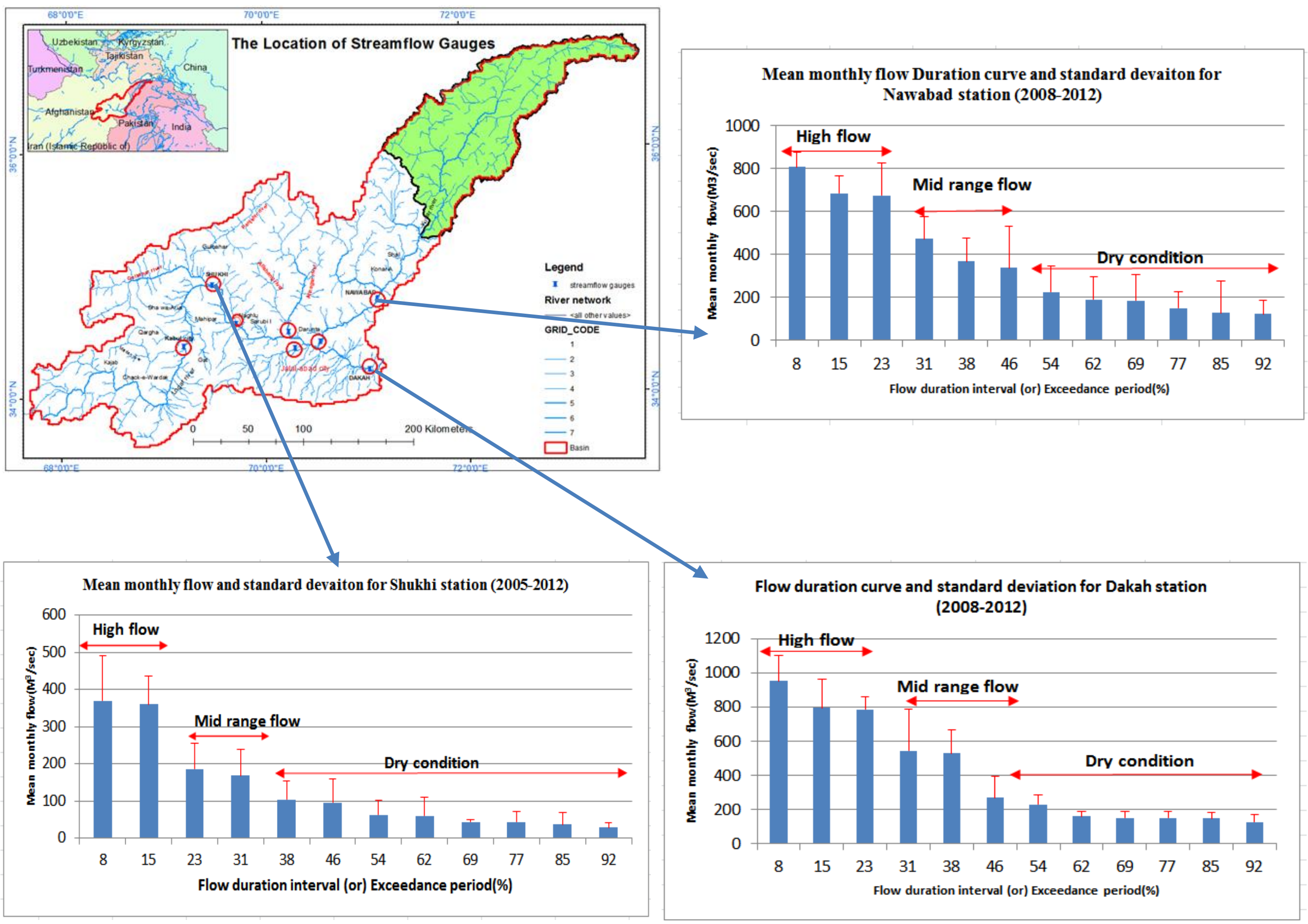
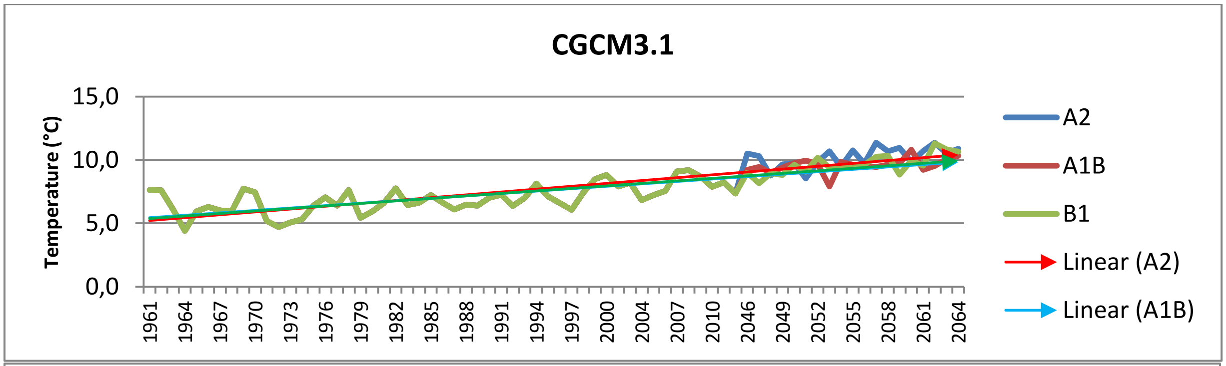


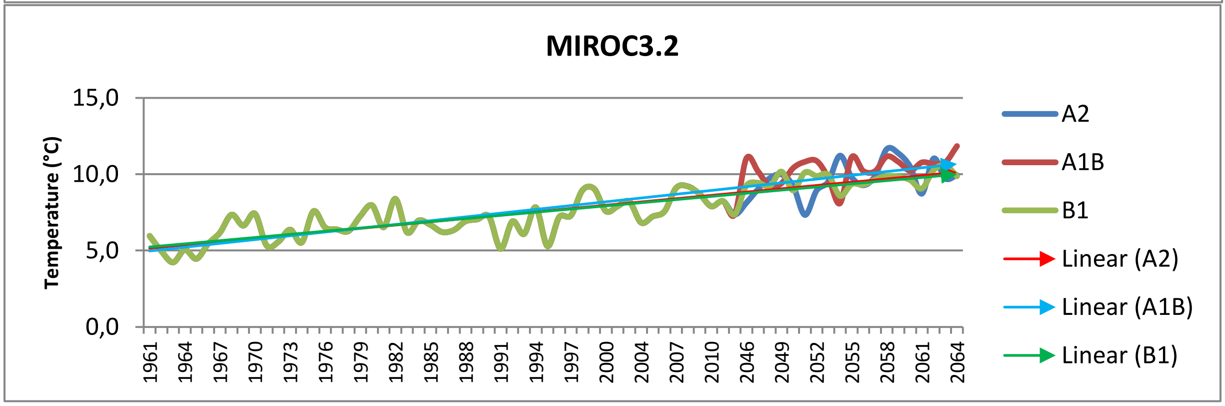

**Figure 7.3  Flow duration curve**

## 7.4. Climate change analysis

### 7.4.1. Temperature change analysis

The distribution of temperature throughout the seasons is important in the study of climate change impact on the Kabul river basin. Figure 7.4 and Figure 7.5 summarize this distribution for the study area. Future climatic prediction data of four GCMs namely MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3 were analyzed statistically to identify mean temperature trend from past, current to future. Three emission scenarios namely A2, AIB and B1 were selected for each GCMs totaling to 12 combinations of scenarios were simulated and the results were analyzed. The mean monthly and annual temperature changes estimated by the combinations of each GCM and scenarios. It can be identified from figure 7.4 that despite an overall increase in mean annual temperature shows a decreasing pattern for the majority of the GCMs simulations ( which include MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3) .



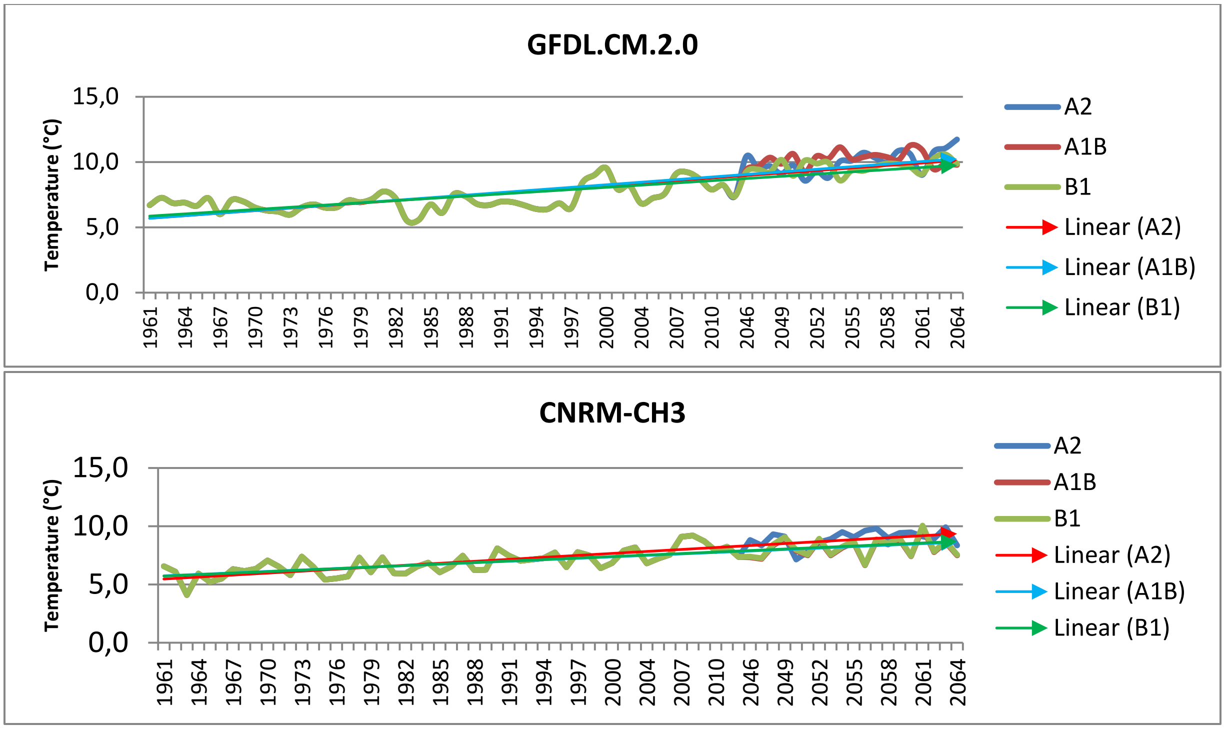



**Figure 7.4**: Regional trends across 23 watersheds for mean temperature from the baseline (1961 – 2000), to middle of century (2046 – 2064) in the Kabul river basin.

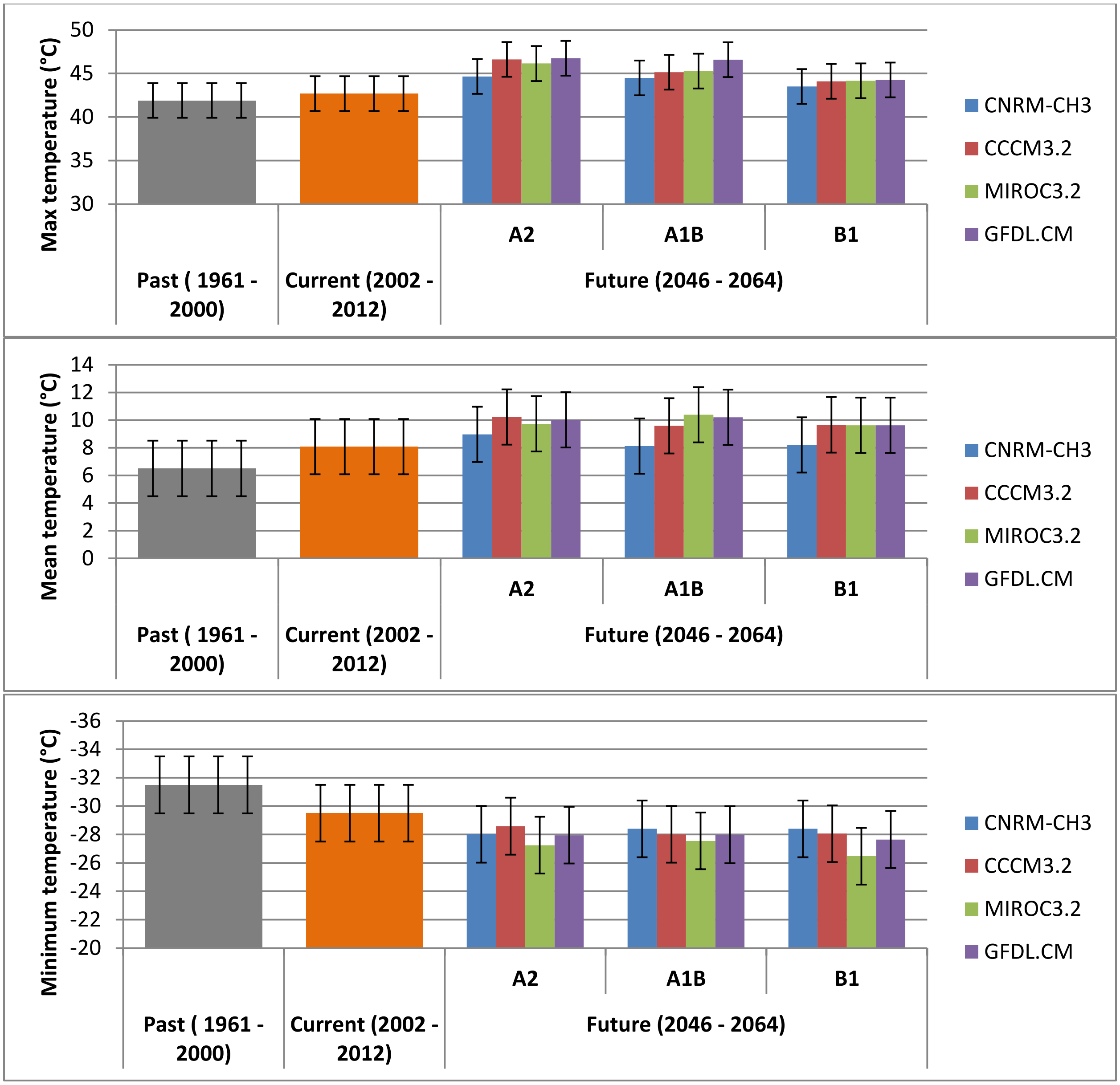



**Figure 7.5 comparison of historic, current and past average temperature based on GCMs (MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3) under three scenarios (A2) high emission, (A1B) medium emission and (B1) low emission greenhouse gases to estimate temperature trends in the Kabul river basin. Daily data set downloaded based on CMIP3 from Climate change data for SWAT.**

**Table 7.5 Annual mean temperature change based on scenarios**

| | | Mean temperature trend by (°C) | | | |
|---|---|---|---|---|---|
| | | Past ( 1961 - 2000) | Current (2002 - 2012) | Future (2046 - 2064) | Δ T |
| **CNRM-CH3** | A2 | 6.50 | 8.08 | 8.96 | 2.46 |
| | A1B | 6.50 | 8.08 | 8.12 | 1.62 |
| | B1 | 6.50 | 8.08 | 8.20 | 1.69 |
| **CCCM3.2** | A2 | 6.56 | 8.08 | 10.23 | 3.67 |
| | A1B | 6.56 | 8.08 | 9.58 | 3.02 |
| | B1 | 6.56 | 8.08 | 9.65 | 3.09 |
| **MIROC3.2** | A2 | 6.53 | 8.08 | 9.73 | 3.21 |
| | A1B | 6.53 | 8.08 | 10.39 | 3.87 |
| | B1 | 6.53 | 8.08 | 9.63 | 3.10 |
| **GFDL.CM** | A2 | 6.80 | 8.08 | 10.01 | 3.21 |
| | A1B | 6.80 | 8.08 | 10.20 | 3.40 |
| | B1 | 6.80 | 8.08 | 9.63 | 2.83 |

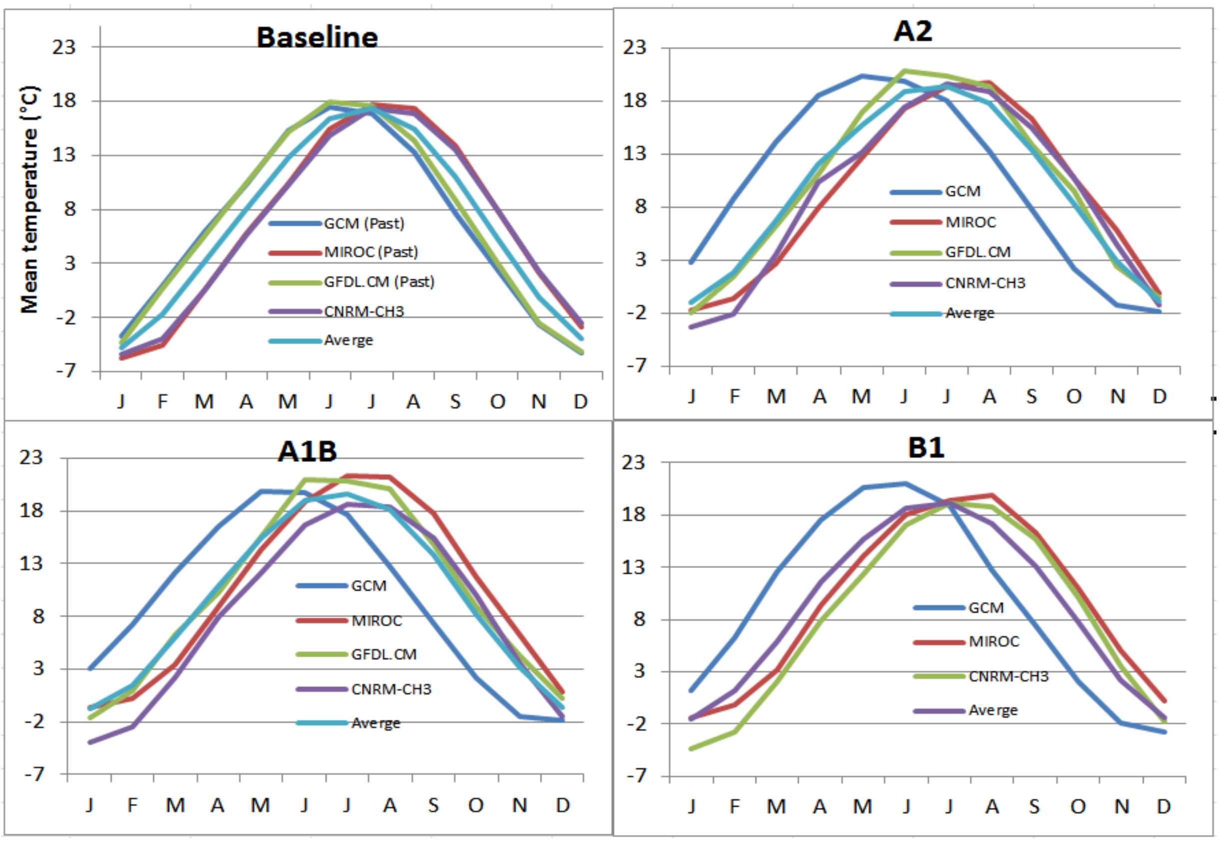



**Figure 7.6** **Monthly means for the most variable climate element, temperature analyzed over the river basin for the baseline (1961 2000), middle of the century (2046 2064) periods, under A2, A1B and B1 scenarios.**

### 7.7.2. Temperature rise and snow cover decrease

Annual and monthly temperature analysis shows that, mean annual temperature is increased by 2.9°C from 1961 to middle of century, 2065 and the months of December, January and February very sensitive, temperature raised from(- 7) to (-2, -1) degree as shown in the figures of 7.4, 7.5 and 7.6. long term temperature and precipitation patterns in the upper Kabul basin using the CFSR interpolated 0.5 ° grid and provide best climate components demonstrated that, average temperature decrease due to increasing in elevation and precipitation pattern form rainfall to snowfall in the mountainous area, in the upper Kabul, where the majority of annual stream flow originates. In all areas of the catchment. There is a clear warming trend in all seasons, with the serious trend in winter and weaker in the summer. For example, based on CGCM3.1 historic climate data (1961- 2000), mean temperature in December, January and Febraury estimated ( -6, -5,-4) respectively, the same model under three scenarios, A2, A1B and B1 for the future (2046- 2064) simulated mean temperature in December, January and Febraury (-2, +2,+3) respectively as shown in the figure 7.6. The increasing temperature will exacerbate snow melting time and stream flow in the early of the spring season and cause depletion of snow coverage areas in the early summer. Considering both historical and GCMs predictions under scenarios A2, A1B and B1 that temperature in the upper Kabul will rise by 2.9 °C in the winter and 1. 5 in the summer between 1961 and 2064. However, the rate of warming in the lower troposphere increases with altitude,(Francesca Pellicciotti, 2012). The altitude of the basins ranges from 350 meters to 7600 meters above sea level, the climate within the basin varies greatly. The mountainous parts of the basin is in the rain shadow of the Himalayas and not affected by the summer monsoon (Immerzeel et al., 2009), low intensity winter and spring precipitation originating from western low pressure systems as a primary source of water. Average annual precipitation is around 415 mm with a peak in January and February and 45 % of precipitation estimated as snowfall using SWAT model. Surface temperature determines the form of precipitation. If temperature is above 2°C, precipitation occurs as rain, and if the temperature falls below 0°C, then the precipitation happens as snow. An Interval of 0-2°C, precipitation is a mixture of snow and rain. The depth of snowmelts in the unit of area is calculated based on multiplying the surface temperature with the degree factor in mm/°C/day as shown in figure 7.7

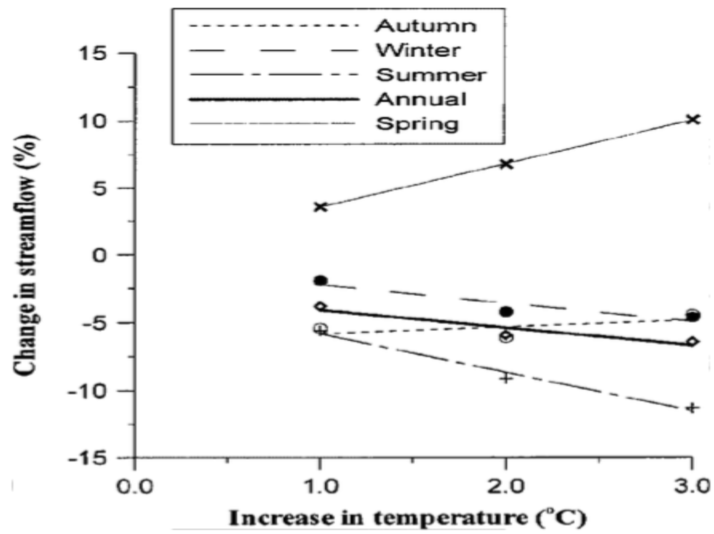



**Figure 7.7 Effect of increase in temperature on seasonal and annual stream flow in snow fed streams.**

Above figure shows that , 2.9°C rise in winter and spring seasons, will increase glacial melt by (13- 15) % . This increase in glacial melt may or may not cause a depletion of the glacier or snow cover in upstream. Using the SWAT model, the precipitation pattern (Snow or Rain) under temperature simulated to determine the trend in pattern from 1961 to 2046 using historic precipitation records and GCMs simulations based on Climate change scenarios (A2, A1B and B1), as shown in figure 7.8.

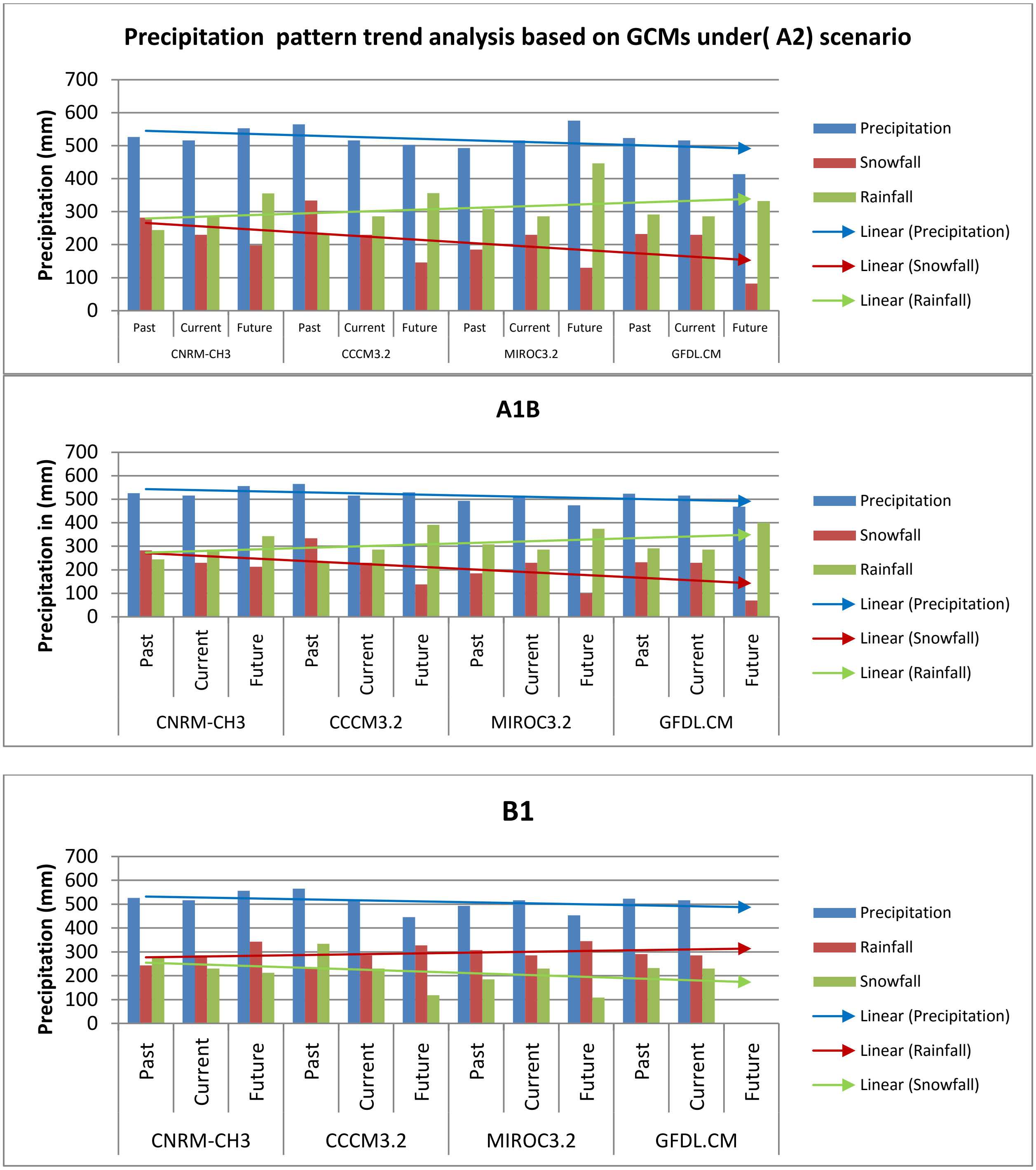



**Figure 7.8 Pecipitation trend analysis based on past (1961-2000), current (2002 – 2012)and Future average ( 2046 – 2064) and GCMs (MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3) under three scenarios (A2) high emission, (A1B) medium emission and (B1) low emission greenhouse gases to estimate the precipitation pattern in the Kabul river basin. Daily data set downloaded based on CMIP3 from Climate change data for SWAT.**

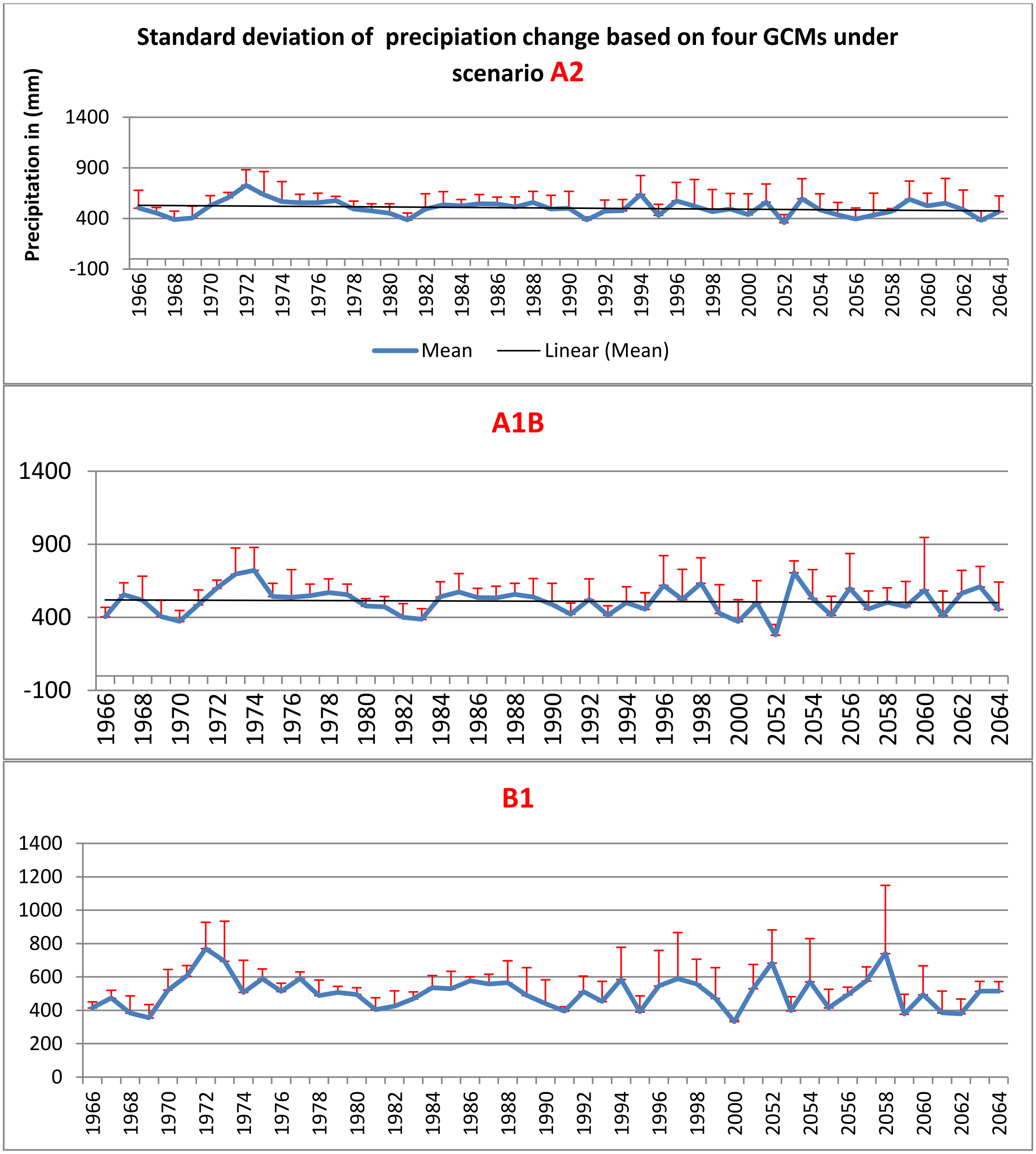



**Figure 7.9 Mean and standard deviation of GCMs (MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3) under three scenarios (A2) high emission, (A1B) medium emission and (B1) low emission greenhouse gases to identify the precipitation trend in the Kabul river basin. Daily data set downloaded based on CMIP3 from Climate change data for SWAT.**

Comparison of monthly historic precipitation and GCMs have been performed to identify monthly based trends in based on three scenarios. Figure 7.10 demonstrates monthly trends based on past (1961-2000), current (2002 – 2012) and Future average ( 2046 – 2064) and GCMs (MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3) under three scenarios.

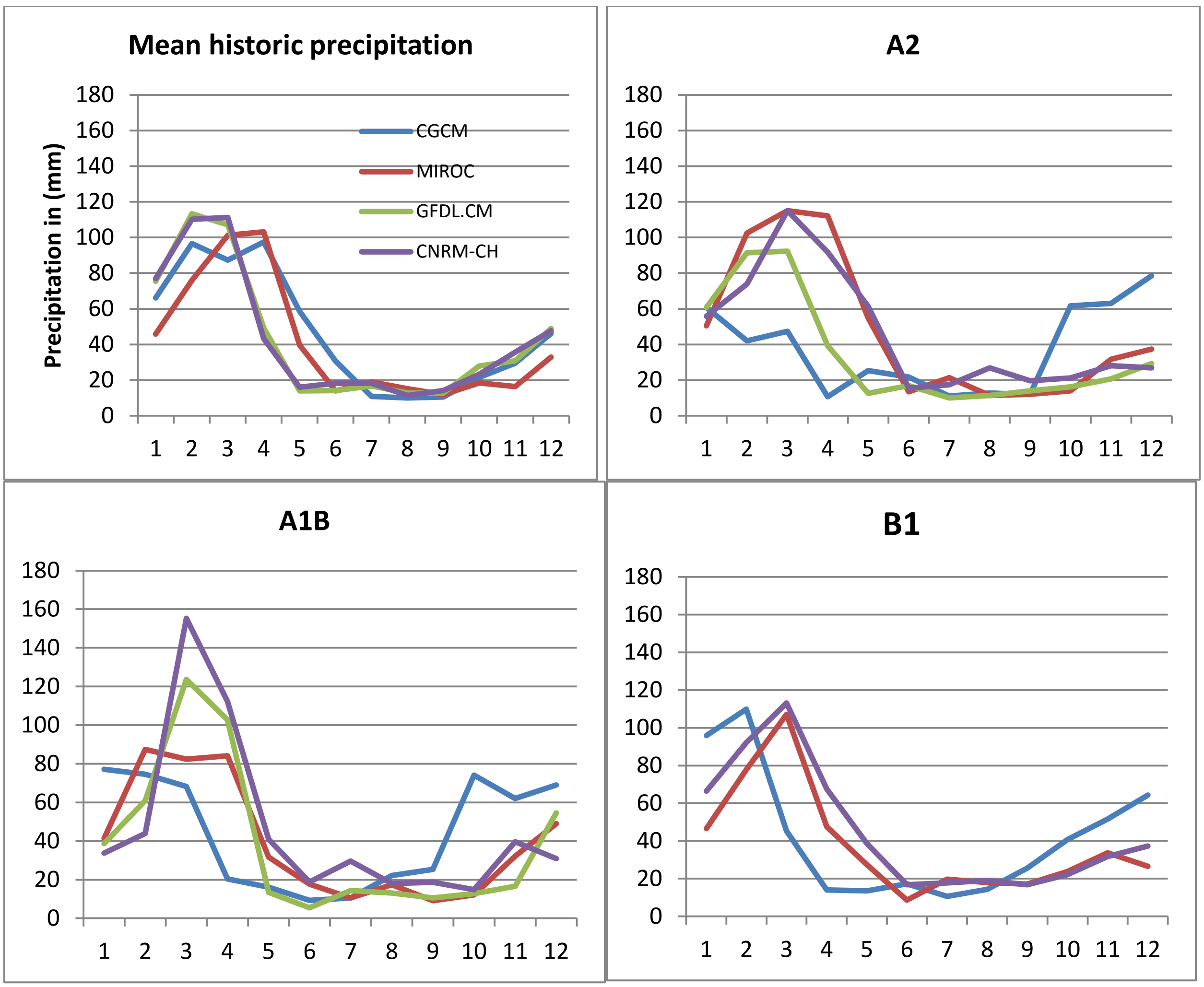



**Figure 7.10 Mean monthly precipitation distribution in the Kabul river basin. Data source : CMIP3.**

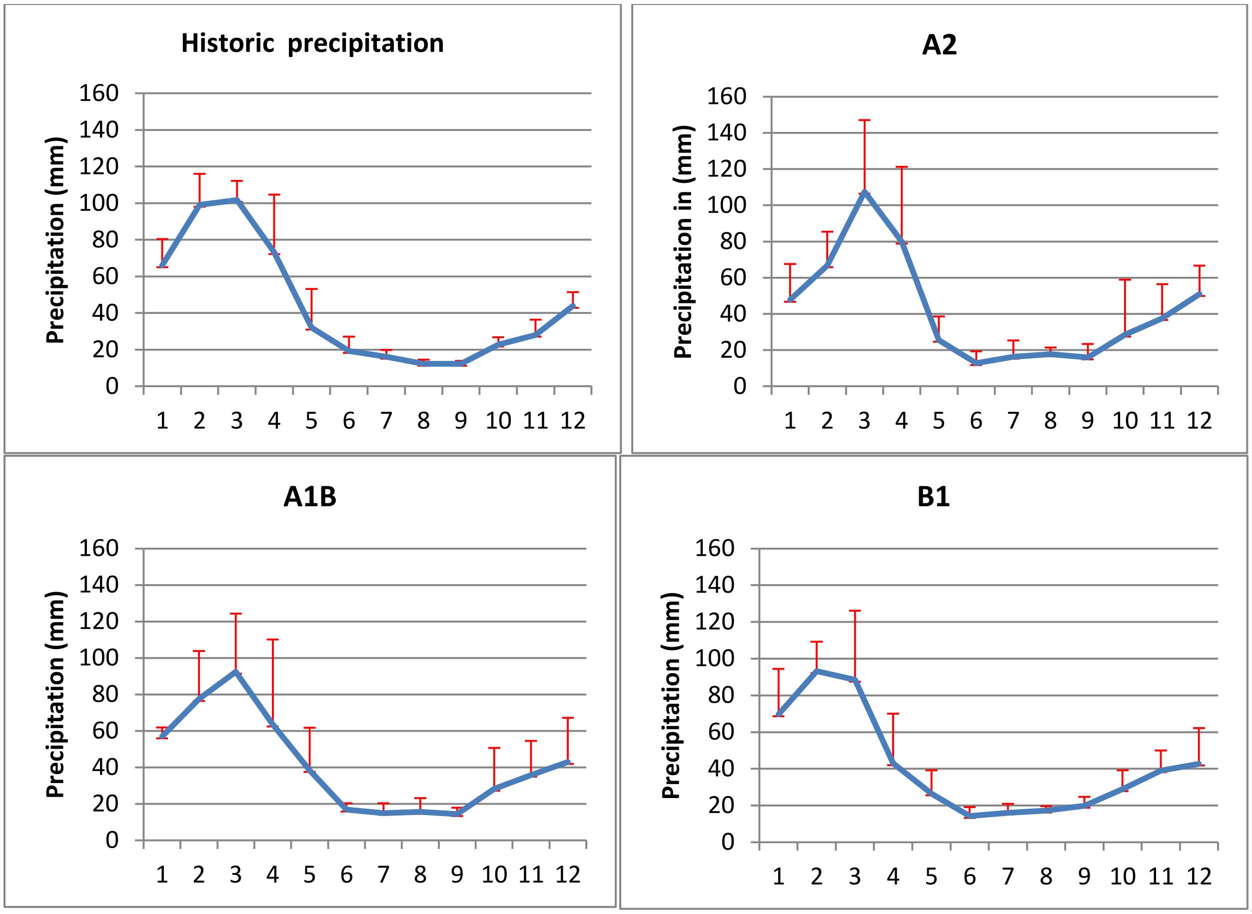



**Figure 7.11 based on the above graphs, mean and standard deviaton calculated from four GCMs including MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3) under three scenarios. Graphs demonstrate that, December, January, February and March, have big oscillated.**

### 7.7.3 Precipitation trend analysis

Past precipitation (1961 – 2000) , present (2002 – 2012) and future (2046 – 2064) data of four GCMs namely, MIROC 3.2 (Med), CGCM 3.1 (T47), GFDL-CM2.0 and CNRM-CM3) were analyzed using the SWAT model in the Kabul river basin. Three emission scenarios were then simulated and the results were analyzed. The precipitation monthly changes estimated by combining of GCMs and scenarios were directly employed on the TablOut (SWATOutput.mdb). Then monthly precipitation based on each model and scenarios combined yearly and percent bias (PBIAS) formula applied to identify the bias of past to future. Detail description of model analysis demonstrated in figure 7.11.

**Table 7.6. Precipitation trend analysis based on four GCMs and three scenarios in the Kabul basin**

| GCMs | Scenario | Annul Precipitation (mm) | | | |
|---|---|---|---|---|---|
| | | Past (1961 - 2000) | Present (2002 - 2012) | Future (2046 - 2064) | PBIAS (%) |
| CNRM-CH3 | A2 | 526 | 516 | 553 | 5 |
| | A1B | 526 | 516 | 556 | 6 |
| | B1 | 526 | 516 | 543 | 3 |
| CCCM3.2 | A2 | 522 | 516 | 502 | -4 |
| | A1B | 522 | 516 | 529 | 1 |
| | B1 | 522 | 516 | 446 | -15 |
| MIROC3.2 | A2 | 493 | 516 | 576 | 17 |
| | A1B | 493 | 516 | 474 | -4 |
| | B1 | 493 | 516 | 454 | -8 |
| GFDL.CM | A2 | 523 | 516 | 414 | -21 |
| | A1B | 523 | 516 | 469 | -10 |
| | B1 | 523 | 516 | | |
| | | | | | |

### 7.7.4. Stream flows analysis

The results of observed and simulated stream flow afterwards were analyzed by only considering the outlet of sub-watershed 23 which lies outlet of the Kabul river basin in Afghanistan . This has been done for a couple of reasons:

- The Kabul river basin is located in the upstream of Indus catchment, the Dakah station, which is located at sub-watershed 22  recording stream runoff of whole the Kabul river basin. This station tell us the volume of water flowing from the Kabul basin to the Indus, Pakistan territory.
- Dakah station, which is installed in the sub-watershed of 22, recording daily, monthly and annual flow rate, it is very very important for water development in the upstream.
- Data collaboration between upstream (Afghanistan) and downstream (Pakistan) for the purpose of negotiation on water allocation.
- Long term stream flow analysis for climate change impact assessment.

- Time is also the other reason in which incorporating more than one outlet will need a longer period as it need to look each outlet separately and as a master ‘s thesis this could be difficult to achieve.

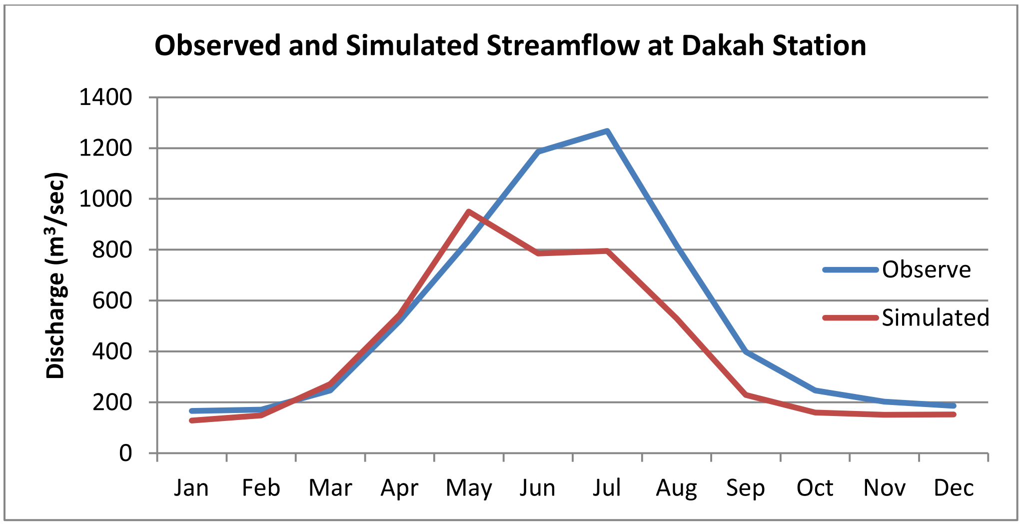



**Figure 7.12 Monthly distribution of observed (2008- 2012) and simulated stream flow (2008-2012) at Dakah station.**

### 7.7.5. Projected future runoff

The patterns of projected changes in runoff are shown in figure 7.13. For the whole the basin, the value of mean annual streamflow is calculated by averaging across stream flow projection obtained using different GCM applied as input to the SWAT model. The runoff is likely to decrease in most of the model output in the outlet (Dakah station) also changing in the runoff regime. Although the spatial pattern in stream flow change is similar to the pattern of changes in precipitation, decrease and changing in precipitation patterns resulted decrease in stream flow and changing the runoff regime in the Kabul river basin. Using streamflow projection from 23 watersheds and three future scenarios (based on averages across streamflow projections from four GCMs), I have 11 combinations. The result of monthly flow series after simulating for each model under each scenario combination was converted to average yearly flow. Finally, the average of the yearly flows, standard deviation applied to quantify the variation of mean annual runoff. Linear regression applied to show the trend.

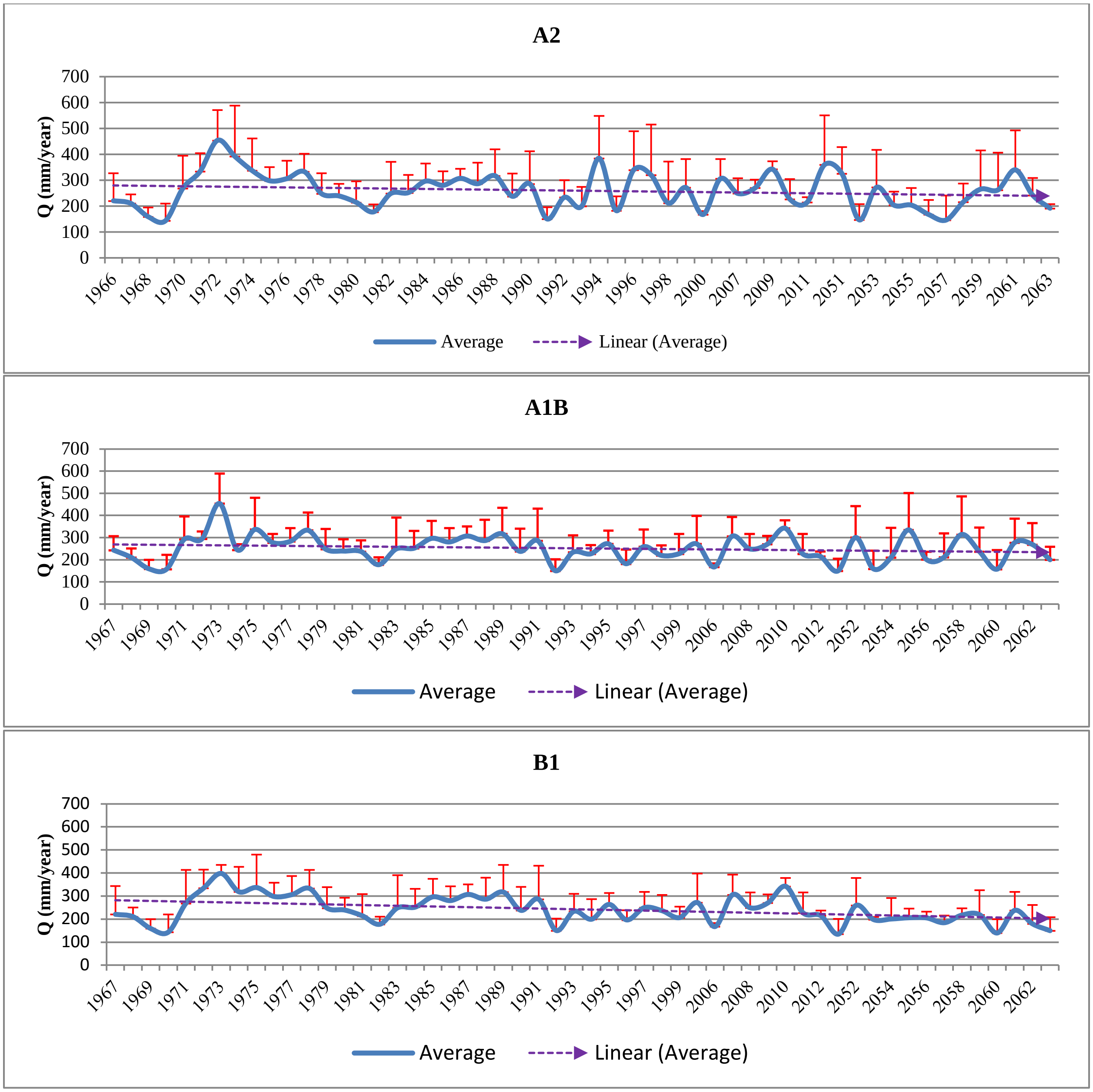



**Figure 7.13. Line chart present change in projected mean annual streamflow from baseline (1961 – 2000) to middle of century (2046 – 2064) for future emission scenarios A2, A1B and B1 for all watersheds and GCMs.**

### 7.7.6. Projected future monthly runoff

The monthly distribution of flow has been presented on figure 7.14. Generally, this figure illustrates the monthly changes on flow regimes as estimated by four GCM under three scenarios and compared with past observed stream flow (1969 – 1979) in Dakah station, pour point of the Kabul river basin. The result shown that pick of stream flow in the months of June and July with change to the month of May at the middle of the twenty first century.

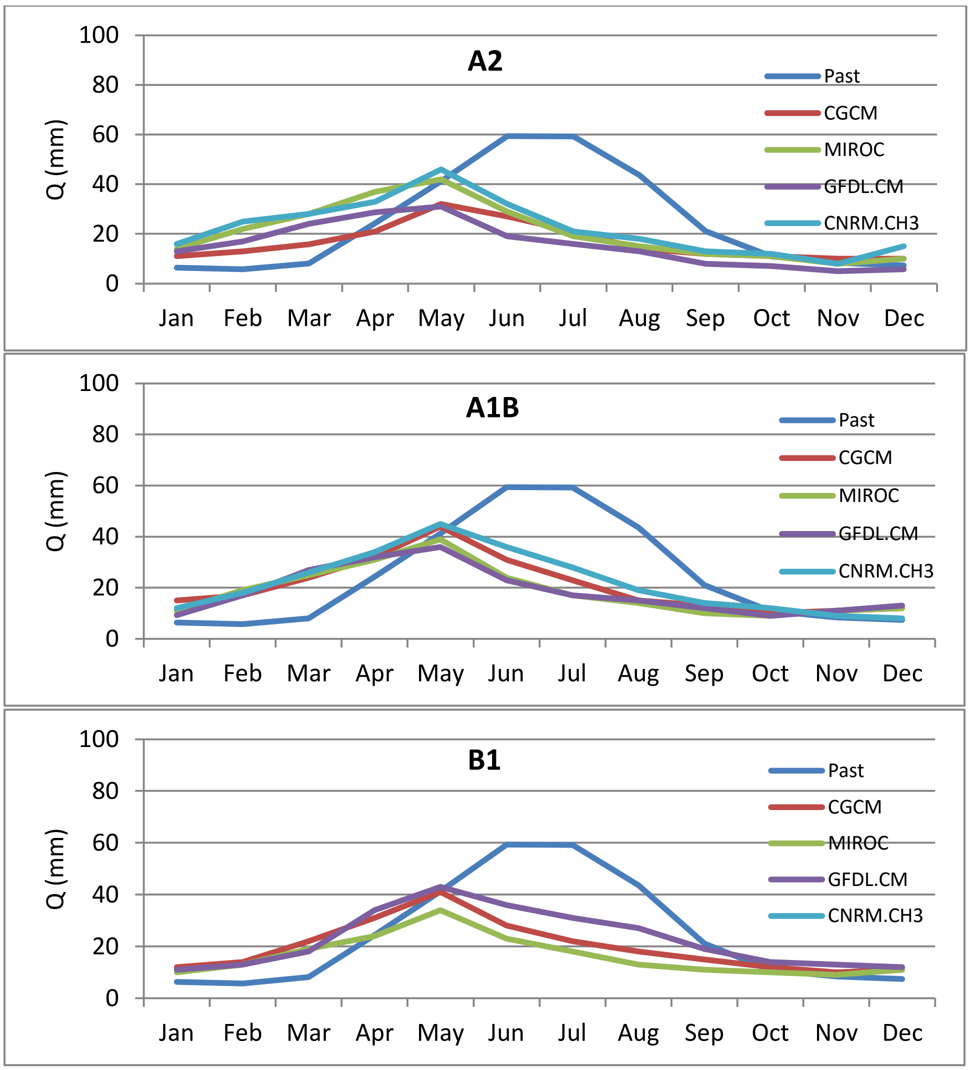



**Figure 7.14 Change in projected mean monthly streamflow regime based on observed dataset (1969 – 196) to middle of the century (2046 – 2064) for future emission scenarios A2, A1B and B1 with four GCMs.**

## 7.8. Projected Future Water Availability

Future climate prediction data of four GCMs namely, CNRM-CH3, CGCM3.2, MIROCS.2 and GFDL.CM were analyzed and employed on the SWAT model, the Kabul river basin. Three emission scenarios namely, A2, A1B and B1 were selected for each GCMs except of B1 for GFDL.CM, totaling 11 combinations of scenarios were then simulated and the results were analyzed. Eleven years (1969 – 1979) Observational stream runoff data for Dakah station converted from ($m^3$/sec) to millimeter according to the catchment area and the result compared with the Future projected stream runoff for trend assessment as shown in the Table 7.7. It can be noticed from table 7.7. that, the annual water availability shows a decreasing pattern for the GCMs. This is mainly due to the fact that the decrease in precipitation will eventually be compensated by the increase in Evapotranspiration due to temperature increase. This is an indicative of the vital impact of global temperature rise in the annual water availability of the Kabul river basin.

**Table 7.7. Projected Future water availability based on GCMs under three scenarios**

| GCMs | Scenarios | Annual water Availability (mm) | | | | |
|---|---|---|---|---|---|---|
| | | Observed (1969 - 1979) | Present (2002 - 2012) | Future (2046 - 2064) | Trend (mm) | ΔAWA % |
| CNRM-CH3 | A2 | 289 | 245 | 267 | 22 | -7.6 |
| | A1B | 289 | 245 | 261 | 28 | -9.7 |
| | B1 | 289 | 245 | 271 | 18 | -6.2 |
| CGCM3.2 | A2 | 289 | 245 | 197 | 92 | -31.8 |
| | A1B | 289 | 245 | 247 | 42 | -14.5 |
| | B1 | 289 | 245 | 236 | 53 | -18.3 |
| MIROC3.2 | A2 | 289 | 245 | 247 | 42 | -14.5 |
| | A1B | 289 | 245 | 222 | 67 | -23.2 |
| | B1 | 289 | 245 | 195 | 94 | -32.5 |
| GFDL.CM | A2 | 289 | 245 | 185 | 104 | -36.0 |
| | A1B | 289 | 245 | 221 | 68 | -23.5 |
| | B1 | 289 | 245 | x | x | |

## 7.9. Water stress assessment

To evaluate water stress by population growth and climate change, exponential population growth calculated in every watershed based on statistics till 2045. Present and future water availability evaluated based on weather data and projected climate data (CMIP3) using SWAT model 2012, with four GCMs namely CNRM-CH3, CGCM3.2, MIROCS.2 and GFDL.CM and three scenarios such A2, A1B and B1, then the present and future freshwater availability in every sub-watershed divided by the number of present and projected future population as shown in figure 7.15.

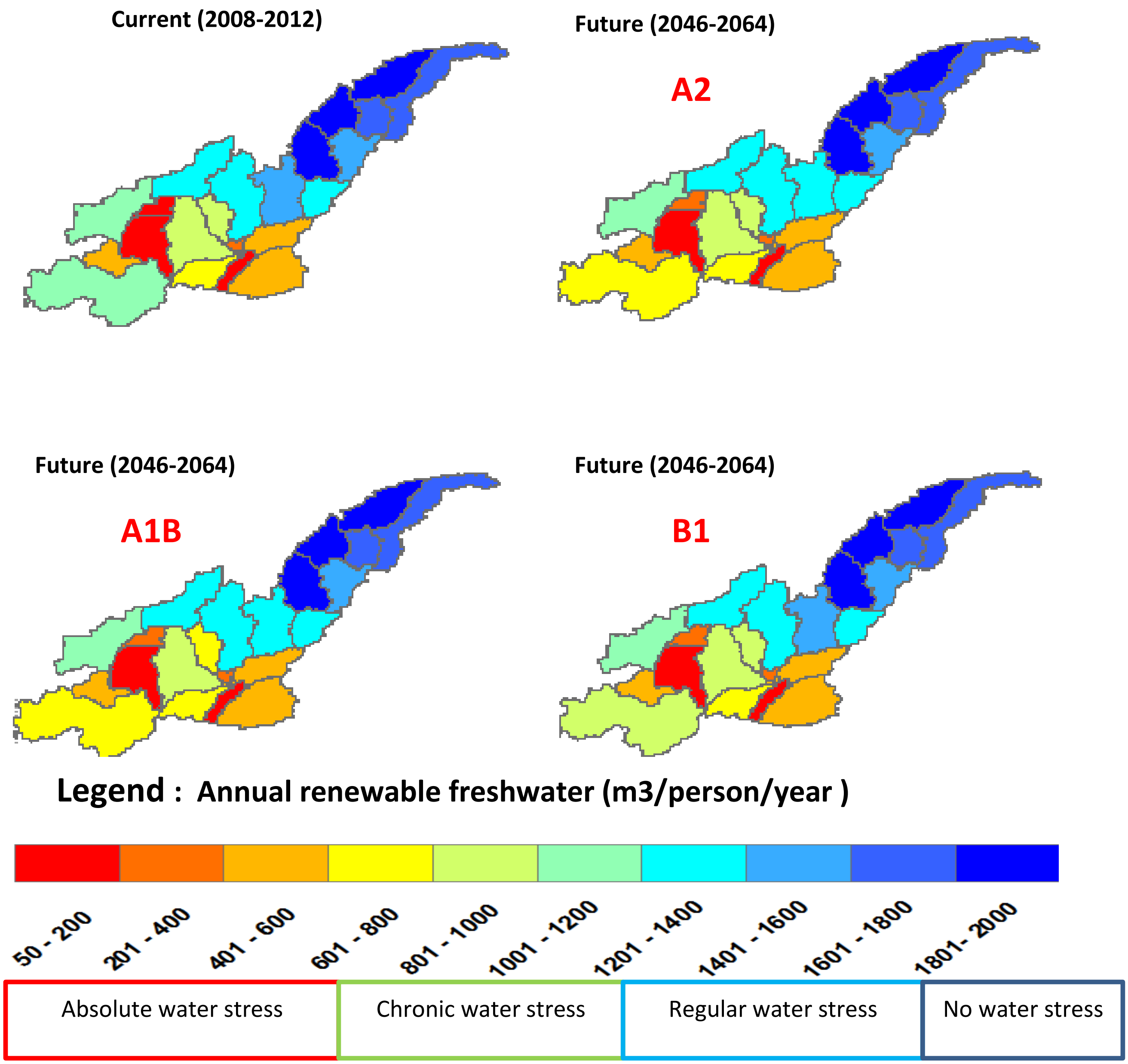



**Figure 7.15 Consideration of present and Future water stress indicator in each sub-watershed , Kabul river basin.**

## 7.4. Sectoral water demand

In this study, simulated monthly available water resources in a period of (2008 to 2012) compared with sectoral water demand in the Kabul river basin. As shown in the table 7.8 Industrial water requirements are small in comparison to irrigation demands which constitute 66% of total demands. Environmental Flow requirement, Domestic and Indestrial devote 25.4 %, 7. 8 % and 1.1%, respectively.

**Table 7.8. Shows the available water resources in the Kabul river and compares with the sectorial water requirements. SWAT2012**

| Monthls | Irrigation | Domestic | EFR | Indestrial | Total sectoral water demand | Available water resources excluding Kunar | Available water resources including Kunar |
|---|---|---|---|---|---|---|---|
| Jan | 95 | 29 | 25 | 4 | 153 | 341 | 556 |
| Feb | 131 | 35 | 26 | 5 | 197 | 370 | 524 |
| Mar | 227 | 35 | 37 | 5 | 304 | 857 | 1331 |
| Apr | 235 | 38 | 104 | 5 | 382 | 1079 | 2020 |
| May | 352 | 38 | 167 | 5 | 563 | 1467 | 3325 |
| Jun | 546 | 41 | 356 | 6 | 948 | 760 | 2543 |
| July | 616 | 44 | 380 | 6 | 1046 | 428 | 1565 |
| Aug | 517 | 41 | 163 | 6 | 727 | 408 | 1239 |
| Sep | 320 | 38 | 60 | 5 | 424 | 376 | 848 |
| Oct | 229 | 35 | 37 | 5 | 306 | 391 | 782 |
| Nov | 204 | 32 | 30 | 5 | 271 | 414 | 668 |
| Dec | 176 | 29 | 28 | 4 | 237 | 319 | 552 |
| TOTAL | 3648 | 435 | 1414 | 62 | 5558 | 7211 | 15953 |
| Percentage | 65.60% | 7.80% | 25.40% | 1.10% | 100% | | |

The comparison of current annual demands by the different sectors reveals the clear dominance of agriculture water use over domestic, EFRs and industrial. Comparing the annual total flow with annual total sectoral demands, it is mentionable that, domestic water demand partly depends on ground water, ground water availability in the basin is not known ad strongly depends on the stream flow in upstream and midstream in the Kabul river basin. In this study, ground water simulated by SWAT 2012 model. Estimate monthly and yearly ground water availability .The following charts estimate the sectoral water requirement and simulated water availibiliy. Water availability assessment performed into two scenarios:

1- **Scenario one**: sectoral water demand compared with available water resource in the Kabul river basin except of Kunar, due to lack of Agriculture and, Hydropower, population density and industrial companies. Water just generate in the Kunar watershed and leave Kabul basin without usage.

2- **Scenario two**: Sectoral water requirement compared with available water resources in the basin, including Kunar to estimate whole water available against all sectors demand.

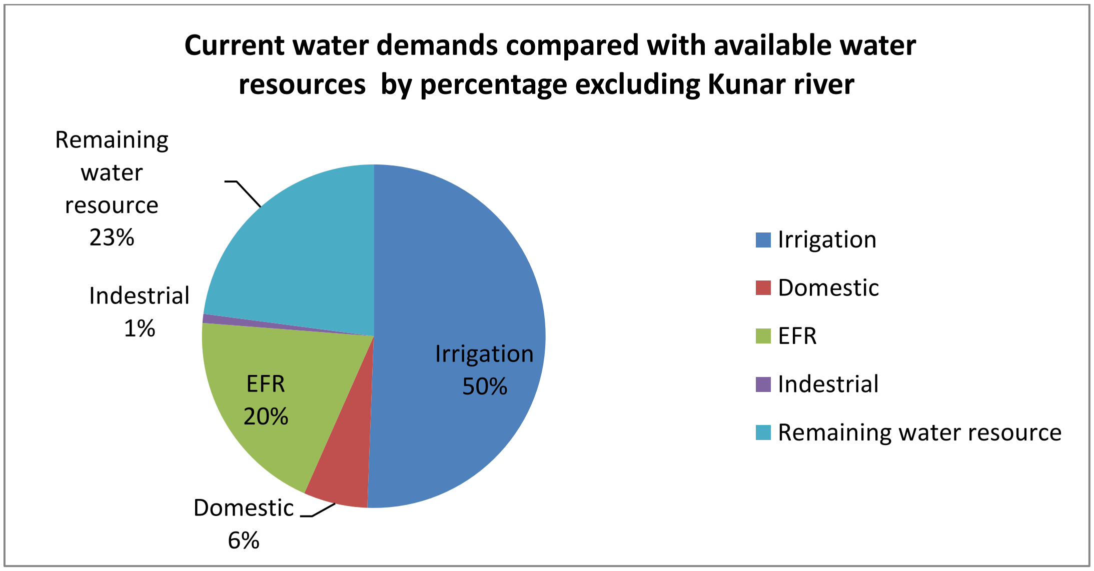



**Figure 7.16 current annual sectoral water demands compared with available water resources, excluding Kunar river at Nawabad station.**

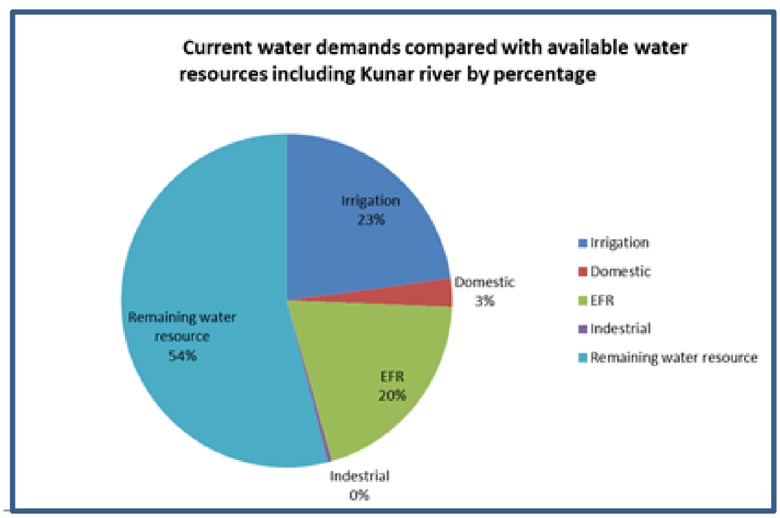



**Figure 7.17 current annual sectoral water demands compared with available water resources, including Kunar river. SWAT model (simulated water availability in the whole the basin**

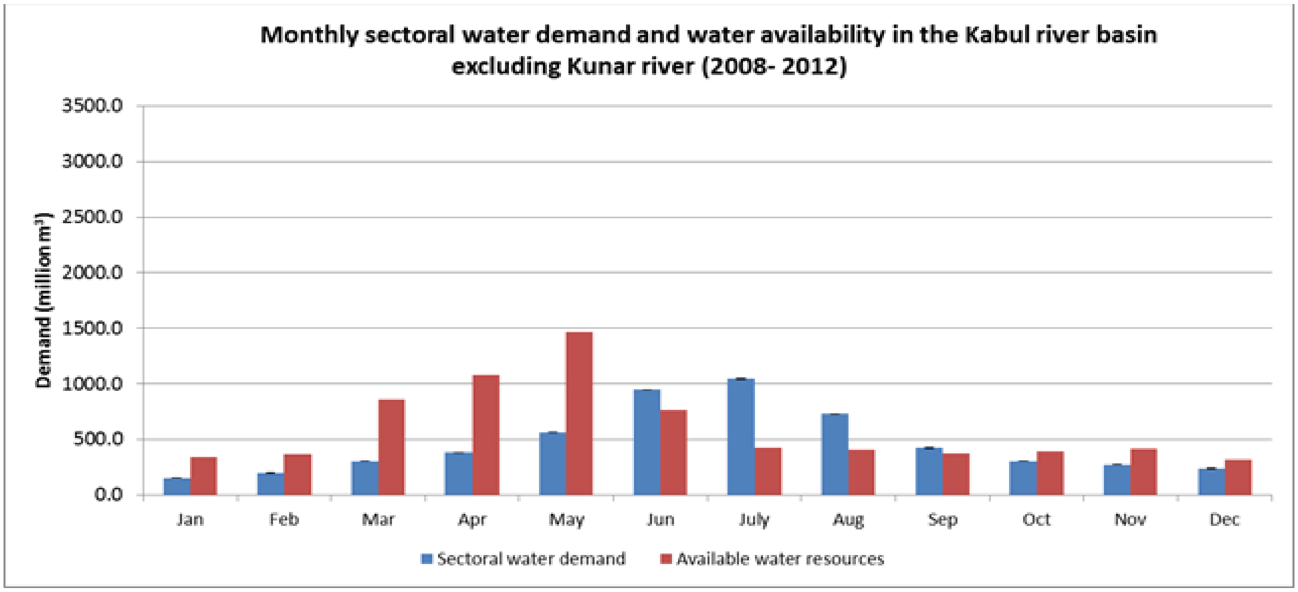



**Figure 7.18 Estimated Monthly sectoral water demand and water availability, excluding Kunar river.**

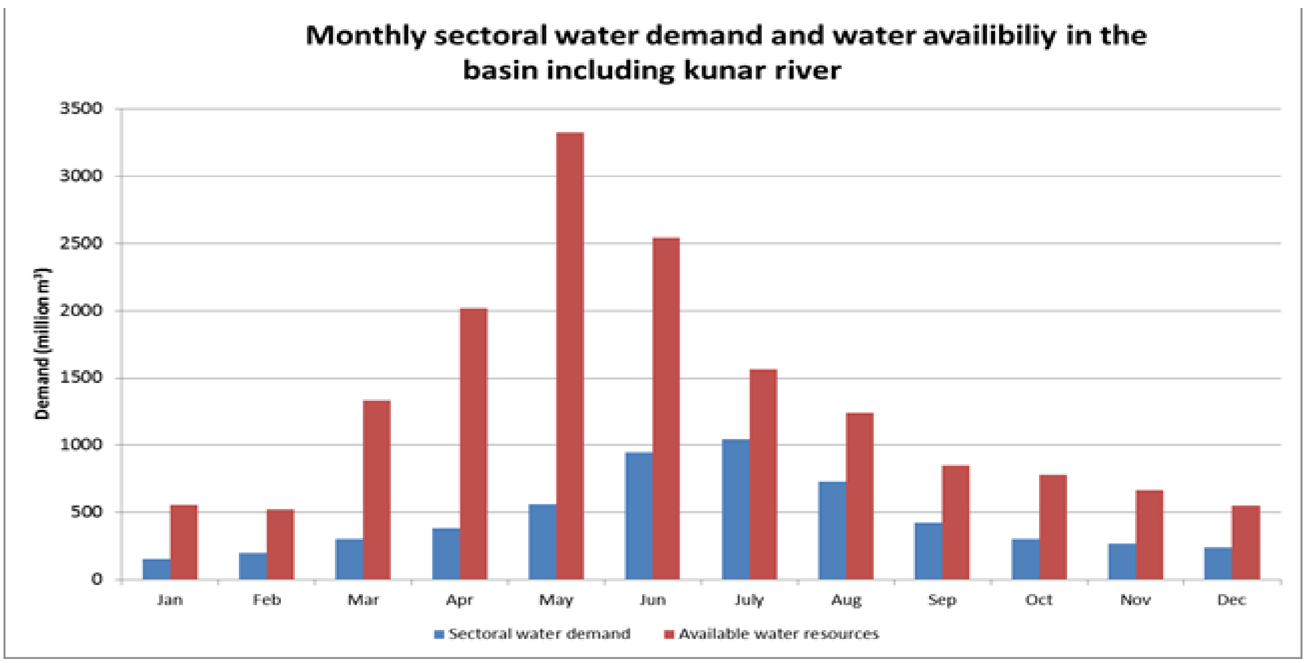



**Figure 7.19 Comparison of monthly sectoral water demand and availability in the whole the basin.**

## 7.4. Population growth and water demand based on lifestyle

Projected Population water demand by 2045, compared under three scenarios, first with basic life style 80 litters per day with loss index in the summer season, second with intermediate lifestyle 120 litters per day like China and Maxico, thirdly, to Advanced lifestyle like Japan  200 litter per day.

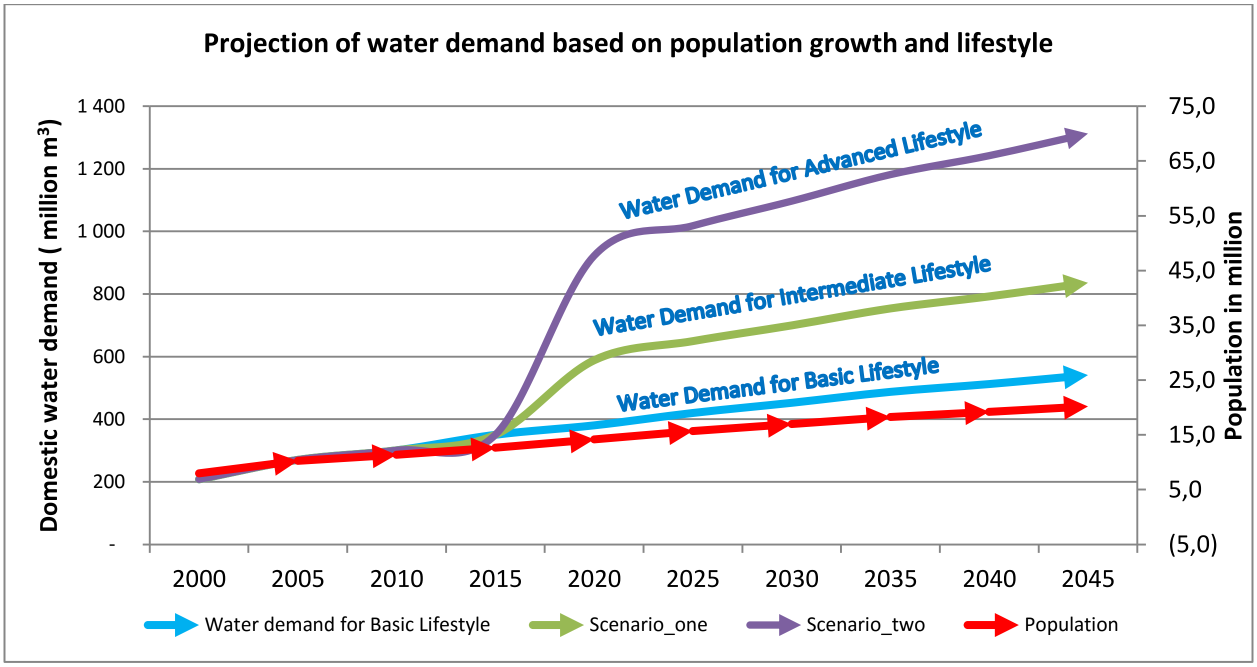



**Figure 7.20. Projected domestic water demand based on population growth and lifestyle in the basin.**

## 7.5. Land cover  analysis

In this study, two land use data sets have been used, GLCF and MODIS based global land cover data sets. GLCF (1982- 1992) with a resolution of (1km) was used as baseline and MODIS based global land cover dataset (2001 -2010) have been applied in SWAT model for land cover changes. All land use and land cover classes were aggregated into seven categories according to their hydrologic properties. These are included rangeland, grassland, mixed forest, barren, cropland, settlement and water. The overall result of the analysis showed in table 7.8

**Table 7.8 Land cover/land use changes in the Kabul river basin. Land cover Baseline (sources: GLCF and LCI- 1982-2010).**

| Number | Land cover/ land use | Land cover / land use area (Thousand hectare) | | Percent of Changes (1982-1992 to 2000-2010) |
|---|---|---|---|---|
| | | (1982 – 1992) | (2000 – 2010) | |
| 1 | Water | 9.1 | 7.8 | -14.3 |
| 2 | Urban/ Built up | 11.3 | 14.6 | 29.2 |
| 3 | Rangeland | 3652.5 | 2848.6 | -22.0 |
| 4 | Mixed forest | 448.3 | 195.7 | -56.3 |
| 5 | Grassland | 1413.8 | 1586.6 | 12.2 |
| 6 | Cropland / Irrigated area | 94.2 | 264.1 | 180.4 |
| 7 | Barren | 891 | 1602.8 | 79.9 |

According to the output of land cover analysis, cropland or irrigated land shows 180 % increased after 20 years, if we project the land cover changes, in contrast to the two data sets, and projection of irrigation, land could be significant, for projection of irrigated area by 2045 the cropland assumed 496 (thousand hectare).

## 7.6. Projected sectoral water demand by 2045

Assuming a high growth scenario for 2045, where,

- Agriculture production in the Kabul river basin is increased, maintaining the irrigation infrastructure along the river valleys in upstream, midstream and downstream and achieving a maximum river water , plus extension of irrigated land due to the implementation of MAIL policy for land improvement and irrigation extension from 264000 to 496000 hectares in the Kabul basin.
- The population in the Basin has grown to almost 22 million in 2045 based on statistic analysis. Domestic water demand evaluates as developed country, 200 litters per day per person.

- Environmental flow demands stay the same with 1.3 indices in the summer season due to increasing temperature to (4-3°C) by mid- century.
- Aynik mine fro extraction and processing of copper and some other manufacturing companies evaluated ongoing .
- Future water availability, estimated based on climate change scenarios with GCMs using SWAT model for 2045- 2064.

Projection of annual sectoral water demands compared with water availibiliy under climate change scenarios in the Kabul river basin and determined and illustrated in Table 7.9.

**Table 7.9 Projected sectoral water demand and water availability using SWAT model, water availability evaluated based on climate change scenario (A2) and the average of three GCMs ( CCMA, MIROC 3-2 and CNRM).**

| Projected sectoral water demand and Available water resources ( million $m^3$/month) in the Kabul basin by (2046 - 2064) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Monthls | Irrigation | Domestic | EFR | Indestrial | Total sectoral water demand | Available water resources excluding Kunar | Available water resources including Kunar |
| Jan | 133 | 108 | 25 | 8 | 274 | 343 | 880 |
| Feb | 184 | 130 | 26 | 10 | 349 | 784 | 1174 |
| Mar | 341 | 130 | 37 | 10 | 518 | 923 | 1561 |
| Apr | 352 | 141 | 104 | 11 | 608 | 900 | 1951 |
| May | 598 | 141 | 167 | 11 | 918 | 336 | 2347 |
| Jun | 928 | 152 | 356 | 12 | 1447 | 189 | 1744 |
| July | 924 | 163 | 380 | 12 | 1479 | 150 | 1255 |
| Aug | 828 | 152 | 163 | 12 | 1155 | 125 | 978 |
| Sep | 480 | 141 | 60 | 11 | 692 | 117 | 734 |
| Oct | 320 | 130 | 37 | 10 | 497 | 150 | 668 |
| Nov | 286 | 119 | 30 | 9 | 445 | 154 | 505 |
| Dec | 246 | 108 | 28 | 8 | 391 | 168 | 665 |
| TOTAL | 5620 | 1614 | 1414 | 124 | 8772 | 4340 | 14462 |
| Percentage | 64% | 18% | 16% | 1% | 100% | | |

The projected water demand and water availability under rapid population growth and climate change condition seriously moving in unexpected directions. The future sectoral water requirement expected to increase 63% more than today's demand and available water resources will decline 14 % compared to current available water resources. Also, it is mentionable that , the monthly stream flow regime changed based on increasing temperature and deceasing snowfall in the winter season under A2 climate change scenario. Projected sectoral water demand and future available water compared in the below figures.

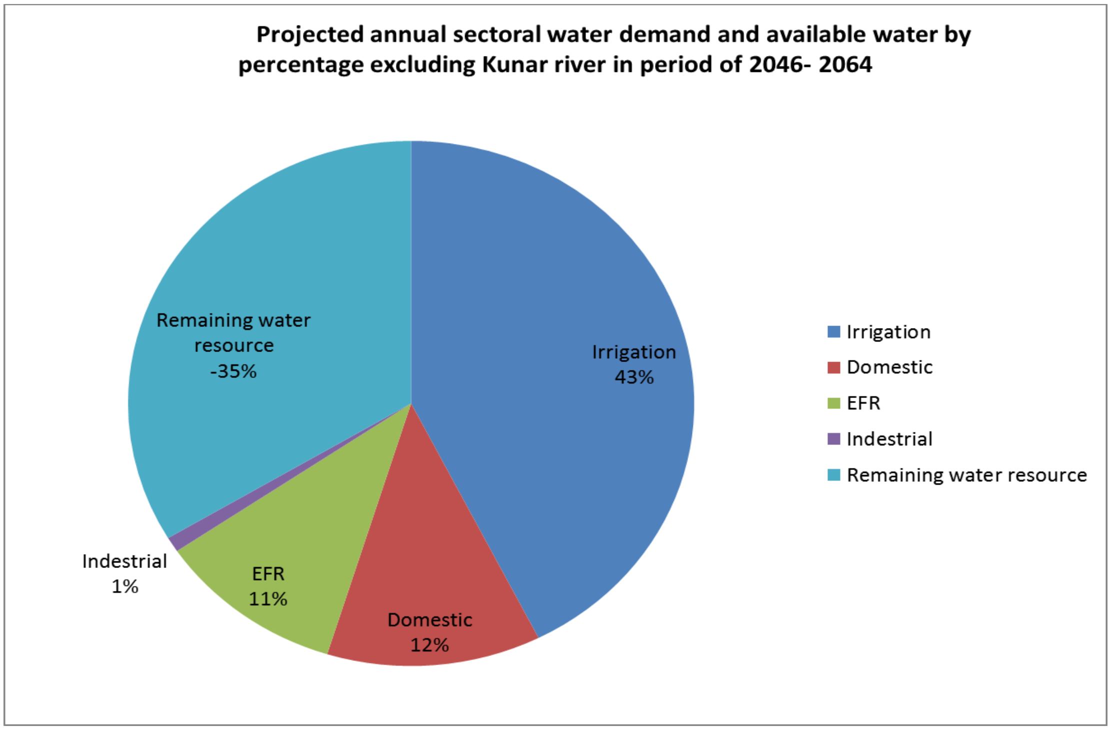



**Figure 7.21 Projected annual sectoral water demand and available water resources, in the Kabul river basin excluding Kunar river.**

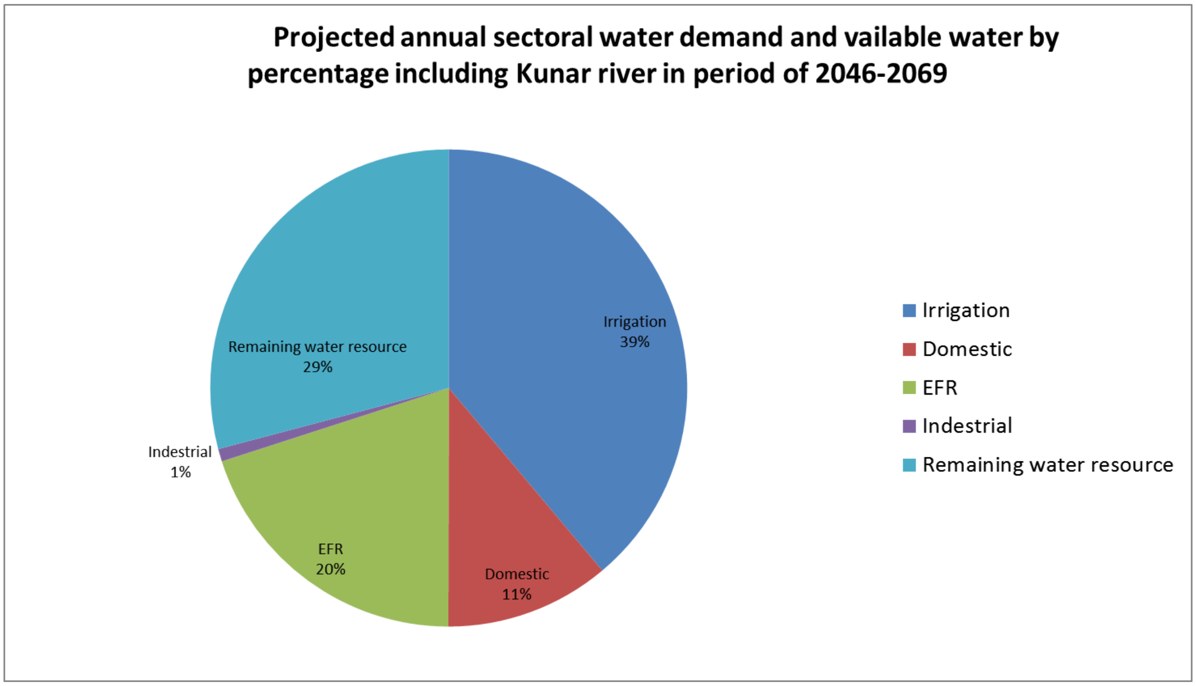



**Figure 7.22 Projected annual sectoral water demand and available water resources, in the Kabul river basin excluding Kunar river.**

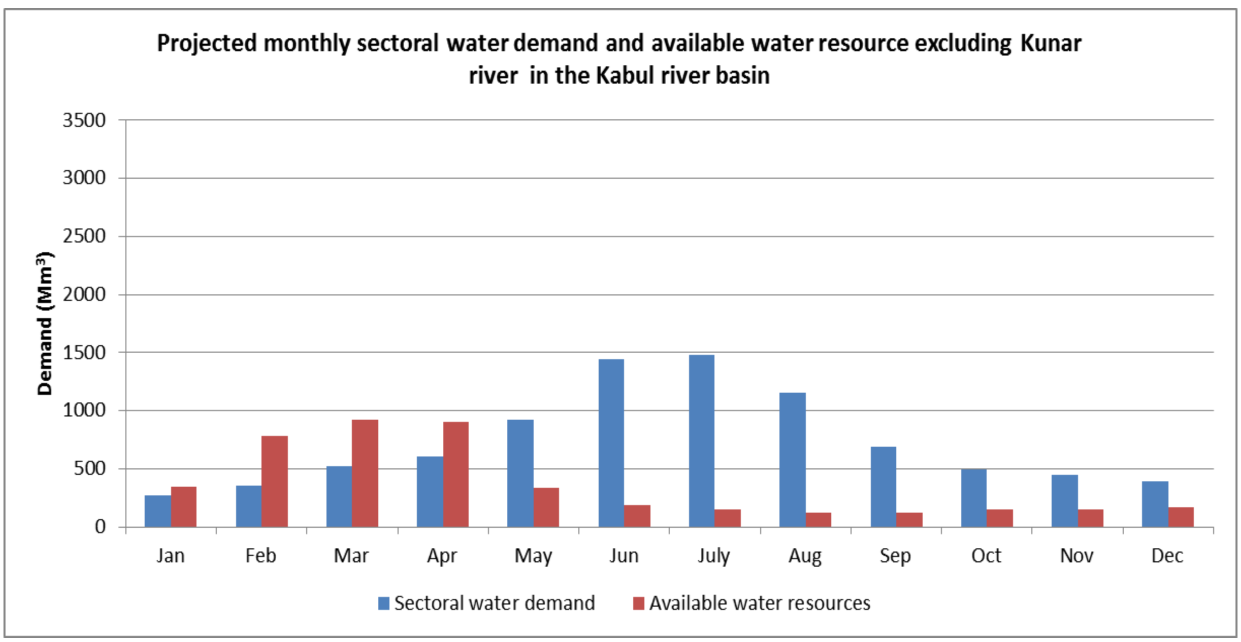



**Figure 7.23 Projected monthly sectoral water demand and available water resources in the Kabul river basin except of Kunar river in by 2046 to 2064.**

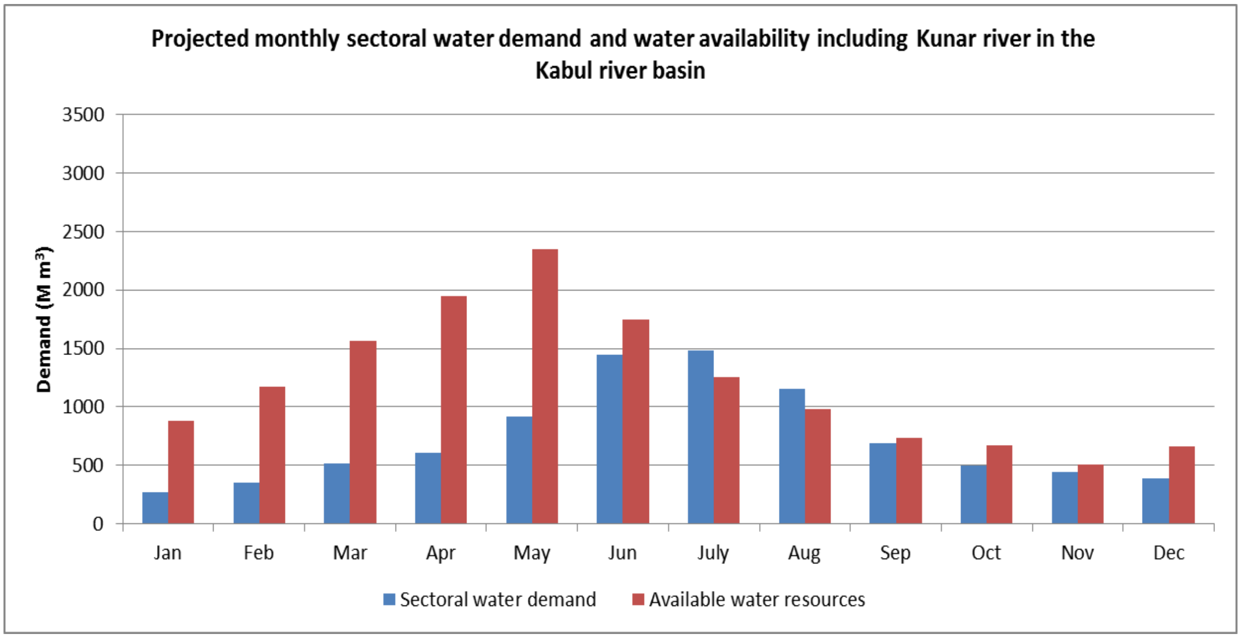



**Figure 7.24 Projected monthly sectoral water demand and available water resources in the Kabul river basin, including the Kunar river in by 2046 to 2064.**

As shown in figure 7.21, the remaining river flow, is the result of the initial flow, total annual flow (4772 million cubic meters per year) except of Kunar river, minus the Kabul river basin water needs for the Agriculture (5620 million $m^3$), domestic ( 1614 million $m^3$), environmental water demand (1414 million $m^3$) and industries (124 million $m^3$), so, sectoral water demand totally estimated 8772 million $m^3$ and available water resources estimated 4340 million cubic meters for the entire Kabul river basin. The negative result of the remaining river flow is again not entirely correct, since, as mentioned above, not all demands area actually satisfied from the river. The domestic as well as livestock demands are partly satisfied by groundwater, eventually compensating the deficit. The total river flow would be reduced to a minimum in any case. And if environmental demands were in fact higher than the assumed 10 %, the limits of development would be crossed and development would happen at the cost of environmental services. It is mentionable that, the projected monthly water demand shows a water deficit in the Summer and Autumn seasons (May to January) in figure 7.23 and (May to November) based on figure 7.24, In the Kabul river basin. This water deficit expected to happen in the midstream and downstream based on population density and agriculture extension.

# CHAPTER EIGHT

# CONCLUSIONS AND RECOMMENDATIONS

In this research, current water balance, future water availability based on climate change scenarios, current and projected sectoral water demand and water stress have been assessed. Observe and reliable meteorological and hydrological data sets were the main obstacle toward the present research. Regression and dynamic method have been applied for gap filling of existing meteorological data which, I have been obtained in stage of data collection, all observed stations located in the flat areas of the basin. Then, the observed precipitation in four stations compared with TRMM precipitation data set based on blocking method, the $R^2$ applied for total variation in the both data sets the result evaluated satisfactory with $R^2$= 0.8, eventually, TRMM identified as acceptable precipitation data set. Extension of hydro meteorological networks in whole the basin are essential to create accurate and reliable database for future planning, research and development.

GIS and SWAT 2012 model used for modeling hydrology spatially estimation of current (2008 – 2012) available water resource potential in the Kabul river basin, Afghanistan. the SWAT model applied to quantify the current water balance , calibration scenarios tested. The optimal scenario results for the simulated monthly and yearly flows the SWAT 's runoff simulation were tested against measured runoff data. The annually averaged simulated stream discharge (244 mm) is 86% of the measured average value (284 mm). So, the water yield results of simulation shown underestimate less than 14 % of observed annual stream discharge. Each water budget components of the model gave reasonable output, which reveals that this model can be used for the assessment of tile drainage with its associated practices.

The SWAT model works in the framework of GIS to generate outputs of hydrology components based on GIS and meteorological input data. Three emission scenarios namely, A2, A1B and B1 were selected for each GCMs for the middle of twenty first century, namely, CNRM-CH3, CGCM3.2, MIROCS.2 and GFDL.CM except of B1 for GFDL.CM, totaling 11 combinations were applied in the SWAT model to project future monthly and yearly water availability based on high, medium and low emission green house gases till 2064 to assess changes in temperature, precipitation and hydrology components in the study area .

Calculation shown that, the annual sectoral anthropogenic water demands, Agirculture, with 3.65 Billion cubic meters (billion cubic meters)is currently by far the largest water consumer in the basin, followed by domestic 435 million cubic meters ($Mm^3$) and Industry by 64 million cubic meters **.** This research made an important conceptual contribution to the discussion of local water demands by considering basin environmental needs. With the assumption of 20% environmental reserve flow (3.73 bcm), the annual environmental demands are currently slightly greater than the agricultural water use. The research revealed how Kabul river basin is affected and will affected by the regional interplay of upstream development, population extension and climate change . Under medium and high growth assumptions the basin would be left with river flow of about 4212 Million cubic meters, while, If the government do not pay attention on water development of across the Kuner river, Kabul river basin would experience an annual deficit of 4432 million cubic meters. Dam construction in midstream and upstream of the Kabul river basin could be the best solution to balance monthly water demand for Agriculture, domestic, environment and industry and feed ground water aquifer. If the hydrological deficit is compensated by accessing the environmental reserve flows, key ecosystem functions as well as ground water renewal may be threatened and by that the livelihood of of people in the upstream and downstream could be jeopardized.

Four GCMs and three climate scenarios (A2, A1B and B1) were used to project future temperature, precipitation and water stream runoff in the Kabul river basin for the period of 1961 to 2065. Based on the results of the three climate scenarios, the trend of impacts of climate charge is similar. A warmer climate is anticipated for the study area with a projected change of temperature between 1.5°C and 2.9°C for summer and winter seasons. Based on A2 scenario, the precipitation pattern (Snowfall) is anticipated to decrease for the months of November, December, January, February specially between 20% to 40% due to increasing temperature in the mentioned months. Generally, based on these three scenarios snowfall is anticipated to decrease significantly in 2064, and rainfall expected to increase slightly. The change in pattern of temperature and precipitation will change the stream runoff regime and the peak of stream flow will change from June and July to May.The SWAT model output shown that, stream runoff will will increase in the months of January, February, March and April between (35% to 45%) and runoff is expected to decrease in the months of June, July, August and Septermber. Between (40 % to 50%). The study shows that, the potential impacts on water availability in the study area of climate change, the results must be understood within the context of the assumptions of the study.

Finally, the result of the population explosion in each 23 sub-watersheds for 2012 to 2065 compared with the results of water availability for current (2008 – 2012) and four GCMs (2046 – 2064) under A2, A1B and B1senarios to assess the zonal water stress. The overall results show that, Kabul upstream and midstream is experiencing serious water stress, especially the most populated areas such as, Kabul in midstream and Nangarhar province in downstream. Integrated watershed management should be the priority of the government for water resources development. Decentralization and distribution of population based on employment can also reduce the risk of water stress. Adaptation and mitigation policy in the framework of IWRM seriously recommended can reduce the risk of water stress and water shortage in the basin.

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**APPENDIX**

1. Comparison of precipitation records based on three different data sources

| Station Asmar (2009) | | Precipitation mm/month | |
|---|---|---|---|
| **Months** | **MoEW** | **TRMM_5** | **MAIL** |
| **Jan** | 46 | 37 | 47 |
| **Feb** | 84 | 42 | 77 |
| **Mar** | 104 | 95 | 97 |
| **Apr** | 59 | 91 | 78 |
| **May** | 55 | 38 | 39 |
| **Jun** | 40 | 16 | 67 |
| **Jul** | 66 | 13 | 14 |
| **Aug** | 27 | 30 | 14 |
| **Sep** | 18 | 37 | 18 |
| **Oct** | 29 | 11 | 9 |
| **Nov** | 31 | 31 | 28 |
| **Dec** | 5 | 15 | 5 |
| **Annual** | 565 | 456 | 493 |

| Station Asmar (2010) | | Precipitation mm/month | |
|---|---|---|---|
| **Months** | MoEW | **TRMM_5** | **MAIL** |
| **Jan** | 57 | 36 | 55 |
| **Feb** | 85 | 18 | 97 |
| **Mar** | 104 | 4 | 32 |
| **Apr** | 59 | 47 | 93 |
| **May** | 55 | 61 | 66 |
| **Jun** | 40 | 59 | 38 |
| **Jul** | 180 | 266 | 101 |
| **Aug** | 45 | 121 | 24 |
| **Sep** | 30 | 39 | 39 |
| **Oct** | 8 | 0 | 0 |
| **Nov** | 1 | 0 | 10 |
| **Dec** | 102 | 1 | 2 |
| **Annual** | 767 | 650 | 557 |

| Station Dakah (2009) | | Precipitation mm/month | |
|---|---|---|---|
| **Months** | **MoEW** | **TRMM_6** | **MAIL** |
| **Jan** | 53 | 28 | 43 |
| **Feb** | 60 | 49 | 39 |
| **Mar** | 42 | 69 | 50 |
| **Apr** | 36 | 187 | 52 |
| **May** | 26 | 27 | 25 |
| **Jun** | 10 | 15 | 10 |
| **Jul** | 8 | 12 | 0 |
| **Aug** | 18 | 19 | 17 |
| **Sep** | 10 | 71 | 30 |
| **Oct** | 7 | 1 | 10 |
| **Nov** | 15 | 13 | 13 |
| **Dec** | 8 | 1 | 0 |
| **Annual** | 294 | 492 | 289 |

| Station Dakah (2010) | | Precipitation mm/month | |
|---|---|---|---|
| **Months** | **MoEW** | **TRMM_6** | **MAIL** |
| **Jan** | 15 | 4 | 27 |
| **Feb** | 35 | 51 | 33 |
| **Mar** | 28 | 1 | 0 |
| **Apr** | 33 | 68 | 41 |
| **May** | 33 | 49 | 56 |
| **Jun** | 8 | 80 | 17 |
| **Jul** | 18 | 221 | 66 |
| **Aug** | 27 | 163 | 17 |
| **Sep** | 25 | 34 | 51 |
| **Oct** | 0 | 2 | 0 |
| **Nov** | 0 | 0 | 0 |
| **Dec** | 15 | 0 | 0 |
| **Annual** | 238 | 671 | 308 |

| Station Panjshir (2009) | | Precipitation mm/month | |
|---|---|---|---|
| Months | MoEW | TRMM_5 | MAIL |
| Jan | 81 | 65 | 73 |
| Feb | 79 | 56 | 67 |
| Mar | 24 | 79 | 61 |
| Apr | 0 | 63 | 43 |
| May | 0 | 44 | 44 |
| Jun | 31 | 8 | 19 |
| Jul | 5 | 8 | 0 |
| Aug | 1 | 13 | 18 |
| Sep | 4 | 21 | 46 |
| Oct | 10 | 7 | 67 |
| Nov | 74 | 30 | 33 |
| Dec | 39 | 51 | 24 |
| Annual | 348 | 445 | 495 |

| Station Panjshir (2010) | | Precipitation mm/month | |
|---|---|---|---|
| Months | MoEW | TRMM_5 | MAIL |
| Jan | 12 | 24 | 5 |
| Feb | 87 | 119 | 140 |
| Mar | 26 | 45 | 54 |
| Apr | 86 | 56 | 36 |
| May | 67 | 56 | 49 |
| Jun | 6 | 28 | 33 |
| Jul | 20 | 180 | 55 |
| Aug | 8 | 45 | 60 |
| Sep | 17 | 30 | 80 |
| Oct | 0 | 1 | 0 |
| Nov | 14 | 10 | 25 |
| Dec | 1 | 12 | 0 |
| Annaul | 344 | 608 | 537 |

| Station Gulbahar (2009) | | Precipitation mm/month | |
|---|---|---|---|
| Months | MoEW | TRMM_5 | MAIL |
| Jan | 38 | 103 | 62 |
| Feb | 75 | 76 | 57 |
| Mar | 22 | 78 | 29 |
| Apr | 29 | 60 | 132 |
| May | 46 | 39 | 28 |
| Jun | 17 | 6 | 11 |
| Jul | 16 | 0 | 0 |
| Aug | 19 | 0 | 4 |
| Sep | 6 | 8 | 1 |
| Oct | 0 | 3 | 9 |
| Nov | 4 | 14 | 26 |
| Dec | 0 | 22 | 13 |
| Annual | 272 | 409 | 373 |

| Station Gulbahar (2010) | | Precipitation mm/month | |
|---|---|---|---|
| Months | MoEW | TRMM_5 | MAIL |
| Jan | 29 | 36 | 13 |
| Feb | 36 | 125 | 106 |
| Mar | 47 | 35 | 27 |
| Apr | 46 | 46 | 83 |
| May | 15 | 47 | 84 |
| Jun | 4 | 18 | 0 |
| Jul | 0 | 32 | 21 |
| Aug | 6 | 48 | 16 |
| Sep | 8 | 7 | 30 |
| Oct | 29 | 2 | 0 |
| Nov | 3 | 12 | 16 |
| Dec | 0 | 32 | 2 |
| Annual | 224 | 441 | 398 |

2. Comparison of observed and simulated stream runoff in Dakah station.

| Station | | Runoff |
|---|---|---|
| Dakah | | $m^3$/second |
| Date | Observed | Simulated by SWAT |
| 1/1/2008 | 168 | 67 |
| 2/1/2008 | 168 | 99 |
| 3/1/2008 | 230 | 166 |
| 4/1/2008 | 483 | 250 |
| 5/1/2008 | 714 | 1041 |
| 6/1/2008 | 1188 | 734 |
| 7/1/2008 | 1040 | 730 |
| 8/1/2008 | 694 | 490 |
| 9/1/2008 | 388 | 172 |
| 10/1/2008 | 229 | 160 |
| 11/1/2008 | 191 | 93 |
| 12/1/2008 | 178 | 106 |
| 1/1/2009 | 172 | 91 |
| 2/1/2009 | 171 | 140 |
| 3/1/2009 | 239 | 250 |
| 4/1/2009 | 496 | 361 |
| 5/1/2009 | 930 | 897 |
| 6/1/2009 | 1012 | 914 |
| 7/1/2009 | 1499 | 734 |
| 8/1/2009 | 1020 | 657 |
| 9/1/2009 | 437 | 187 |
| 10/1/2009 | 249 | 158 |
| 11/1/2009 | 199 | 150 |
| 12/1/2009 | 158 | 160 |
| 1/1/2010 | 154 | 155 |
| 2/1/2010 | 185 | 185 |
| 3/1/2010 | 292 | 158 |
| 4/1/2010 | 601 | 817 |
| 5/1/2010 | 864 | 1008 |
| 6/1/2010 | 1243 | 774 |

| Station | | Runoff |
|---|---|---|
| Dakah | | $m^3$/second |
| Date | Observed | Simulated by SWAT |
| 7/1/2010 | 1181 | 718 |
| 8/1/2010 | 775 | 372 |
| 9/1/2010 | 435 | 289 |
| 10/1/2010 | 242 | 113 |
| 11/1/2010 | 190 | 185 |
| 12/1/2010 | 193 | 212 |
| 1/1/2011 | 169 | 168 |
| 2/1/2011 | 162 | 160 |
| 3/1/2011 | 225 | 330 |
| 4/1/2011 | 499 | 562 |
| 5/1/2011 | 841 | 710 |
| 6/1/2011 | 1300 | 771 |
| 7/1/2011 | 1350 | 703 |
| 8/1/2011 | 776 | 438 |
| 9/1/2011 | 337 | 212 |
| 10/1/2011 | 267 | 185 |
| 11/1/2011 | 231 | 132 |
| 12/1/2011 | 216 | 149 |
| 1/1/2012 | 209 | 158 |
| 2/1/2012 | 219 | 161 |
| 3/1/2012 | 339 | 453 |
| 4/1/2012 | 756 | 735 |
| 5/1/2012 | 742 | 1098 |
| 6/1/2012 | 1121 | 731 |
| 7/1/2012 | 1810 | 1092 |
| 8/1/2012 | 1002 | 692 |
| 9/1/2012 | 509 | 288 |
| 10/1/2012 | 293 | 185 |
| 11/1/2012 | 256 | 196 |
| 12/1/2012 | 225 | 138 |

3. Comparison of observed and simulated stream runoff in Shukhi station.

| Station | | Runoff |
|---|---|---|
| Shukhi | | $m^3$/second |
| Date | Observed | Simulated by SWAT |
| 1/1/2008 | 40 | 82 |
| 2/1/2008 | 34 | 79 |
| 3/1/2008 | 48 | 203 |
| 4/1/2008 | 95 | 159 |
| 5/1/2008 | 187 | 289 |
| 6/1/2008 | 232 | 310 |
| 7/1/2008 | 132 | 230 |
| 8/1/2008 | 33 | 140 |
| 9/1/2008 | 30 | 135 |
| 10/1/2008 | 31 | 91 |
| 11/1/2008 | 32 | 45 |
| 12/1/2008 | 34 | 39 |
| 1/1/2009 | 38 | 58 |
| 2/1/2009 | 33 | 61 |
| 3/1/2009 | 41 | 33 |
| 4/1/2009 | 143 | 162 |
| 5/1/2009 | 225 | 410 |
| 6/1/2009 | 268 | 380 |
| 7/1/2009 | 254 | 218 |
| 8/1/2009 | 91 | 72 |
| 9/1/2009 | 35 | 29 |
| 10/1/2009 | 25 | 37 |
| 11/1/2009 | 27 | 53 |
| 12/1/2009 | 39 | 41 |
| 1/1/2010 | 37 | 38 |
| 2/1/2010 | 35 | 12 |
| 3/1/2010 | 51 | 102 |
| 4/1/2010 | 88 | 59 |
| 5/1/2010 | 213 | 265 |
| 6/1/2010 | 287 | 369 |

| Station | | Runoff |
|---|---|---|
| Shukhi | | $m^3$/second |
| Date | Observed | Simulated by SWAT |
| 7/1/2010 | 256 | 198 |
| 8/1/2010 | 162 | 139 |
| 9/1/2010 | 79 | 37 |
| 10/1/2010 | 27 | 42 |
| 11/1/2010 | 29 | 44 |
| 12/1/2010 | 30 | 30 |
| 1/1/2011 | 29 | 34 |
| 2/1/2011 | 36 | 29 |
| 3/1/2011 | 49 | 61 |
| 4/1/2011 | 196 | 241 |
| 5/1/2011 | 303 | 419 |
| 6/1/2011 | 177 | 231 |
| 7/1/2011 | 61 | 65 |
| 8/1/2011 | 48 | 31 |
| 9/1/2011 | 34 | 17 |
| 10/1/2011 | 25 | 29 |
| 11/1/2011 | 25 | 36 |
| 12/1/2011 | 31 | 12 |
| 1/1/2012 | 32 | 8 |
| 2/1/2012 | 33 | 9 |
| 3/1/2012 | 66 | 82 |
| 4/1/2012 | 130 | 221 |
| 5/1/2012 | 242 | 418 |
| 6/1/2012 | 399 | 559 |
| 7/1/2012 | 272 | 220 |
| 8/1/2012 | 240 | 137 |
| 9/1/2012 | 120 | 87 |
| 10/1/2012 | 75 | 116 |
| 11/1/2012 | 29 | 44 |
| 12/1/2012 | 33 | 22 |

4. Observed stream runoff in Nawabad station, Kabul river basin.

| Station | | Runoff |
|---|---|---|
| Nawabad | | $m^3$/second |
| Date | Observed | Simulated by SWAT |
| 1/1/2008 | 52 | |
| 2/1/2008 | 74 | |
| 3/1/2008 | 103 | |
| 4/1/2008 | 208 | |
| 5/1/2008 | 458 | |
| 6/1/2008 | 846 | |
| 7/1/2008 | 822 | |
| 8/1/2008 | 669 | |
| 9/1/2008 | 299 | |
| 10/1/2008 | 217 | |
| 11/1/2008 | 155 | |
| 12/1/2008 | 120 | |
| 1/1/2009 | 112 | |
| 2/1/2009 | 100 | |
| 3/1/2009 | 128 | |
| 4/1/2009 | 404 | |
| 5/1/2009 | 432 | |
| 6/1/2009 | 960 | |
| 7/1/2009 | 1080 | |
| 8/1/2009 | 966 | |
| 9/1/2009 | 546 | |
| 10/1/2009 | 354 | |
| 11/1/2009 | 301 | |
| 12/1/2009 | 251 | |
| 1/1/2010 | 199 | |
| 2/1/2010 | 154 | |
| 3/1/2010 | 368 | |
| 4/1/2010 | 484 | |
| 5/1/2010 | 736 | |
| 6/1/2010 | 916 | |

| Station | | Runoff |
|---|---|---|
| Nawabad | | $m^3$/second |
| Date | Observed | Simulated by SWAT |
| 7/1/2010 | 1297 | |
| 8/1/2010 | 1244 | |
| 9/1/2010 | 582 | |
| 10/1/2010 | 351 | |
| 11/1/2010 | 329 | |
| 12/1/2010 | 236 | |
| 1/1/2011 | 219 | |
| 2/1/2011 | 241 | |
| 3/1/2011 | 321 | |
| 4/1/2011 | 457 | |
| 5/1/2011 | 786 | |
| 6/1/2011 | 1020 | |
| 7/1/2011 | 789 | |
| 8/1/2011 | 813 | |
| 9/1/2011 | 611 | |
| 10/1/2011 | 308 | |
| 11/1/2011 | 272 | |
| 12/1/2011 | 251 | |
| 1/1/2012 | 221 | |
| 2/1/2012 | 208 | |
| 3/1/2012 | 225 | |
| 4/1/2012 | 503 | |
| 5/1/2012 | 504 | |
| 6/1/2012 | 819 | |
| 7/1/2012 | 969 | |
| 8/1/2012 | 675 | |
| 9/1/2012 | 311 | |
| 10/1/2012 | 205 | |
| 11/1/2012 | 191 | |
| 12/1/2012 | 181 | |

5. Mean monthly observed stream runoff by (cubic meters per second ) in the Kabul river basin in the period of (2008 - 2012)

| | Observed stations measures with MoEW ($M^3$/second) | | | | |
|---|---|---|---|---|---|
| **Months** | **Shukhi** | **Sultanpor** | **Pul-Qarghai** | **Nawabad** | **Dakah** |
| Jan | 34.9 | 2 | 4 | 154 | 166 |
| Feb | 33.7 | 2 | 6 | 148 | 171 |
| Mar | 59.9 | 8 | 30 | 224 | 247 |
| Apr | 125.8 | 10 | 97 | 409 | 520 |
| May | 234.5 | 10 | 152 | 571 | 837 |
| Jun | 284.7 | 4 | 175 | 827 | 1186 |
| Jul | 196.1 | 2 | 109 | 973 | 1268 |
| Aug | 71.5 | 3 | 33 | 813 | 817 |
| Sep | 37.4 | 3 | 14 | 444 | 399 |
| Oct | 28.0 | 1 | 7 | 272 | 247 |
| Nev | 28.5 | 2 | 5 | 230 | 203 |
| Dec | 33.2 | 2 | 5 | 183 | 186 |

6. Average monthly hydrology components by (mm/month) in the Kabul river basin using SWAT model

| Month | Rainfall | Snowfall | Surf (Q) | Lat (Q) | Yield | ET | PET | Yield (T/HA) |
|---|---|---|---|---|---|---|---|---|
| Jan | 53.4 | 49.4 | 1.0 | 0.1 | 8.5 | 3.6 | 14.0 | 0.2 |
| Feb | 55.4 | 50.5 | 1.6 | 0.2 | 8.0 | 6.6 | 16.6 | 0.7 |
| Mar | 47.6 | 33.6 | 13.4 | 1.0 | 20.4 | 15.2 | 39.6 | 12.0 |
| Apr | 74.7 | 32.6 | 22.3 | 2.2 | 31.0 | 25.3 | 62.1 | 46.1 |
| May | 49.6 | 10.5 | 48.3 | 4.7 | 51.0 | 35.9 | 109.3 | 90.1 |
| Jun | 40.0 | 3.5 | 35.7 | 4.8 | 39.0 | 34.9 | 138.5 | 88.4 |
| Jul | 32.3 | 0.0 | 1.1 | 2.7 | 24.0 | 33.2 | 145.3 | 1.1 |
| Aug | 32.8 | 0.0 | 0.3 | 1.7 | 19.0 | 30.5 | 139.5 | 0.2 |
| Sep | 33.3 | 1.6 | 0.3 | 1.5 | 13.0 | 25.7 | 114.2 | 0.3 |
| Oct | 33.9 | 7.6 | 0.8 | 1.2 | 12.0 | 21.1 | 81.0 | 1.2 |
| Nov | 41.7 | 21.2 | 1.0 | 0.7 | 10.2 | 15.1 | 42.0 | 0.8 |
| Dec | 22.2 | 20.3 | 0.1 | 0.2 | 8.5 | 7.4 | 26.0 | 0.1 |

| Years | Precipitation (mm) | Measured Streamflow (mm) | Simulated Streamflow (mm) |
|---|---|---|---|
| 2008 | 453.86 | 228.74 | 219.65 |
| 2009 | 560.12 | 265.50 | 273.39 |
| 2010 | 629.41 | 256.27 | 329.34 |
| 2011 | 484.14 | 257.11 | 187.05 |
| 2012 | 450.42 | 414.65 | 211.12 |
| **Total** | 2577.95 | 1422.27 | 1220.55 |
| **Average** | 515.59 | 284.45 | 244.11 |

SIMULATED WATER BUDGET FOR THE KABUL RIVR BASIN FORM 2088 TO 2012

| Years | Precipitation (mm) | Water yield (mm) | Evapotranspiration(mm) | ± Losses |
|---|---|---|---|---|
| 2008 | 453.86 | 219.65 | 231 | 3.21 |
| 2009 | 560.12 | 273.39 | 289 | -2.27 |
| 2010 | 629.41 | 329.34 | 296 | 4.07 |
| 2011 | 484.14 | 187.05 | 294 | 3.09 |
| 2012 | 450.42 | 211.12 | 234 | 5.3 |

**Sectoral water demand in (million cubic meters) during 2008- 2012**

| Available water resources and sectoral water demand | | | | | | | |
|---|---|---|---|---|---|---|---|
| Months | Irrigation | Domestic | EFR | Indestrial | Total sectoral water demand | Available water resources exclding Kunar | Available water resources including Kunar |
| Jan | 94.8 | 29.2 | 24.9 | 4.2 | 153.0 | 341 | 556 |
| Feb | 131.2 | 35.0 | 25.7 | 5.0 | 196.9 | 370 | 524 |
| Mar | 227.3 | 35.0 | 37.0 | 5.0 | 304.3 | 857 | 1331 |
| Apr | 234.7 | 37.9 | 104.0 | 5.4 | 382.0 | 1079 | 2020 |
| May | 352.0 | 37.9 | 167.5 | 5.4 | 562.8 | 1467 | 3325 |
| Jun | 545.6 | 40.8 | 355.7 | 5.8 | 948.0 | 760 | 2543 |
| July | 616.0 | 43.8 | 380.3 | 6.2 | 1046.3 | 428 | 1565 |
| Aug | 517.5 | 40.8 | 163.3 | 5.8 | 727.4 | 408 | 1239 |
| Sep | 320.3 | 37.9 | 59.9 | 5.4 | 423.5 | 376 | 848 |
| Oct | 228.8 | 35.0 | 37.0 | 5.0 | 305.8 | 391 | 782 |
| Nov | 204.2 | 32.1 | 30.4 | 4.6 | 271.2 | 414 | 668 |
| Dec | 176.0 | 29.2 | 27.9 | 4.2 | 237.3 | 319 | 552 |
| TOTAL | 3648.5 | 434.6 | 1413.5 | 61.8 | 5558.4 | 7211 | 15953 |
| Percentage | 66 | 8 | 25 | 1 | 100 | | |

**Projected sectoral water demand and available water resources (million m3/month) in the Kabul river basin by (2046 - 2064)**

| Monthls | Irrigation | Domestic | EFR | Indestrial | Total secoral water demand | Available water resources exclding Kunar | Available water resources including Kunar |
|---|---|---|---|---|---|---|---|
| Jan | 132.7 | 108.3 | 24.9 | 8.3 | 274.2 | 343 | 880 |
| Feb | 183.7 | 130.0 | 25.7 | 9.96 | 349.3 | 784 | 1174 |
| Mar | 341.0 | 130.0 | 37.0 | 9.96 | 518.0 | 923 | 1561 |
| Apr | 352.1 | 140.8 | 104.0 | 10.79 | 607.7 | 900 | 1951 |
| May | 598.4 | 140.8 | 167.5 | 10.79 | 917.5 | 336 | 2347 |
| Jun | 927.5 | 151.7 | 355.7 | 11.62 | 1446.5 | 189 | 1744 |
| July | 924.0 | 162.5 | 380.3 | 12.45 | 1479.3 | 150 | 1255 |
| Aug | 827.9 | 151.7 | 163.3 | 11.62 | 1154.5 | 125 | 978 |
| Sep | 480.5 | 140.8 | 59.9 | 10.79 | 692.0 | 117 | 734 |
| Oct | 320.3 | 130.0 | 37.0 | 9.96 | 497.3 | 150 | 668 |
| Nov | 285.8 | 119.2 | 30.4 | 9.13 | 444.5 | 154 | 505 |
| Dec | 246.4 | 108.3 | 27.9 | 8.3 | 391.0 | 168 | 665 |
| Total | 5620.5 | 1614.2 | 1413.5 | 123.67 | 8771.8 | 4340 | 14462 |

7. Projected sectoral water demand compared with monthly water availability in the Kabul river basin using SWAT 2012 model outputs.

| | Available water resource excluding Kunar river 2008 | | | Avilable water resource including kunar river 2008 | | | |
|---|---|---|---|---|---|---|---|
| | water demand | Water yeild | | water demand | Water yeild | | |
| Jan | 153 | 341 | | 153 | 556 | | |
| Feb | 197 | 370 | | 197 | 524 | | |
| Mar | 304 | 857 | | 304 | 1331 | | |
| Apr | 382 | 1079 | | 382 | 2020 | | |
| May | 563 | 1467 | | 563 | 3325 | | |
| Jun | 948 | 760 | | 948 | 2543 | | |
| July | 1046 | 428 | | 1046 | 1565 | | |
| Aug | 727 | 408 | | 727 | 1239 | | |
| Sep | 424 | 376 | | 424 | 848 | | |
| Oct | 306 | 391 | | 306 | 782 | | |
| Nov | 271 | 414 | | 271 | 668 | | |
| Dec | 237 | 319 | | 237 | 552 | | |
| | 5558 | 7211 | | 5558 | 15953 | | |

| | Available water resource excluding Kunar river 2064 | | | Available water resource including Kunar river 2064 | | | |
|---|---|---|---|---|---|---|---|
| | water demand | Water yeild | | | water dema | Water yeild | |
| Jan | 274 | 343 | | | 274 | 880 | |
| Feb | 349 | 784 | | | 349 | 1174 | |
| Mar | 518 | 923 | | | 518 | 1561 | |
| Apr | 608 | 900 | | | 608 | 1951 | |
| May | 918 | 336 | | | 918 | 2347 | |
| Jun | 1447 | 189 | | | 1447 | 1744 | |
| July | 1479 | 150 | | | 1479 | 1255 | |
| Aug | 1155 | 125 | | | 1155 | 978 | |
| Sep | 692 | 117 | | | 692 | 734 | |
| Oct | 497 | 150 | | | 497 | 668 | |
| Nov | 445 | 154 | | | 445 | 505 | |
| Dec | 391 | 168 | | | 391 | 665 | |
| | 8772 | 4340 | | | 8772 | 14462 | |
| | | | | | | | |

8. Mean annual steam flow projection based on SWAT model output

| Mean annual stream flow from (1961 - 2064 ) in the Dakah station | | | | | | |
|---|---|---|---|---|---|---|
| | Global Climate Models | | | | | |
| years | CCCM3.2 | MIROC3.2 | GFDL.CM | CNRM | Average | STD |
| 1966 | 93 | 153 | 368 | 269 | 221 | 106 |
| 1967 | 254 | 198 | 229 | 160 | 210 | 35 |
| 1968 | 164 | 156 | 208 | 108 | 159 | 35 |
| 1969 | 78 | 165 | 242 | 89 | 144 | 66 |
| 1970 | 71 | 401 | 347 | 256 | 269 | 125 |
| 1971 | 253 | 312 | 328 | 445 | 334 | 70 |
| 1972 | 461 | 317 | 401 | 635 | 454 | 117 |
| 1973 | 703 | 238 | 212 | 414 | 392 | 196 |
| 1974 | 415 | 143 | 467 | 322 | 337 | 124 |
| 1975 | 278 | 367 | 226 | 320 | 298 | 52 |
| 1976 | 291 | 201 | 345 | 387 | 306 | 70 |
| 1977 | 357 | 386 | 375 | 215 | 333 | 69 |
| 1978 | 190 | 155 | 296 | 350 | 248 | 79 |
| 1979 | 311 | 191 | 206 | 248 | 239 | 47 |
| 1980 | 257 | 286 | 77 | 238 | 214 | 81 |
| 1981 | 225 | 174 | 157 | 154 | 178 | 29 |
| 1982 | 108 | 272 | 435 | 180 | 249 | 122 |
| 1983 | 149 | 240 | 335 | 284 | 252 | 68 |
| 1984 | 280 | 205 | 395 | 306 | 296 | 68 |
| 1985 | 270 | 222 | 262 | 367 | 280 | 54 |
| 1986 | 358 | 270 | 273 | 327 | 307 | 37 |
| 1987 | 338 | 247 | 176 | 385 | 286 | 81 |
| 1988 | 410 | 167 | 279 | 412 | 317 | 102 |
| 1989 | 390 | 178 | 203 | 180 | 238 | 88 |
| 1990 | 214 | 422 | 391 | 118 | 286 | 125 |
| 1991 | 100 | 113 | 181 | 208 | 150 | 45 |
| 1992 | 201 | 337 | 159 | 238 | 234 | 66 |
| 1993 | 226 | 76 | 216 | 279 | 199 | 75 |
| 1994 | 244 | 570 | 523 | 203 | 385 | 163 |
| 1995 | 169 | 98 | 219 | 243 | 182 | 55 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1995 | 169 | 98 | 219 | 243 | 182 | 55 |
| 1996 | 225 | 165 | 446 | 524 | 340 | 149 |
| 1997 | 544 | 89 | 168 | 478 | 320 | 195 |
| 1998 | 466 | 184 | 22 | 173 | 211 | 160 |
| 1999 | 144 | 398 | 361 | 185 | 272 | 109 |
| 2000 | 144 | 175 | 175 | 175 | 168 | 14 |
| 2006 | 175 | 350 | 350 | 350 | 306 | 75 |
| 2007 | 350 | 215 | 215 | 215 | 249 | 58 |
| 2008 | 215 | 289 | 289 | 289 | 270 | 32 |
| 2009 | 289 | 360 | 360 | 360 | 342 | 31 |
| 2010 | 360 | 182 | 182 | 182 | 227 | 77 |
| 2011 | 182 | 226 | 226 | 226 | 215 | 19 |
| 2012 | 226 | 420 | 151 | 643 | 360 | 191 |
| 2051 | 478 | 346 | 276 | 201 | 325 | 102 |
| 2052 | 165 | 47 | 210 | 165 | 147 | 61 |
| 2053 | 73 | 481 | 255 | 282 | 273 | 145 |
| 2054 | 187 | 287 | 146 | 195 | 204 | 52 |
| 2055 | 235 | 283 | 192 | 104 | 204 | 66 |
| 2056 | 168 | 89 | 167 | 247 | 168 | 56 |
| 2057 | 67 | 150 | 67 | 300 | 146 | 95 |
| 2058 | 176 | 140 | 218 | 329 | 216 | 71 |
| 2059 | 136 | 508 | 272 | 146 | 265 | 150 |
| 2060 | 308 | 95 | 474 | 173 | 262 | 144 |
| 2061 | 221 | 540 | 168 | 431 | 340 | 152 |
| 2062 | 236 | 337 | 149 | 247 | 242 | 66 |
| 2063 | 170 | 198 | 187 | 212 | 192 | 15 |

## 9. Annual renewable fresh water availability assessment based on population growth and climate change scenarios

| Sub-watersheds | Area (sq.km) | Population based on 2015 | Water availibility ($M^3$/person /year) under three scenarios A2 | A1B | B1 |
|---|---|---|---|---|---|
| 1 | 3350 | 44952 | 13609 | 14105 | 13163 |
| 2 | 4228 | 112176 | 5705 | 6269 | 6027 |
| 3 | 2378 | 27725 | 16301 | 17455 | 16756 |
| 4 | 1660 | 41117 | 6022 | 6670 | 6805 |
| 5 | 3093 | 37592 | 15535 | 18303 | 15345 |
| 6 | 2351 | 157116 | 4772 | 5238 | 4558 |
| 7 | 3607 | 452489 | 2664 | 3261 | 2713 |
| 8 | 4283 | 434924 | 1475 | 1705 | 1674 |
| 9 | 845 | 597546 | 288 | 334 | 272 |
| 10 | 3766 | 169532 | 3184 | 3780 | 3751 |
| 11 | 1854 | 93071 | 2760 | 2862 | 3044 |
| 12 | 1531 | 169521 | 840 | 823 | 898 |
| 13 | 4516 | 337335 | 2461 | 2811 | 3097 |
| 14 | 248 | 100233 | 223 | 239 | 222 |
| 15 | 4348 | 470089 | 953 | 1128 | 1093 |
| 16 | 81 | 15471 | 395 | 395 | 480 |
| 17 | 883 | 520620 | 136 | 150 | 141 |
| 18 | 2197 | 394457 | 423 | 472 | 488 |
| 19 | 3173 | 6426724.8 | 46 | 53 | 51 |
| 20 | 1615 | 274077.8 | 459 | 464 | 492 |
| 21 | 1949 | 237273 | 578 | 751 | 671 |
| 22 | 4104 | 762492 | 390 | 417 | 378 |
| 23 | 9144 | 776905 | 735 | 852 | 850 |

| Sub-watersheds | Area (sq.km) | Population based on 2064 | Water availibility ($M^3$/person /year) under three scenarios | | |
|---|---|---|---|---|---|
| | | | A2 | A1B | B1 |
| 1 | 3350 | 73426 | 999 | 1036 | 966 |
| 2 | 4228 | 183231 | 1045 | 1149 | 1104 |
| 3 | 2378 | 42582 | 694 | 743 | 713 |
| 4 | 1660 | 67161 | 404 | 448 | 457 |
| 5 | 3093 | 61404 | 954 | 1124 | 942 |
| 6 | 2351 | 116025 | 554 | 608 | 529 |
| 7 | 3607 | 412637 | 1099 | 1346 | 1119 |
| 8 | 4283 | 710414 | 1048 | 1211 | 1189 |
| 9 | 845 | 976044 | 281 | 326 | 265 |
| 10 | 3766 | 276917 | 882 | 1047 | 1039 |
| 11 | 1854 | 152024 | 420 | 435 | 463 |
| 12 | 1531 | 276899 | 232 | 228 | 249 |
| 13 | 4516 | 551010 | 1356 | 1549 | 1707 |
| 14 | 248 | 163723 | 36 | 39 | 36 |
| 15 | 4348 | 767853 | 732 | 866 | 839 |
| 16 | 81 | 25271 | 10 | 10 | 12 |
| 17 | 883 | 850392 | 115 | 128 | 120 |
| 18 | 2197 | 644314 | 273 | 304 | 315 |
| 19 | 3173 | 10497548 | 488 | 552 | 538 |
| 20 | 1615 | 447685 | 205 | 208 | 220 |
| 21 | 1949 | 387567 | 224 | 291 | 260 |
| 22 | 4104 | 1245471 | 485 | 520 | 471 |
| 23 | 9144 | 1269013 | 933 | 1081 | 1078 |