Kabul Polytechnic University

Water Resources & Environmental Engineering Faculty

MS Board

Investigation of Climate Change Impact Using Water Balance Model for Water Infrastructures & Adaptation Development in Maidan-Kabul River Basin, Afghanistan

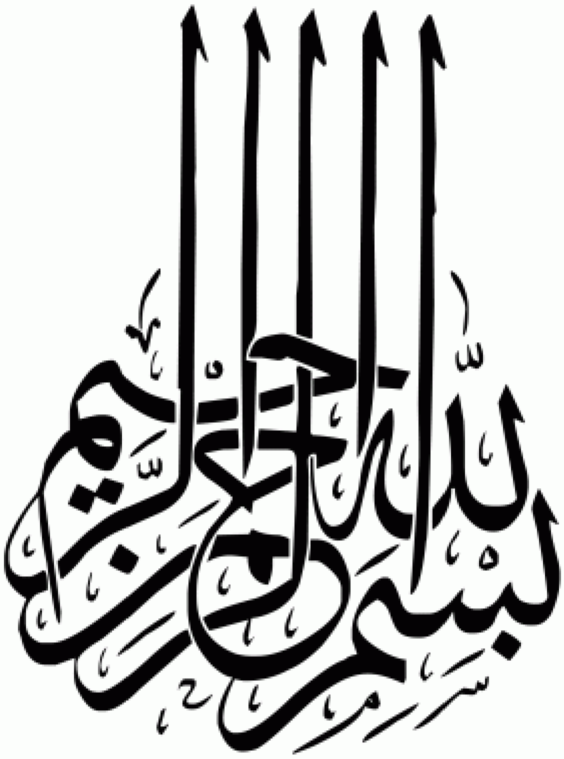
بررسی تغییرات اقلیم با استفاده ازمودل بیلانس آبی برای ساختمان های آبی و توسعه سازگاری آن در حوزه دریایی کابل – میدان

Thesis Submitted in Partial Fulfillment of the Requirements for The MSc Degree in Hydraulic Structures

Researcher: Mohammad Najim Nasimi

Supervised by: Prof Dr. Mohammad Qasim Seddiqy & Prof Jay Sagin

Year: March 2019 (1397)


بسم الله الرحمن الرحيم

Research Topic:

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Researcher: Mohammad Najim Nasimi

Thesis jury committee members confirmed his thesis and research.

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NAZARBAYEV
UNIVERSITY
SCHOOL OF ENGINEERING

Letter of Recommendation

Kabul Polytechnic University

Water Resources & Environmental Engineering Faculty MS Board

Dear Board Committee,

I am writing this letter to give my highest possible recommendation for Mr. Mohammad Najim Nasimi. Thanks to the support and cooperation programs with CAREC, https://carececo.org/en/main/, German-Kazakhstan University, CAJWR, https://www.water-ca.org/, USAID PEER Kabul River Basin Research project, www.ckrb.org, I have been involved as a Supervisor for Mr. Mohammad Najim Nasimi in his thesis research work “Investigation of Climate Change Impact Using Water Balance Model for Water Infrastructures & Adaptation Development for Maidan-Kabul River Basin, Afghanistan”. Mr. Mohammad Najim Nasimi has showed himself as a promising young researcher demonstrating excellent modeling skills and deep knowledge of remote sensing and GIS techniques. Mr. Mohammad Najim Nasimi consistently demonstrates excellent analytic skills with strong written and oral expression. Mr. Mohammad Najim Nasimi is a hard-working and creative Reseacher. Mr. Mohammad Najim Nasimi has shown himself as a responsible and knowledgeable resercher; he was able to prepare the excellent thesis research work. Mr. Mohammad Najim Nasimi has showed high responsibilities of working on the dedicated research work activities and managed to prepare everything on time.

Given his great intelligence and diligence, I am sure that he could be defending his research work properly. Mr. Mohammad Najim Nasimi has an excellent vision what he would to do and how he would like to develop academically. I enthusiastically endorse Mr. Mohammad Najim Nasimi’s MS thesis and very much hope that the Board committee will be favorable.

Please feel free to contact me with any further questions at zhanay.sagintayev@nu.edu.kz

Sincerely,

Jay Sagin
Professor, School of Engineering, Nazarbayev University

6 March 2019

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Mohammad Najim Nasimi   Date

The above candidate has carried out research for the Master's thesis under my supervision.

……………………………..   ……………………………

Prof Mohammad Qasim Seddiqy   Date

This Thesis is gratefully dedicated to my family.

For their endless love, support and encouragement

بررسی تغییرات اقلیم با استفاده ازمودل بیلانس آبی برای ساختمان های آبی و توسعه سازگاری آن در حوزه دریایی کابل – میدان

چکیده

تغییرات اقلیم در افغانستان در دهه های اخیر یک موضوع چالش برآنگیزبوده که بالای سکتورهای مختلف کشور منجمله آب، زراعت، انرژی و تنوع زیستی تاثیرات مختلف گذاشته است. مطالعات تغییرات اقلیم به نسبت کمبود ارقام، مودل ها، متخصصین و سایر منابع دیگر به شکل گسترده آن مورد مطالعه و ارزیابی قرار نگرفته است. چنانچه توسعه زیرساخت های آبی، تأمین دوامدار غذا و امنیت اقتصاد و طبیعت مستلزم مطالعات تغییرات اقلیم میباشد. تحقیق ذیل تغییرات اقلیم را در قسمت حوزه دریایی فرعی میدان کابل بالای منابع آب و فاکتورهای اقلیمی برای دریافت راه حل ها، مورد مطالعه قرارمیدهد. تحقیق ذیل برای پالیسی سازان و تصمیم گیرنده ها این امکان را فراهم مینمایید تا اقدامات مناسب و عملی را برای پاسخ به تغییرات در بخش های زراعت، منابع آب و سایر بخش های ذی دخل دراین حوزه بردارند. اهمیت این تحقیق برای تعیین حجم آب در تحت شرایط تغییرات اقلیم بادرنظرداشت سنا ریو های متوسط و خطرناک در خصوص بند ذخیره وی شاتوت که در قسمت پایینی این حوزه اعمار میگردد اهمیت حیاتی دارد.

تحلیل روند تاریخی منابع آبی و فاکتورهای اقلیمی در طول سال های (2017-2009) به جز مقدارجریان که ارقام تاریخی سال های (1961-1980) نیز موجود است به مقایسه گرفته شده است. چنانچه مودل هایدرولوژیکی بخاطر پیش بینی وضعیت آینده یک بخش مهم مطالعه تغییرات اقلیم رانشان میدهد دراین تحقیق از مودل هایدرولوژیکی (HEC-HMS) با الگوریتم SCN واندیکس درجه حرارت و استفاده از مودل بیلنی کریدل برای شبیه سازی تبخیر وتعرق مورد کارگرفته شده است. دراین مودل از ارقام بازنده گی، مقدار جریان و درجه حرارت روزانه به مدت نه سال که از سال 2009-2013 م در مرحله تنظیم مناسب سازی مودل و ازسال 2014-2017 م در مرحله کنترول وتایید مودل مورد استفاده قرارگرفته است. جهت ارزیابی منابع آبی و وضعیت آب وهوا، درجه حرارت وبارنده گی بااستفده از مودل GCM ودوسناریوی متوسط (RCP 4.5) و خطرناک (RCP 8.5) برای سال های (2010-2039)، (2040-2069) و(2070-2099) پیش بینی گردیده است. برعلاوه اقدامات سازگاری با تغییرات اقلیم با استفاده از تحقیقات قبلی و بازرسی ساحه پیشنهاد شده است. همچنان حجم آب تخمین شده بنده شاتوت بادر نظر داشت تغییرات اقلیم مورد بررسی قرارگرفته است.

نتیجه تحلیل روند تاریخی مقدار جریان نشان دهنده تغییردر پیک مقدار جریان از ماه می به ماه اپریل را در مقایسه به سال 1961 نشان میدهد. برعلاوه، روند درجه حرارت نشان دهنده تمایل بطرف گرم شدن بیشتر را بخصوص در فصل زمستان درمقایسه با تابستان دارد. نتایج مرحله مناسب سازی و کنترول مدل از نقطه نظر هایدروگراف، منحنی تکراری، بیلانس آبی و تحلیل احصائیوی نشان میدهد که مقدار جریان اندازه شده با مقدار جریان شبیه سازی شده نزدیکی بسیارزیاد دارد. بارنده گی پیشبینی شده تحت هر دو سناریوی (RCP4.5 & RCP 8.5) افزایش را در سال های نزدیک (2010-2049)َ، در فصول زمستان و بهار نشان میدهد. همچنان درجه حرارت پیش بینی شده نشان دهنده افزایش از دمای 1.9 الی 5 درجه سانی گیراد را الی اخیر این قرن به نمایش می گذارد. تحلیل مقدار جریان همراه با سایر فاکتورهای اقلیمی نشان میدهد که الگوهای بارندگی از شکل جامد (برف) به شکل مایع (باران) برای سال های 2040 و بعد از آن تغییر خواهد نمود. برعلاوه این تحقیق نشان میدهد که حجم مقدار جریان در طول سال های 2010-2039 تحت هردوسناریوی موجود افزایش و متعاقباً کاهش میابد.

به صورت عموم از این تحقیق نتیجه گرفته میشود که بلند رفتن درجه حرارت و تغییرات در الگوهای بارندگی تأثیرات مخرب را بالای سکتورهای زراعت و تنوع حیه بجا خواهد گذاشت. روی این ملحوظ لزوم ضرورت به اتخاذ تدابیر عملی در جهت کاهش اثرات و انطباق پذیری به آن است. بیشترازآن، این تحقیق میتواند با استفاده از ارقام بارند گی را دار و براه اندازی سروی های ساحوی توسعه پیدا نمایید.

کلمات کلیدی: پیش بینی درجه حرارت و بارند گی، مودل هایدرولوژیکی آب، روند تاریخی آب وهوا، بند شاتوت، مقدار جریان

Investigation of Climate Change Impact Using Water Balance Model for water Infrastructures & Adaptation Development for Maidan-Kabul River Basin, Afghanistan

ABSTRACT

climate change over Afghanistan in the recent decades is a serious issue which is affected different sectors including water, agriculture, energy and biodiversity ecosystem. Climate change studies is not conducted in broader manner across Afghanistan due to many constraints including of data, models, experts and other resources. Developing future water infrastructures, sustaining food, environment and economic security needs climate change studies. This research wok conducted to evaluate the impact of climate change on Maidan-Kabul river basin respect to water resources and climate factors for giving proper solutions. The research work will help decision makers and planners to take appropriate action of adaptations in response to climate change effect on agriculture and other main stakeholders. Shahtoot reservoir is supposed to build at the downstream of basin which this research work is very critical in determining the water availability under mid and extreme anticipated climate scenarios to the end of this century.

Trend analyses of water resources and climate factors are evaluated for last decades (2009-2017) except the streamflow which historical data of (1961-1980) was available compare with the present situation. Hydrological modeling is a requisite part of study for predicting the future water resources and climate factors. The HEC-HMS model with SCN algorithm and Temperature Index algorithm along with beleny Kriddle formula for calculating evapotranspiration is used for the hydrological modeling. Precipitation, temperature and streamflow from 2009-2013 is used for calibration and from 2014-2017 for verification. Forecasted precipitating and temperature using the GCM models for the RCP 4.5 and RCP 8.5 scenarios are used for future (2020s, 2050s and 2080s) climate and water resources assessment. Suitable adaptions based on literatures and filed visits is studied and the water availability is compared with normal volume of Shahtoot reservoir.

The result of historical analysis indicates that streamflow peak is shifted from May to April from 1961 to present. In addition, the temperature trends reveal that winter temperature is more rapidly increasing compare to summer. The HEC-HMS model calibration and results for lumped and distributed model indicates a good match respect to hydrograph, flow duration curves, water balance and statistics. Forecasted precipitations show increases of precipitation during winter and spring seasons in near future (2010-2040) under both RCP 4.5 and 8.5 scenarios. Similarly, forecasted temperature shows increase of temperature from 1.9 up to 5℃ to the end this century. The analysis of streamflow combined with climate factor indicates that precipitation pattern is changed to liquid during summer for the 2050s and later. It also predicated increase in water volume by 2050s and decrease after 2050s under both scenarios.

It can be concluded that increase in temperature and change in perception patterns will have wide effect to agriculture and biodiversity. Taking practical actions on implementing adaptations measures is requisite. further this research can be extended with using radar precipitation data and extensive field visits.

Key words: Temperature & precipitation forecast, HEC_HMS model, climate Historical trend, Shahtoot Dam, streamflow.

ACKNOWLEDGEMENTS

First and foremost, I am thankful to the God for giving me the strength, knowledge, ability and opportunity to undertake this research study and to persevere and complete it satisfactorily.

I would like to express my deep gratitude to my thesis advisor Professor Mohammad Qasim seddiqy, for his continuous support in my Postgraduate studies. I am grateful for knowing such a knowledgeable, patient, humble and helpful mentor in my life.

My sincere thanks also goes to Assistant professor Dr Jay Sagin for his support and guidance and for his advices, for his patience, motivation and immense knowledge. His guidance helped me all the time of research and writing of this thesis.

I also would like to acknowledge my thesis committee, Prof Mohammad Nasim Nasimi dean faculty of environmental & water resource engineering for his support, advice, guidance and necessary support to accomplish my research work. I am also thankful of my teachers Prof Dr Mohammad Asif, Professor Dr Mohammad Anwar Safi, Professor Dr Mohammad Imam Alimi for their help. I take this opportunity to express gratitude to all of faculty members of the environmental & water resources engineering faculty for their help and support.

My sincere thanks also goes to Professor N.T.S. Wijesekera and Dr.R.L.H Lalith Rajapaksa which I learned from them a lot through my professional and personal life.

I place on record, my sincere thanks go to ministry of water and energy Afghanistan, CAREC and CAJWR for their technical assistant.

Last but not the least; I would like to thank my family for providing me with unfailing support and continuous encouragement through my life.

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1 INTRODUCTION

1.1 General

Afghanistan is a country with many water resources from snow, rainfall, glaciers, lakes and springs. Over 80 percent of the country's water resources have their origin from Hindu Kush mountain ranges at altitudes above 2,000 m, the total of this resources are estimated 75 billion cubic meters (BCM), which 55 BCM is surface water and 20 BCM is groundwater (Qureshi, 2002). Traditionally, these resources are used for the drinking, houses, agriculture and industry purposes. It estimated that 80% of the people livelihood are dependent on natural resources which water reserve is a valuable resource for this people. Agriculture is the most important source of the income and play a major role in the life of the people (Poole, Amira, Amiri, & Farhank, 2019). Due to lack of water storage infrastructures in this country, most part of agriculture is rain fed and some little part of that are irrigated. People are relying to very traditional system of agriculture which directly diverting the water from the river and using it without knowing the proper requirement of the crops needs.

Traditionally, the water resources management in Afghanistan is almost relying to the natural trends which historical evidence suggest that it's under the threat of severe drought and floods incidences. Building infrastructures are used very rarely in the era of water management in this country which some part of these infrastructures are damaged due to civil war. It is clear that any management of water required a wide study and researches in hydrology fields to quantify the real amount of water and sediments prior to any decision making. New challenges of climate make difficult to conduct hydrology studies without considering the future and possible scenarios of floods, drought or any kind of change in the climate variables. It is the fact that hydrological modeling is a pre requisite for any of these studies and a good hydrological modeling need a broader survey and study. Further the appropriate hydrological model has to well calibrate and verified to acquire the optimum certainty and assurance.

Afghanistan has the potential of 23,000 MW renewable energy from the hydropower (world bank, 2018) which utilization from this resources needs critical and broader studies. Potentially, building of reservoirs, hydropower stations, irrigation canals will have potential to change the view of this country to a developed country. The current economy of this country is almost relying on the natural resources and agriculture but the studies is conducted by U.S. scientists indicates that Afghanistan raw mine are near to cost $1 trillion. which almost the same of the oil reserves of Saudi. Utilization of these mine resources requires adequate energy which hydropower plants has this potential to change this country into an industrialized country of the world.

For cultivation of diverse crops and fruit trees, this country has very suitable climate and soil reserves that needs adequate water, especially during summer season. In another hand, early melting of snows is a challenge to agriculture sectors which leads to shortage or dried up of rivers. Managing the water resources in this country has potential impact on agriculture, mine and industry sectors. This will pave the ground to improve the economy and decrease the level of poverty. As a result of that, it will provide sufficient job and opportunity that will add to the peace and stability not only in the Afghanistan but in the whole region.

Drinking water is a key factor for a healthy life and move toward the stable society. Recently, due to increase of population and urbanization in different cities of Afghanistan specially in the Kabul city, access to the drinking water is one of the major problem for their inhabitants. Primary, the main source of drinking water is the ground resources which according to new surveys, the level of water is swiftly decreased in recent years. In addition to that, the quality of this water is matter of question due to existence of absorb waste water wells which in most part of this city, the use of this source without proper treatment is not hygienic. Insecurity and jobless in most part of the country and reoccurring of droughts lead the people to migrations to main cities. Using the surface water resources is potential alternative that after treatment could response to concerns of drinking water.

In addition, building infrastructure is one of the primary key solution for the mentioned issues in providing drinking water, electricity, agriculture and industries. According to ministry of water and energy, Afghan government has plan to build many small and big reservoirs across the rivers which one of them is the Shahtoot reservoir and it is supposed to build at Lalandar in the outlet of Maidan-Kabul river basin. The primary goal of this reservoir is for recharging the groundwater, controlling flood and providing water for the irrigation purpose in the downstream part of Kabul city. The water in this river is originated from snow accumulation during the winter season and very less storage of glaciers. Before reaching to the Tang-i-Saidan the water of this river is utilizing for variety of purposes such as drinking and agriculture purposes. During the month of May and April due to swiftly melting of snow and forming a big peak of runoff sometimes lead to floods. Managing this water by building a reservoir will manage this huge amount of water and will release it slowly to downstream for controlling flood and environmental management.

The new uprising phenomena which has not considered in past in water management sectors is the climate change. An increase in the levels of GHGs (greenhouse gases) can lead to greater warming, which, in turn, can influence the world's climate, leading to the climate change (Vijayavenkataraman, Iniyan, & Goic, 2012). Climate change is defined as the change on the overall climate variables in the long terms, these change will include the temperature, humidity, wind and precipitation that can potentially effect to water resources. Number of evidence in many corner of the world like in Columbia River basin shows that trend of increase in temperature (Rana, Moradkhani, & Qin, 2016). The situation and state of water in Afghanistan in the face of obvious climate change is exceedingly serious (Shroder, 2014). Recent facts and studies in Afghanistan reveals that the amount of water is decreases while the temperature and evapotranspiration has increasing. The most prominent alteration of climate change sign is vivid in the decrease of glacier's amount and increase of the lakes based on satellite maps across the Hindukush-Pamir mountains.

The proper adaptation and water resource management strategies for combating to mitigate the effect of climate change is requisite. This requires to conduct studies in field of climate change that using of hydrological models and possible climate scenarios are among the requisite part of the study. In the Afghanistan river basins very less hydrological models are used which using the appropriate model in exist of of variety of models requires extensive investigations. It has many reasons such us lack of access to field, experts but the most prominent reason is lack of sufficient and reliable data which make the modeling process is very tough. Studying the future climate effect on water resources is only possible through hydrological modeling by using of climate scenarios. It has been suggested that comprehensive global climate models are the only tools that account for the complex set of processes which will determine future climate change at both a global and regional level (Murphy et al., 2004). It requires to downscale these scenarios for the study area and applied it to hydrological models for analyzing of the future condition of water resources.

Base on the climate and geographical the water resources are interconnected between groundwater, snow and glaciers that selecting of a very good hydrological model according to that is a challenge work. Mathematical modeling which is a direct relation between precipitation and streamflow seems very difficult to apply in these river basins. Some complicate models have recently applied in some catchments like SWAT and J2000 but the results are not very sufficient. Due to existence of variety of models it need a critical investigation to find a suitable model.

In this study, climate change impact has studied in the Maidan-Kabul river basin. The reason for selecting this catchment is the closeness to the Kabul city and sensitivity of the climate change in this river basin. In addition to that, constructing of Shahtoot reservoir at the outlet of this river basin, increases the importance of this study. For conducting this research first, the historical trend of climate and water resources is studied, subsequently, hydrological modeling is carried out, climate scenarios are studied and applied to model and further adaptation measures are developed and suggested. The result of this study will contribute in enriching the information regarding the future climate of Kabul and will help future scientist and researchers to study and develop climate change researches across Afghanistan. In addition to that, this research work will help the decision makers to take appropriate actions for mitigating the effect of climate change in this river basin.

1.2 Problem statement

Climate change is the critical topic that can impose threat to future water infrastructures if this study is ignored. There is a big concern that if the climate change factors are not considered for the future water projects like reservoirs and bridges will be under the sever threat of unexpected hydrological events such as floods and droughts. Therefore, it is a matter of question that how the hydrologic regimes of rivers will response to the climate change phenomena. And how the future hydraulic structures will build to safely pass any devastating flood events and functions normally under the drought conditions. Beside of that, a proper hydrological model is a necessity that can model the catchment properly that could be applying of any future scenario will be possible. In this study the Shahtoot reservoir which is located across the Maidan Kabul river a sub basin of Kabul river basin is matter of question respond to climate change. The HEC-HMS model due to its free availability and suitability is selected for studying the possible climate change scenarios that could be a great help for building of Shahtoot reservoir and any relevant reservoirs in the future.

1.3 Objective of the study

The objective of this study is split out into the overall and specific objective that will be discussed in below:

1.3.1 Overall objective

The overall objective of this is to study the effect of climate change and the respond of future climate and water resources to possible climate change scenarios for infrastructure and adaptation development in Maidan-Kabul river basin, Afghanistan.

1.3.2 Specific objectives

1- Studying the impact of climate change using the historical data.
2- Streamflow simulation
3- Developing the future climate change scenarios
4- Assessment of water resources and climate under the climate change scenarios
5- Studying the possible adaptation measures
6- Recommendation for the mitigation climate change effect and future studies.

2 LITRATRURE REVIEW

2.1 Climate change in Afghanistan

Afghanistan as one of the fragile states which vulnerability of population to weather and climate variability is typically much higher compare to other countries. These countries, and their populations, face a higher exposure to climate change as a result of their geography. As such, climate change poses a significant challenge to the transition of fragile states toward peace and stability (Mason, Kruczkiewicz, Ceccato, & Crawford, 2015). Global climate change will likely have severe impacts in Afghanistan. Even an “optimistic” scenario with limited Green House Gas (GHG) emissions (RCP 4.5) is projected to lead, with high certainty, to strong warming (Aich & Khoshbeen, 2016). Afghanistan GHG total emissions are below the World median of 40.4 Mt CO2 e. The country contributes only 0.06% of the World GHG total emissions but it’s among the world most vulnerable country to climate change. Its emissions have doubled since 1995 (Thomas, 2016).

Studies conducted by UNDP indicates from 1960 to 2003 in Afghanistan that Mean annual temperature has increased by 0.6°C since 1960. Similarly, the average number of ‘hot’ days per year has increased by 25, the average number of ‘hot’ nights per year has increased by 26, the average number of ‘cold’ days per year has decreased by 12 and Mean rainfall over Afghanistan has decreased slightly (at an average rate of 0.5mm per month (or 2%) per decade)(McSweeney, New, & Lizcano, 2003). In the same manner, in another study, in analyzing the future and past climate change of Afghanistan using the regional climate downscaling experiment (CORDEX) indicates increase in temperature by 2050 from 1.7-2.3℃ and afterwards even 2.7-6.4℃. it also shows temperature has increased substantially higher than in the global mean, amounting to 1.8℃ between 1951 and 2010. This change will enhance drought, hazard related to runoff such as landslides, floods, and flash floods are likely to be enhanced (South et al., 2017).

Study the impact of climate change on the transboundary of Kabul river basin from 2001-2016 indicates change in cryosphere spatio-Temporal variability from 2001-2016. Rising temperatures due to climate change causes snow and glaciers to melt rapidly. It was found during daily analyzes in the snow covered area data, significantly increasing trend in the lowest and middle elevation but the highest elevation zone showed a negligible decreasing trend. similarly, seasonal and annual analysis indicates slight increasing trend in annual volume basis (Masood, Zia, & Haris, 2018). Another study in this river basin is conducted for future climate change project. This study used multi-model ensemble of NEXGDDP for the historical period (1975–2005) that captures the spatial patterns of both temperature and precipitation in accordance with the observational data set. The result indicates increase of temperature by 3.2℃ under RCP 4.5 and 5.8-6.8 ℃ under RCP 8.5 by the end of this century. In addition, the result projection precipitation indicates uneven distribution of precipitation across the basin under both emission scenarios. This result is also add that change in precipitation pattern and along with an increase in warming, may induce frequent occurrences of flash floods and affect streamflow dynamics (Ahsan et al., 2018).

The Amu Darya’s watercourse serves as an international border between Tajikistan and Afghanistan and between Uzbekistan and Afghanistan that feeding the Aral Sea with a flow of about 70 cubic kilometers per year on average. Before 1960, the Aral Sea was the fourth-largest body of water on Earth. Today, it is on the edge of extinction. The sea is fed by Central Asia’s two major rivers the Amu Darya and the Syr Darya (Glantz, 2005). Among the climatic factors, evaporation plays a leading role in the formation of water problems in Central Asia. It contributes to the expenditure of large quantities of water from the surfaces of natural and artificial water bodies and irrigated lands. The evaporation amount in the main irrigated fields/zones of Central Asia reaches 1500–2000 mm/year (Abuduwaili et al, 2019).

As two third of active population of the country depends on agriculture, more than half of Afghanistan’s population suffers during droughts. Almost 85% of all crops in the country are obtained through traditionally irrigated farming. Since 1978, the irrigable area has almost decreased by 60% (Nasrati, 2018). Agriculture is the most important water related sector in Afghanistan and is facing climate change related problems which this put pressure on farming activities, crop patterns, and other resources. A survey by aimed to understand the farmers’ perceptions about climate change and the measures taken by them conducted in two district of Afghanistan: Shkardara in Kabul province and Watapoor in Kunar province. The results indicate that rice has completely vanished in Shakardara while there is not much change in Watapoor’s crops. Wheat, barley, and maize are the main crops for both selected districts (Ghulami, 2018).

2.2 Climate trends in Afghanistan

A study of average monthly rainfall and minimum and maximum temperatures from 1951 to 2009 (CCAFS, 2014) reveals (Figure 2-1) that the average monthly rainfall between October and June has reduced by up to 15 millimeters (0.039 inches) per month in the eastern Nangarhar province compared to just 1 millimeter per month in the southern provinces of Kandahar and Helmand. The average reduction in precipitation during these nine months has been about 100 millimeters for eastern Paktiya and Kabul provinces. Increase in mean minimum and mean maximum temperature has been about 2 degrees Celsius for Badakhshan, Ghor, Helmand, Herat and Kandahar provinces (Sharma, Sonder, & Sika, 2015).

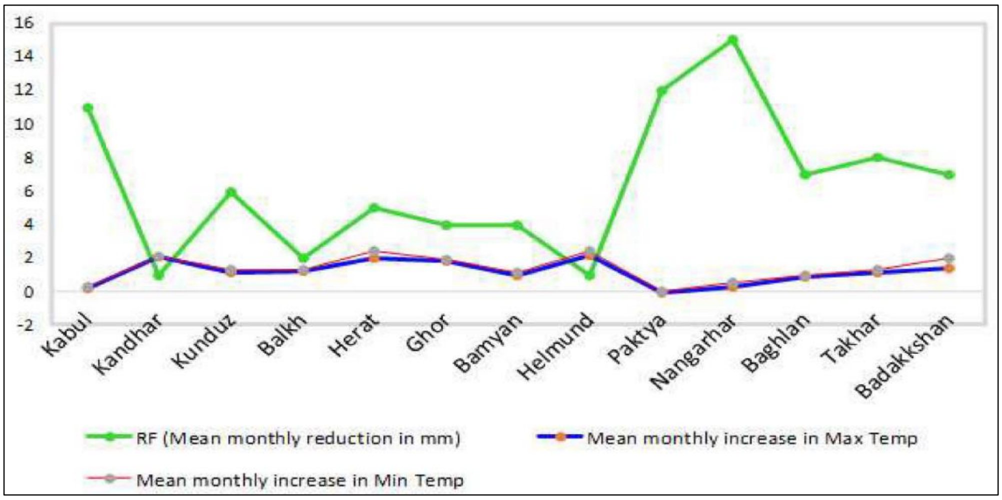


Figure 2-1 Change in rainfall (RF) and temperature (℃) averages of 2001-2009 compared to 1951-1960 averages at different research stations of Afghanistan

Source: (Sharma et al., 2015)

Afghanistan population living far from rivers beside of using directly from streamflow, they rely upon groundwater delivered from karezes (sub-horizontal tunnels). This Karezes are recharged mainly from snow melts, since the multi-year drought that began in 1998, many karezes have stopped flowing. An assessment of a six-district region within Kandahar Province where karezes are the most likely source of water indicates that water demand could have caused water tables to decline by 0.8–5.6 m, more than enough to cause karezes to stop flowing (Macpherson, 2015).

The changes compared between past (1961-1991) and recent (2003-2007) mean monthly temperature in Kabul is presented in Figure 2-2. The graphs indicate a general warming trend throughout the year between the earlier and recent periods. The strongest warming effect are +5°C in February and +3°C in March. similarly, the warming trend in the mean February temperature for 1970-2006 at Kabul, Afghanistan presented in Figure 2-3 (Mack et al., 2010).

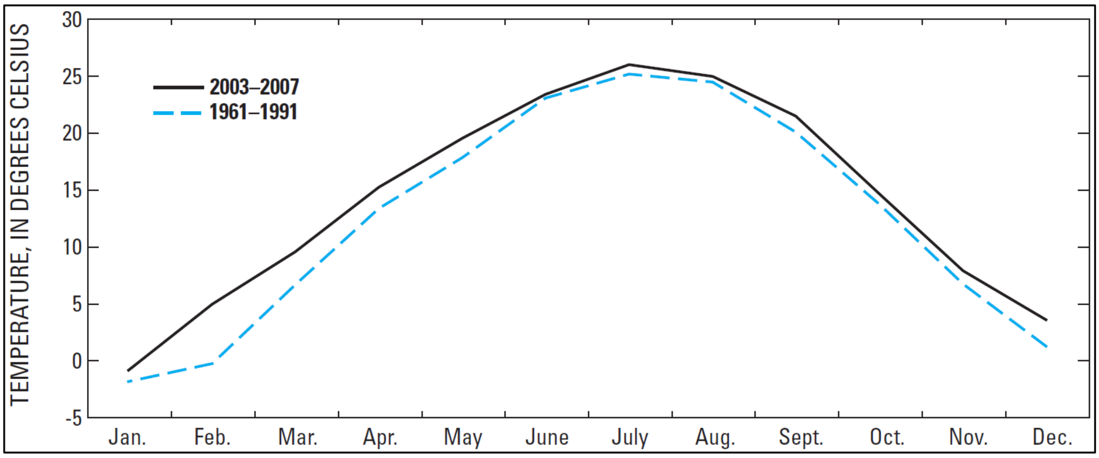


Figure 2-2 Increase in mean monthly temperatures from 1961-1991 to 2003-2007

Source: (Mack et al., 2010)

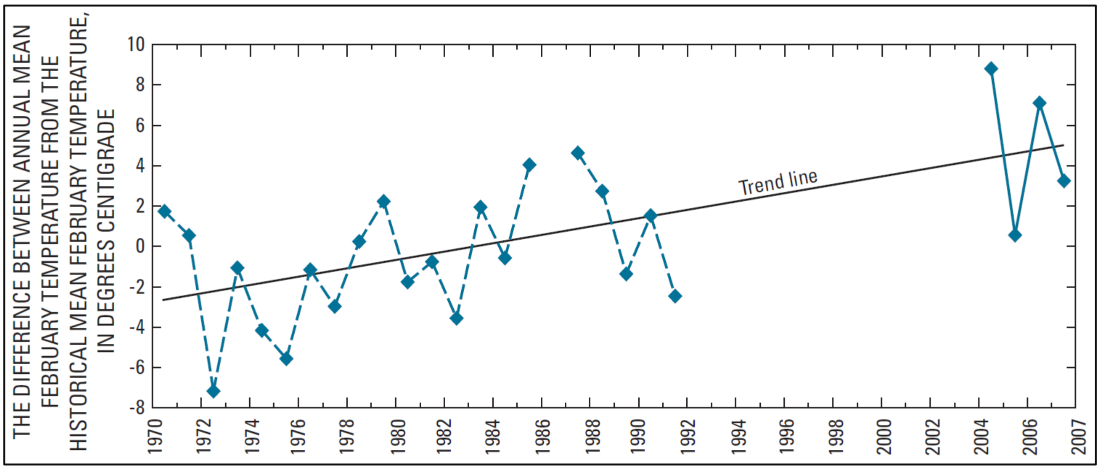


Figure 2-3 warming trend in the mean February temperature for 1970–2006 at Kabul, Afghanistan

Source: (Mack et al., 2010)

The ground water level trends are examined in two different palace of Kabul basin at Shamali in north of Kabul and in the city of Kabul. This study examined groundwater levels in the Kabul river basin from 2004 to 2012. the Kabul river basin as a result of normal precipitation after the drought of the early 2000s. although The rate of groundwater-level decrease in the city is greater for the 2008–2012 period (1.5 meters per year (m/yr) on average) than for the 2004–2008 period (0–0.7 m/yr on average). The trend is presented in Figure 2-4 this result suggests that this changes may be as a result of climate change and increasing in population(Mack et al., 2010).

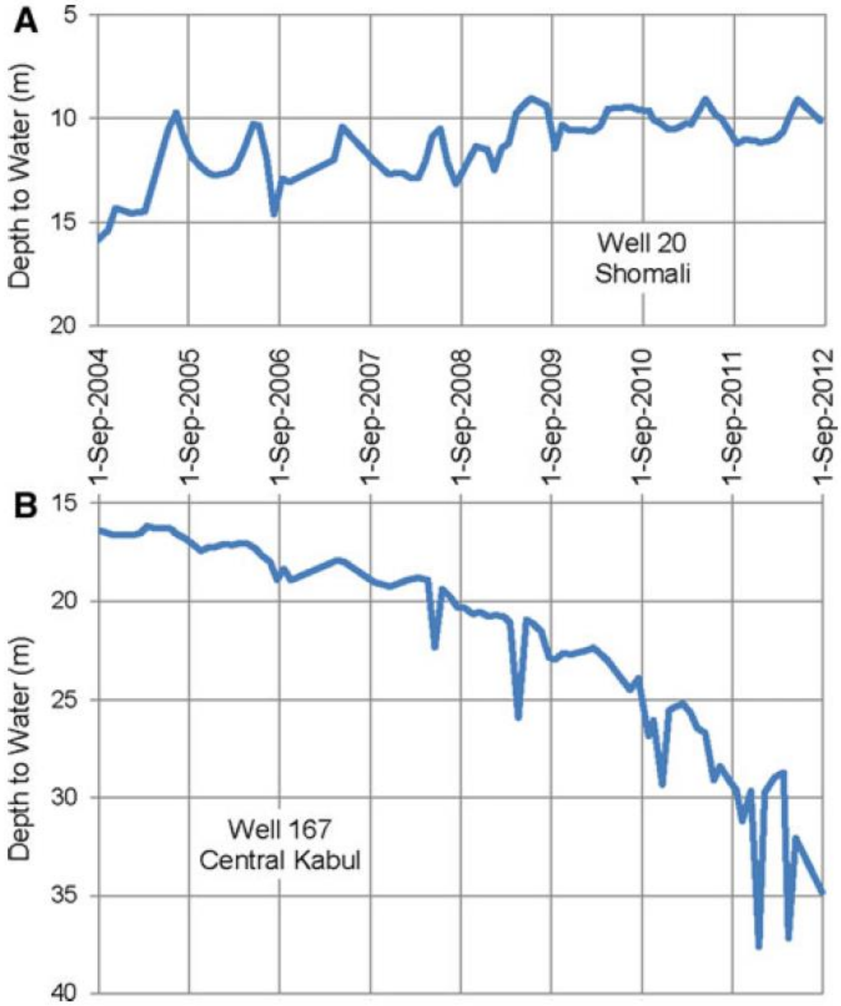


Figure 2-4 Monthly depth to water at Afghanistan Geological Survey wells a 20 and b 167 from September 2004 to 2012 in the Kabul Basin, Afghanistan

` Source: (Mack et al., 2010)

2.3 Watershed modelling

Watershed modelling, or hydrologic simulation (sometimes termed rainfall-runoff modelling) began in the 1950s and 1960s with the advent of the digital computer. Watershed models simulate natural process of the flow of water, sediment, chemicals, nutrients, and microbial organism within watersheds, as well as quantify the impact of human activities on these processes. Simulation of these processes plays a fundamental role in addressing a range of water resources, environmental and social problems. The current generation of watershed models is quite diverse and varies significantly in sophistication and data and computational requirements. Today it’s difficult to think of a environmental or water resources problem whose solution does not involve application of some kind a watershed model (Singh & Frevert, 2006).

The American Society of Civil Engineers (ASCE) introduced the basic terms for various types of mathematical model, namely analytical models; deterministic models; dynamic models; empirical models; heuristic models; interactive models; linear and nonlinear models; numerical models; probabilistic (stochastic) models; semi-empirical models; simulation models and theoretical models (Jajarmizadeh, Harun, & Salarpour, 2012). However, comprehensively, hydrological models described by one or more terms are mostly mathematical structures from four basic categories, namely simulation basis, spatial representation, temporal representation and method of solution (Davie, 2002).

Chow et al.(1988) stated that hydrological models can be classified into two major categories, namely physical models and abstract (mathematical) models. Furthermore, physical models can be divided into two classes again, namely scale models and analog models presented in Figure 2-5. A scale model can be called as a scaled down model of a real system and on the contrary, an analogue model applies physical system having the same characteristic with the first sample this presented in Figure 2-6. Shaw (1994) considering mathematic structures hydrological models divided broadly in two categories, namely deterministic and stochastic presented in Figure 2-6.

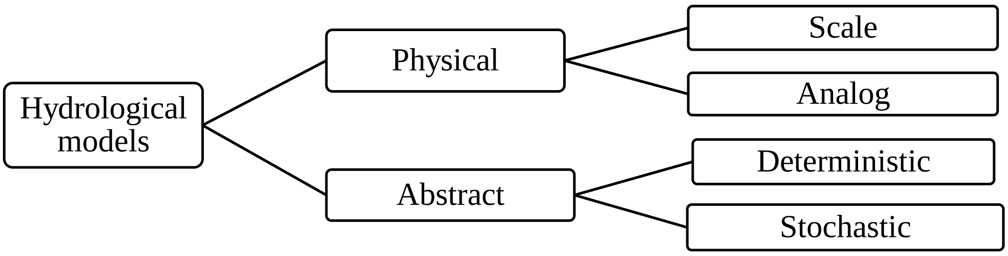


Figure 2-5 Classification of Mathematical modes according to chow et al. (1994)

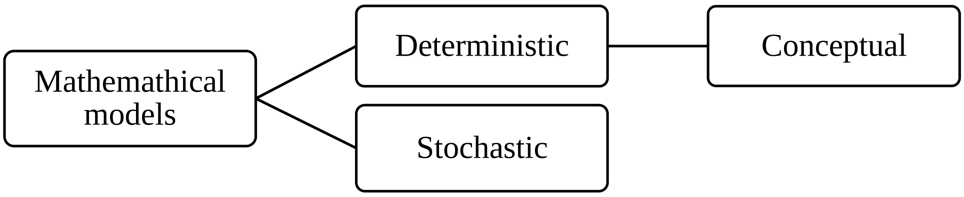


Figure 2-6 Classification of Mathematical modes according to Shaw (1994)

Cunderlik (2003) stated that the deterministic models can be divided into three broad categories--lumped, distributed, and semi-distributed models. lumped model consider a catchment as whole but distributed model dividing it into cells or grid net and flows are passed from one cell to another (Samady, 2017). A model can further be classified and usually applied in two scenarios: continuous and event-based modeling(Xie, et al.,2019). The comparison of event and continuous hydrological modeling based on Hydrological Simulation Program-Fortan (HSPF) indicates that overall performance of the event-based simulation was better than that of the daily simulation for streamflow. It also shows that model performance decreased as the precipitation became intense in the event-based modeling (Xie, Hui Shen, Zhenyao Chen, LEi Lai, Xijun Qiu, Jiali Wei, Guoyuan Dong, Jianwei Peng, Yexuan Chen, 2019). In addition, using of the HEC-HMS model for event and continuous time scales shows different results which more related to the proper calibration, data, and climate (Choudhari, Panigrahi, & Paul, 2014). Achieving good results with hydrological modeling is required manual and automatic calibration.

2.3.1 Manual calibration

According to Boyle, Gupta, and Sorooshian (2000) manual calibration is the ap-proach most widely used to calibrate hydrologic models. In this approach the "closeness" is typically evaluated in terms of several (more than three!) measures, and a semi-intuitive trial-and-error process is used to perform the parameter adjust-ment. Usually, the exact number and nature of these measures is not specified clearly. While some aspects of "closeness" may be evaluated in terms of objective measures (i.e., one or more mathematical criteria), most are, in fact, evaluated subjectively based on visual comparison of the model outputs and the data. Although the performance evaluation and parameter adjust-ment procedures are usually influenced by:

- Guidelines established through previous experience of model calibration
- Expertise of a person in model structure
- Properties of data and
- the characteristics of watershed system

2.3.2 Automatic calibration

Automatic methods for model calibration seek to take advantage of the speed and power of digital computers. Automatic calibration pro-cedures for hydrologic models have been under development for at least three and a half decades, with the degree of sophistication generally paralleling the increases in computing power. The goal has been to develop an objective strategy for parameter estimation that provides consistent performance by eliminating the kinds of subjective human judgements involved in the manual approach. In the automatic approach the performance evaluation and parameter adjustment procedures are objective in the sense that they establish explicit rules by which the actual sequence of parameter adjustments is made. The power of the procedure therefore depends on how well it has been designed to reflect the factors important to a successful calibration, and much effort has been devoted to establishing what those factors are (Boyle et al., 2000).

2.4 Hydrological models in cold and high altitudes catchments

In the upper Heighe river which is the second largest inland river basin in china eco-hydrological simulation is used for flow simulation. The Alpine meadow, sparse vegetation and glacier are located mainly in the high mountain regions with elevations. The model outcome overestimates the runoff in winter and underestimate in spring and early summer. This might be due to non-consideration of the soil freezing/thawing process and the degree-day factor of snow-melting model. In addition, climate over the high cold mountainous region has great spatial variability, which is a major uncertainty source of hydrological simulations. Heterogeneity of the soil and groundwater is also another challenges to hydrological simulation (Yang et al., 2015).

As a result of applying a physically-based semi-distributed hydrological model in the Athabasca river basin in western Canada, it was found that water temperature boundary conditions dominated by snow and glacier melt waters, anthropogenic impacts along the main catchment streams, propagation of errors in model parameters and precipitation products are among the factors affecting the result of hydrological model (Morales-Marín et al., 2019). Soil and Water Assessment Tool (SWAT) is used to simulate runoff for studying the future climate in the Upper Assiniboine catchment, located in the Lake Winnipeg watershed. The model used temperature-index approach to estimate snow accumulation and melt and only observed flow is calibrated. This model considered suitable to simulate runoff although they are some uncertainties exist. The result shows better in monthly time scale compare to daily time scale this could relate due to that SWAT does not account for frozen soil processes, which can strongly affect the magnitude and rate of runoff, and related nutrient transport (Shrestha, Dibike, & Prowse, 2012) .

An energy-balance ice-melt model was integrated within the Variable Infiltration Capacity (VIC) macroscale hydrological model is used to simulate the hydrological processes in Aksu river basin, a large mountainous and glaciered catchment in north-west of China. The VIC model is a semi-distribute considers explicitly the effects of vegetation, topography and soils on the exchange of moisture and energy between land and atmosphere. This model used primary input data included daily precipitation and maximum and minimum daily temperature from 1970-2007. The modeled daily and monthly streamflow were compared with measurements from the stream gauge. The model performance by cooperating glacier-melt scheme is highest improved in the previous VIC model without a glacier scheme. The model simulations under simulate the highest observations due to the lack of accurate spatial precipitation (Zhao, Ye, Ding, & Zhang, 2013).

The Hec-Hms model is used to simulate runoffs in the Karasu Basin for its extremely significant in hydrological studies to optimize the operation of water resources systems. Because of fewer data requirement and simple usage with relatively high performance, a lumped conceptual hydrological models named HEC-HMS is selected to simulate streamflow. Gridded temperature index is used to model snowmelt process. A cold content is used in snowmelt calculations to consider ability of cold snowpack to freeze liquid water from rainfall. Lapse rate parameter was used to distribute temperature over the basin. The result indicates model simulate larger October flow relative to other years. it is very likely attributable to the critical temperature parameter used in HEC-HMS. Critical temperature is utilized to separate snow and rain events. According to performance assessment results, it is reasonable to state that the HEC-HMS model has an adequate ability to simulate runoffs in the Karasu river basin (Yilmaz, Imteaz, & Ogwuda, 2012).

The Hec-Hms model provides soil moisture accounting model (SMA) requisite of many parameters and data. The model along with temperature index (degree-day) is used to simulate streamflow in three great lakes watershed at Kalamazoo, Maumee and St.Louis. The watersheds are calibrated and validated on daily time step using gauge precipitation measurement and observed snow water equivalent data. Due to not allowing the ignoring of evapotranspiration data in continuous hydrological modelling the Hamon method is used. In the same manner, GIS and state soil Geographic (STATSGO) is used for parameter retrieving. The result indicates that HEC-HMS reasonably simulate the streamflow in St.louis watershed (Gyawali & Watkins, 2012).

2.5 SCS method for abstraction

The Soil Conservation Service (1972) developed a method for computing abstrac-tions from storm rainfall. This method is widely used and described in literatures in calculation of runoff(Boszany, 1989; Boughton, 1989; Chow V.T, Maidment D.R., 1988) for the storm as a whole, the depth of excess precipitation or direct runoff Pe is always less than or equal to the depth of precipitation P; likewise, after runoff begins, the additional depth of water retained in the water-shed, Fa, is less than or equal to some potential maximum retention S (see Figure 2-7). There is some amount of rainfall la (initial abstraction before ponding) for which no runoff will occur, so the potential runoff is P - $I\ a$. The hypothesis of the SCS method is that the ratios of the two actual to the two potential quantities are equal, that is:

$$\frac{F_a}{S} = \frac{P_e}{P-I_a} \qquad (2\text{-}1)$$

From the continuity principle

$$P=P_e+I_a+F_a \qquad (2\text{-}2)$$

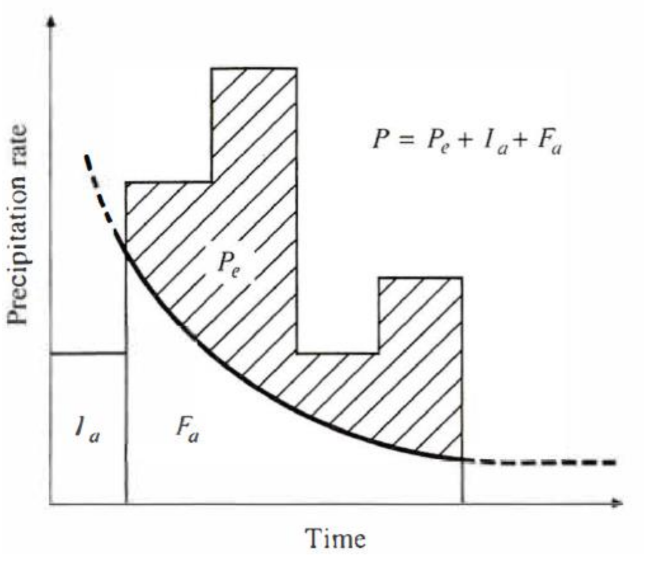


Figure 2-7 Variables in the SCS method of rainfall abstractions: !0 = initial abstraction, P, = rainfall excess, F0 = continuing abstraction, P = total rainfall.

combining (2-1) and (2-2) to solve for Pe gives

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \qquad (2\text{-}3)$$

Which is the basic equation for computing the depth of excess rainfall or direct runoff from a storm by the SCS method. By study of results from many small experimental watersheds, an empirical relation was developed.

$$la = 0.2S \qquad (2\text{-}4)$$

and S calculated through this formula:

$$S = \frac{1000}{CN} - 1 \qquad (2\text{-}5)$$

where CN is the curve number which can be estimated as a function of land use, soil type and antecedent moisture conditions, using tables published by the SCS. The smaller the CN is, the smaller the surface runoff is, while the bigger the CN is, the bigger the surface runoff is (0<CN<100). The SCS curve loss method is provided by Hec-Hms to simulate the runoff and its widely used in catchments around the world which has get good results in event based modeling (Laouacheria & Mansouri, 2015; Joo, Kjeldsen, Kim, & Lee, 2013; Boszany, 1989; Choudhari et al., 2014).

2.6 Blaney-Criddle equation for estimating evapotranspiration

The Penman-Monteith (PM) method is the standard equation for estimating reference crop potential evapotranspiration (ETo) for different climates of the world. this equation needs full weather data. On the other hand, the Blaney-Criddle (BC) equation is a simpler alternative for estimating ETo. Three constant *k* values (0.72, 0.69 and 0.64) that was reported by other investigators used to evaluate the modified BC equation. the results of this modified equation for arid and semi-arid regions in south of Iran showed a good agreement between this method and PM equation (Fooladmand, 2011). Using this the BC (Blaney- Criddle) equation is arid and semi-arid zone of Jordan shows that after calibration accurate calculations of ET_o could be achieved (Mohawesh, 2010).

2.7 Climate change signs

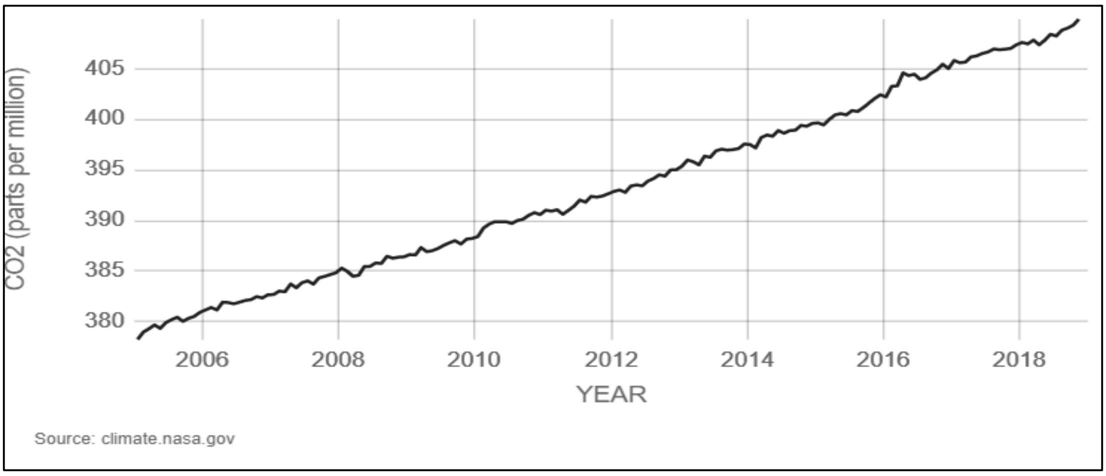
According to the Vijayavenkataraman et al. (2012) Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land-use. The evidence for rapid climate change (IPCC Fourth Assessment Report) is compelling:

1. Sea-level rise: Global sea-level rose about 17 cm (6.7 in) in the last century. The rate in the last decade, however, is nearly double that of the last century.
2. Global temperature rise: Most of this warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years.
3. Warming oceans: the oceans have absorbed much of this increased heat, with the top 700 m (about 2300 ft.) of ocean showing warming of 0.302Fahrenheit since 1969.
4. Shrinking ice sheets: The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA’s Gravity Recovery and climate experiment show Greenland lost 150–250 km3 (36–60 cubic miles) of ice per year between 2002 and 2006, while Antarctica lost about 152 km3 (36 cubic miles) of ice between 2002 and 2005.
5. Declining Arctic sea ice: Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades.
6. Glacial retreat: Glaciers are retreating almost everywhere around the world – including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa.
7. Ocean acidification: Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30%. The amount of carbon dioxide absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year.

The increasing trend of CO_2 emissions, temperature, arctic sea Ice sea level and global surface temperature is shown in Figure 2-8, 2-9, 2-10 and 2-11 respectively. September

Arctic ice is now declining at a rate of 11.5% per decade. Arctic sea ice reaches its minimum in September. The September 2010 extent was the third lowest in the satellite record.

There are lots of initiatives taken by different countries and organizations like United Nations Framework Convention on Climate Change (UNFCCC), United Nations Environment Programme (UNEP) and Intergovernmental Panel on Climate Change (IPCC), in mitigating and adapting to the global climate change. The most important mitigation measures include carbon sequestration, clean development mechanism, joint implementation and most importantly use of renewable and non-polluting sources of energy like solar, wind and geothermal energy sources (Vijayavenkataraman et al., 2012).



Source: climate.nasa.gov

Figure 2-8 Increasing trend of CO_2 emission

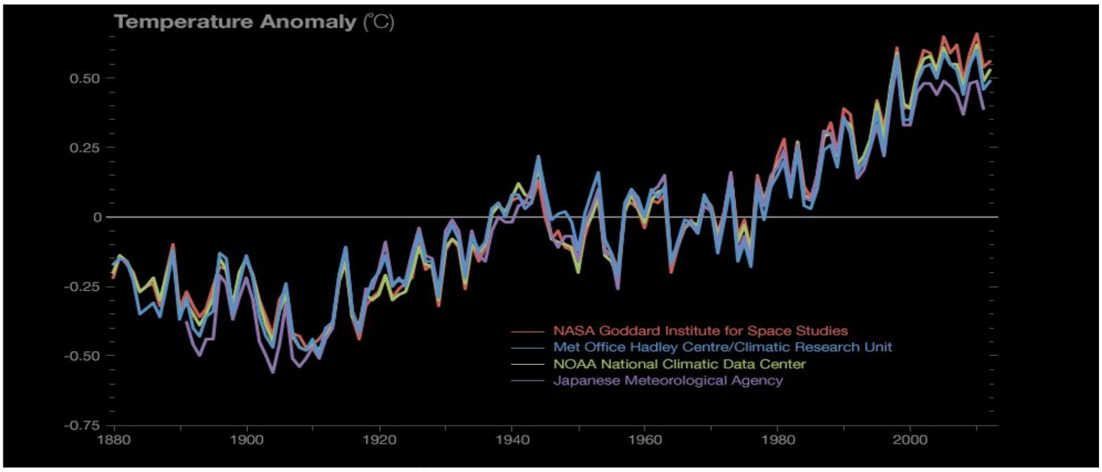
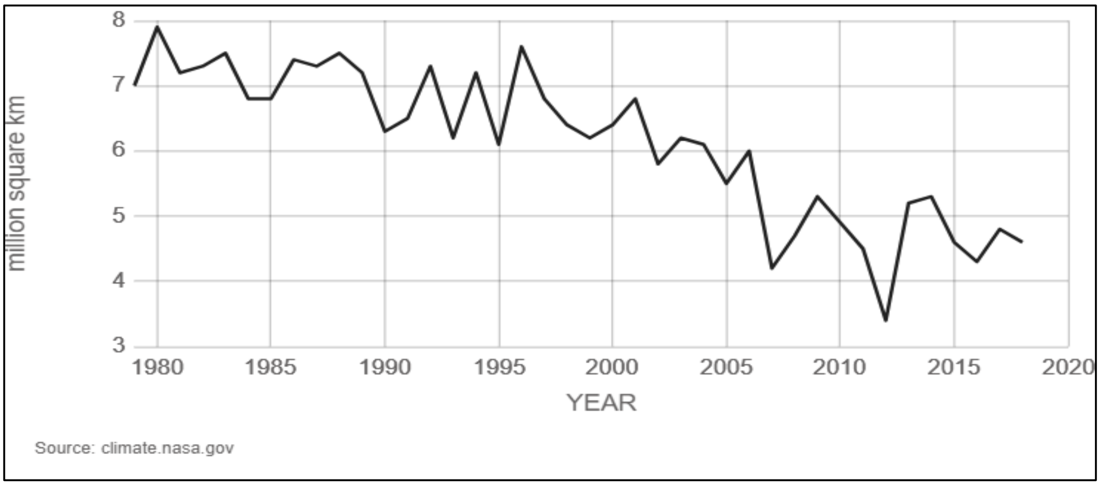
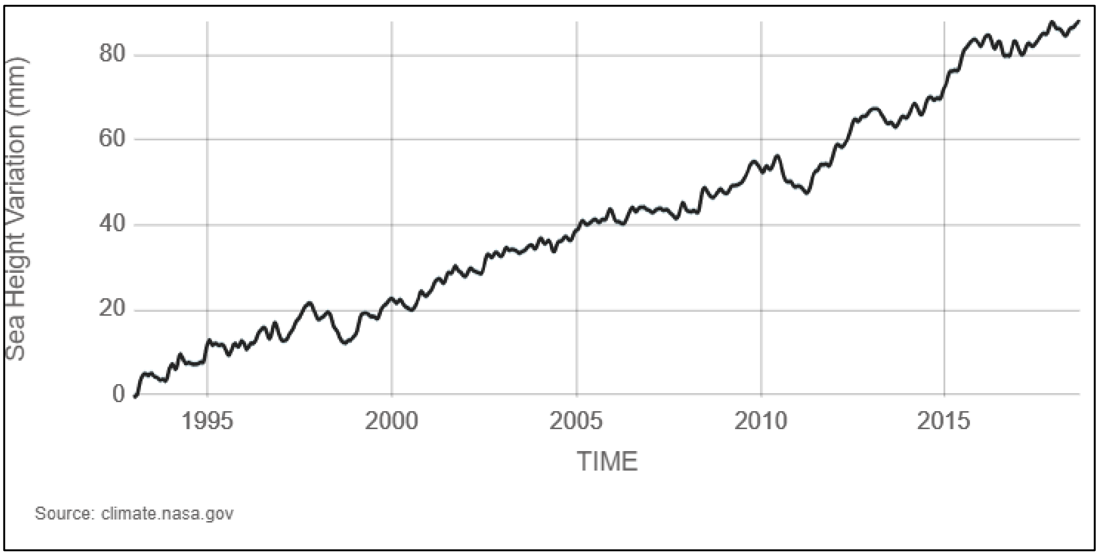


Figure 2-9 Increasing trend of temperature



Source: climate.nasa.gov

Figure 2-10 Arctic sea ice melting from 1980 to 2017



Source: climate.nasa.gov

Figure 2-11 Increasing trend of sea level

According to NASA the Arctic sea ice reaches its minimum each September which is now declining at a rate of 12.8 percent per decade the below graph shows the average monthly Arctic sea ice derived from satellite observations since 1979 and in 2012 sea ice extent is the lowest in the satellite record.

2.8 Climate change impact

2.8.1 Hydropower sector

Hydropower represents an interesting technology: affordable, renewable, and flexible (Ranzani, Bonato, Patro, Gaudard, & De Michele, 2018). According to the new studies the climate change will not lead to significant changes in the global hydropower generation. The generation of hydropower is increasing and is projected to continue increasing till year 2050 as shown in Figure 2-12 and 2-13 respectively.

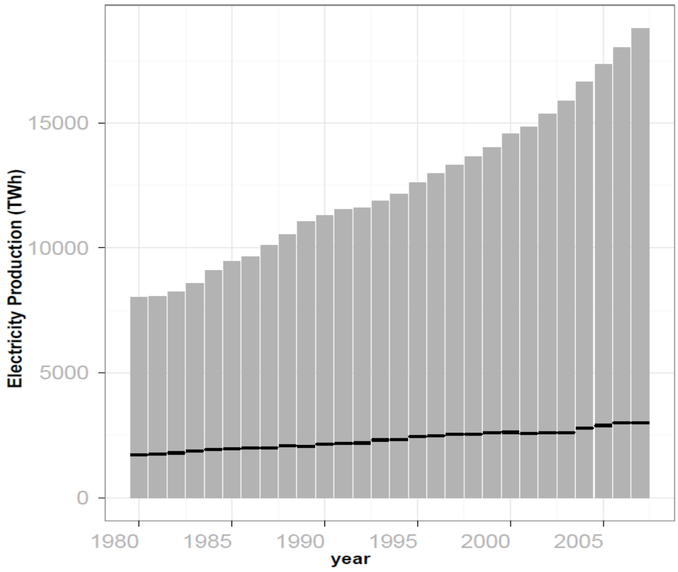


Figure 2-12 Global Total Electricity Generation Trends (TWh) in the last 20

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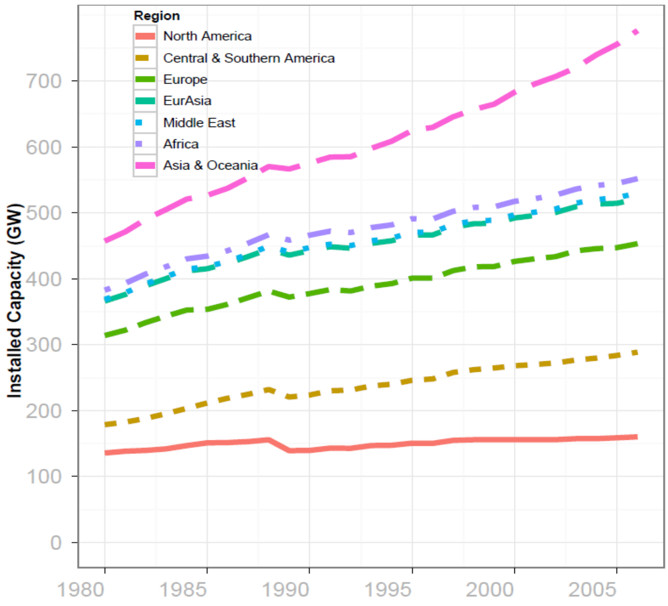


Figure 2-13 Trends in Global Installed Hydropower Capacities (1980–2006)

Based on this approach the current hydropower generation is limited by water availability, on average, runoff can be thought of as the difference between the precipitation and evaporation over long periods of time and this makes it the available water for use, be it for hydropower, irrigation, domestic consumption, etc. In Figure 2-14 shows that runoff of Afghanistan based on 12 GCMs under A1B scenario decreases from -2.5 to -5 in percentage %.

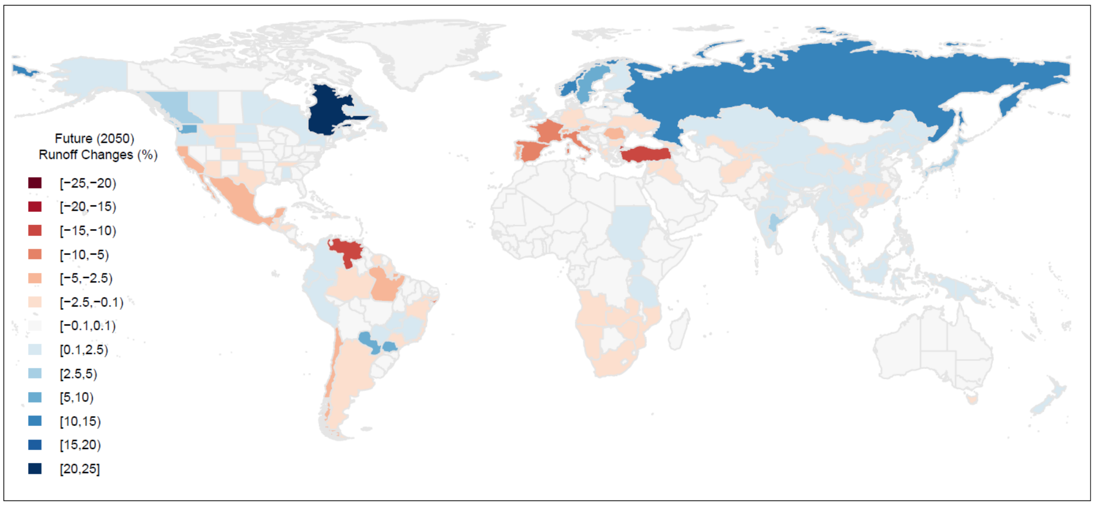


Figure 2-14 Future (2050) Runoff changes (%) based on 12 GCMs under A1B scenario

In overall based on Figure 2-14 for Asia, positive trend owing to climate change have projected but regarding the Afghanistan it has negative impact (Hamududu & Killingtveit, 2012).

In a study in southern Switzerland of future Tremorgio hydropower plant using the eight scenarios: future like present (climate scenario 1), warmer future (climate scenario 2-4), liquid precipitation future (climate scenario 5), mixed scenarios (climate scenario 6-8) predicted the streamflow from a semi-distributed hydrological model most of the result indicates increase in income but the liquid-precipitation future (climate scenario 5) was selected because the effect on volumes and incomes were the most significant that water volumes and incomes decrease by 9.7 % and 10%, respectively. According to that scenario at the beginning of March, the temperatures rise, snow starts to melt, and runoff increases. From October, discharge decreases again because of falling temperatures. There is an offset between the period of the year in which snow falls on the ground and when it becomes liquid. The economic scenarios modelled consider the evolution of prices according to reference EU-Trend (+40% with respect to 2015 income) (Ranzani et al., 2018)

2.8.2 Temperature and snow

Global raise temperature of 1.5 $^{\circ}$C will lead to a warming of 2.1± 0.1°C in high mountains of Asia (HMA), and that 64±7 present-day ice mass stored in the HMA glaciers will remain by the end of the century (Kraaijenbrink, Bierkens, Lutz, & Immerzeel, 2017). Snow Water Equivalent (SWE) is the parameter for the quantifying the availability of water in the snow pack that can be estimated through snow depth and the snow density which is defined by the snow cover area (Collados-lara, Pardo-igúzquiza, & Pulido-velazquez, 2019). Number of studies suggest that potential climate change at higher latitudes will result in higher temperatures and lower precipitation.

2.8.3 Agriculture

The impacts of climate change on agriculture are a key reason for concern. It is now widely acknowledged that adaptation would help to alleviate the worst of the potential impacts (Calzadilla, Zhu, & Rehdanz, 2014). Climate change would modify agricultural productivity through five main factors changes in precipitation, temperature, carbon dioxide (CO_2), fertilization, climate variability, and surface water runoff (world bank, 2008). According to IPCC report (2007) crop production is directly influenced by changes in precipitation and temperature which precipitation determines the level of soil moisture, which is a critical input for crop growth. Higher temperature will shorten the crop cycle and reduce the crop yields, because higher temperature leads to increased crop water requirements.

Study shows that the climate change is impacting the agriculture field and the extent of impact is directly depending on crop type, assumptions related to the CO_2 fertilization effect, climate scenarios and adaptation abilities (Karimi, Karami, & Keshavarz, 2018). Higher atmospheric concentrations of carbon dioxide enhance plant growth and increase water use efficiency (CO_2 fertilization), especially for the C3 crops, and so affect water availability (Betts et al., 2007,Long, Anisworth, Leakey, Nosberger, & Ort, 2006).

In South Africa potential impacts of climate change on global agriculture using the GTAP-W model is multi-region world CGE model and four climate change scenarios from projections of two general circulation models (CSIRO and MIROC) using two IPCC special report on emissions scenarios (A1B,B1) the result indicates using the MIROC-A1B scenario shows the largest crop yield production but using the CSIRO-B1 scenario shows the highest drop in area which finally in both scenarios resulting in the lowest decrease in total production. They found that an increase in agricultural productivity achieves better outcomes than an expansion of irrigated areas mainly through irrigation development and improvement in agriculture productivity (Calzadilla et al., 2014).

2.9 Climate change risks

The climate change can expose the risk in many ways like in threatened systems, causing the extreme weather events, this will encompasses risk to human health, livelihood, assets and ecosystem such as heat waves, heavy rain, drought and associated wildfires, and coastal flooding that this could be happen by transition from Moderate to High risk occurs over the range 1.1-1.6 ˚C (Neill et al., 2017). In Figure 2-15 shows that with the slight increase of temperature under the RCP8.5 the seal level can raise up to 3m which potentially many cities will have gone under water.

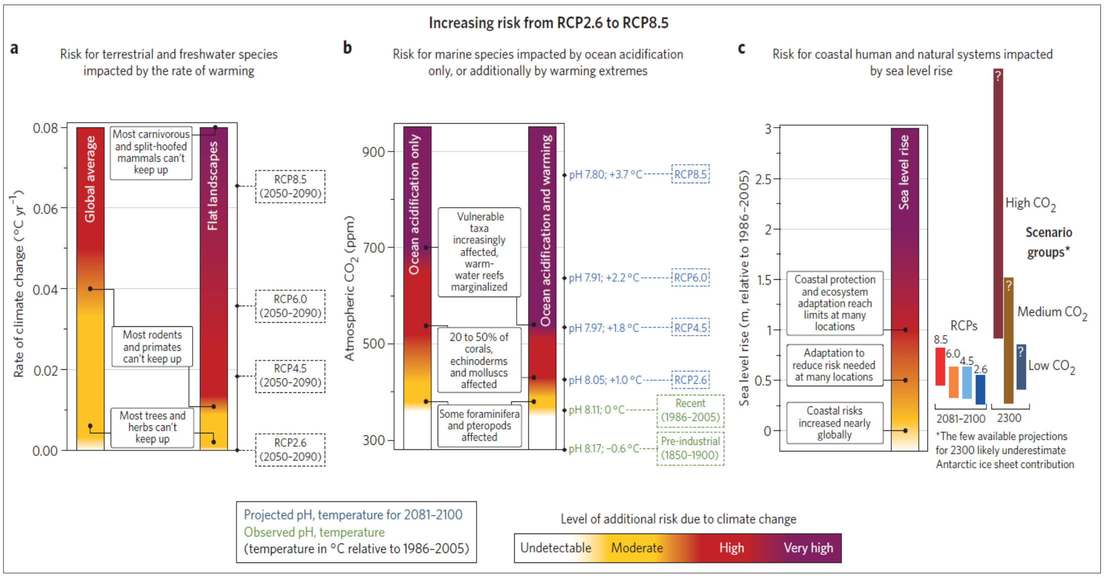


Figure 2-15 Moderate to high risk of increasing temperature over the range 1.1-1.6 ˚C
Source: (Neill et al., 2017)

In the neighborhood of Afghanistan, Pakistan is suffering from the devastating effect of floods and its expected that the seal level will raise in, at the end of this century. Recent studies Neill et al.(2017) assessed the climatic patterns over various regions of Pakistan from the period 1961-2010 shows that temperature is increasing by 0.06 °C per decade and increase of 106mm precipitation in all the period, that would increase the frequency and severity of floods and drought in Pakistan.

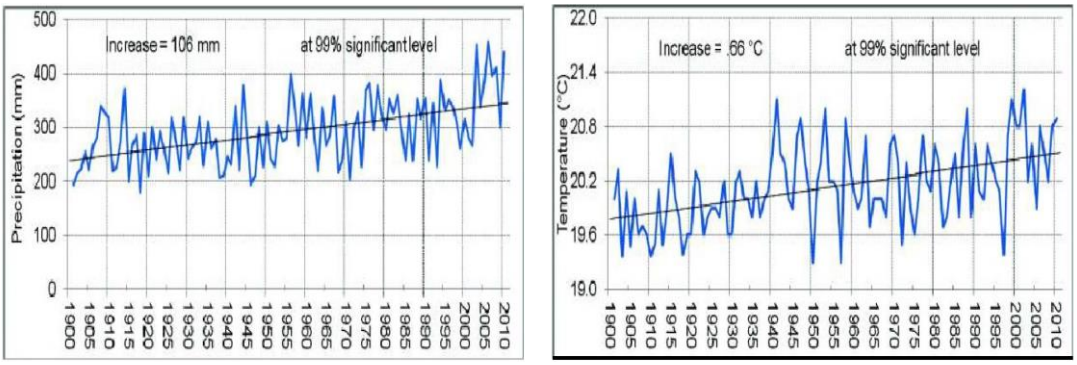


Figure 2-16 Increasing trend of precipitation and temperature from 1900 to 2010 Pakistan

According to Kumar et al. (2017) a case study carried out to predict the future risk of climate change on quality and quantity of Ciliwung river of Jakarta city, Indonisia for year 2030. They used the WEAP hydrological model and regarding the future climatic variables, the general circulation model (GCM) after the downscaling process is used for the reliable impact assessment. The result of simulation indicates the frequency of extreme weather condition such as drought as well as flooding is likely to be increased and the quality of water of water will further deteriorate compared to the base year 2000. Increased climate variability and droughts will affect livestock production as well, through disrupting feedstock supply or even limited water for animal drinking (Calzadilla et al., 2014)

2.10 Climate models and downscaling

General Circulation Models (GCMs) are the most developed tools for the simulation of general responses to the accumulation of greenhouse gases (Parry, Canziani, 2007). Studies have shown that the results of GCMs cannot be exploited directly because they are not accurate enough in describing sub-grid data (Parry, Canziani, 2007). Therefore, Statistical Downscaling Models (SDSMs) are one of the tools that have been developed to deal with this problem (Wilby, 2002). For using the satellite rainfall data and climate change scenarios which they are in large scales, it's required to perform the downscaling methods and there are different downscaling methods like Statistical Downscaling Model (SDSM) (Wilby et al., 2002) and Smooth Support Vector Machine (SSVM) used for the rainfall data. In a study of water balance simulation in upper Hanjiang basin in China, resulted using different downscaling techniques, GCMs and hydrological models shows SDSM has better performance than downscaling rainfall (Chen, Xu, & Guo, 2012).

There are uncertainties in downscaling the global climate change models and a study overt the south Asian monsoon shows that downscaled data of two RCMs (RegCM4 and PRECIS) from ERA40 and ECHAM global climate models (GCM), the ECHAM5 is warmer than ERA40. which in case of temperature downscaled ERA40 by RegCM4 has produced better results in terms of variability. RMSE objective function as compared to the downscaled ERA40 by PRECIS, though the correlations for both the model remain nearly same (Dyn, Waheed, Ahsan, & Bukhari, 2013). It's also found in the modeling climate change impact on runoff across southeast Australia using the five lumped conceptually daily rainfall-runoff models by simulation from 15GCMs the result indicates that the uncertainty sourced from the GCMs in much larger than the uncertainty in the rainfall-runoff models (Chen et al., 2012). A study of climate change on runoff on the upstream mountain area of Manas River basin, China using the base period of 1961 to 2015 where the human influence is low shows the increase of projected precipitation, temperature and runoff from period 2021 to 2060. In that study GCMs is downscaled using TOPMODEL considering the future snowmelt for the monthly, seasonal and yearly scale that under the in "rcp2.6", "rcp4.5", and "rcp8.5" the streamflow will increase by 24.39%, 25.82%, and 29.98% (Ren et al., 2017) .

The climate change is not only affecting to the streamflow but also for the all over the ecosystem including the agriculture field. Finding the winter wheat yield in Iran in the province of Qazvin respect to climate change, they downscaled the two important climatic variables using the CanESM2 and HadCM3 models under five different scenarios. The result indicates that daily mean temperature tended to increase and annual precipitation tended to decrease, rcp2.6 scenario was assumed to be the most efficient to predict the dryland winter wheat to considerably decrease in the third period (2070-2099) mainly because of decrease in precipitation in March (Mirgol & Nazari, 2018).

2.11 Comparison between computed and measured discharge

There are a number of reasons why hydrologists need to evaluate model performance: (1) to provide a quantitative estimate of the model's ability to reproduce historic and future watershed behavior; (2) to provide a means for evaluating improvements to the modeling approach through adjustment of model parameter values, model structural modifications, the inclusion of additional observational information, and representation of important spatial and temporal characteristics of the watershed; (3) to compare current modeling efforts with previous study results (Krause et al., 2005).

2.11.1 Coefficient of determination R^2

The coefficient of determination r^2 is defined as the squared value of the coefficient of correlation according to Bravais-Pearson. It is calculated as:

$$R^2 = \left(\frac{\sum_{i=1}^{n} (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2 \sum_{i=1}^{n} (P_i - \bar{P})^2}} \right)^2 \qquad (2\text{-}6)$$

with O observed and P predicted values.

R^2 can also be expressed as the squared ratio between the covariance and the multiplied standard deviations of the observed and predicted values. Therefore, it estimates the combined dispersion against the single dispersion of the observed and predicted series. The range of r^2 lies between 0 and 1 which describes how much of the observed dispersion is explained by the prediction. A value of zero means no correlation at all whereas a value of 1 means that the dispersion of the prediction is equal to that of the observation(Krause & Boyle, 2005).

2.11.2 Nash-Sutcliffe efficiency E

Nash and Sutcliffe (1970) purposed efficiency is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation. It is calculated as:

$$E = 1 - \frac{\sum(Q_{obs} - Q_{cal})^2}{\sum(Q_{obs} - \bar{Q}_{obs})^2} \qquad (2\text{-}7)$$

With Q_{obs} observed, Q_{cal} simulated and Q_{obs} average observed flow.

2.11.3 Index of agreement

The index of agreement represents the ratio of the mean square error and the potential error (Willomot, 1981) and is defined as:

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| - |O_i - \bar{O}|)^2} \qquad (2\text{-}8)$$

The potential error in the denominator represents the largest value that the squared difference of each pair can attain.With the mean square error in the numerator d is also very sensitive to peak flows and insensitive for low flow conditions as it is E. The range of d is similar to that of r^2 and lies between 0 (no correlation) and 1 (perfect fit).

2.11.4 Percent streamflow volume error (PVE) or percent bias (PBIAS)

It indicates the overall agreement between the observed flow and simulated flow over a specified time interval (Samady, 2017).The percent streamflow volume error (PVE), is used as a primary metric for the objective function in most of hydrologic models(Jain & Singh, 2003) .

$$PVE\% = \frac{Q_{obs} - Q_{sim}}{Q_{obs}} * 100 \qquad (2\text{-}9)$$

Where Q_{obs} is the observed streamflow (m^3/sec) and Q_{sim} is the simulated streamflow (m^3/sec) at the watershed outlet.

2.11.5 Mean absolute error

The mean absolute error (MAE), given by Equation 2-7, measures the global goodness of the fit of the simulated error (the difference between the observed data and the model predicted output)(Laouacheria & Mansouri, 2015).

$$MAE = \frac{\sum_i^N |Q_{i,Obs} - Q_{i,Sim}|}{N} \qquad (2\text{-}10)$$

where $Q_{i,Sim}$ is the simulated discharge at time t=i, $Q_{i,Obs}$ is the observed discharge at time t=i, $\bar{Q}_{Obs}$ is the average observed discharge; N is the number of observations.

2.11.6 Mean Squared Error

Mean Squared Error (MSE, Eq. (2-8)) as the objective functions. The MSE expresses the goodness of fit of a model compares between simulated and observed flows (Joo et al., 2013).

$$MSE = \frac{1}{M} \sum_{m=1}^{M} \sum_{t=1}^{N_m} (Qsim_{t,m} - Qobs_{t,m})^2 \qquad (2\text{-}11)$$

where M is number of flood events, and Nm is number of interval in event. As the difference between observed and simulate runoff get smaller (i.e., model performance improves), the value of MSE approaches to zero.

3 METHOD AND MATERIALS

In this research project, first the problem has identified regarding the concern of climate change effect on water resources and agriculture of Maidan-Kabul river basin at Tang-i-Saidan where the Shahtoot reservoir will be built that has economical and vital benefit for the maintaining of Kabul city drinking water. The methodology used in this research work explained in Figure 3-1 in details. First the problem has identified then the objective of the research is specified. Extensive literature review has carried out for the purpose of enriching the methodology and finding new sight of the research. The hard evidence of climate change is narrated many times from the local people, farmers and water resources engineering in the study area but its hasn’t yet justified scientifically. For fulfilling this purpose and base on the requisite of this study relevant data is gathered from different organization of Afghanistan government. Following, all acquired data extensively checked and purified using the different methods suggested on literatures

The analysis part of this research is categorized in three parts, first, historical trend of climate and water resources is analyzed. Second, HEC-HMS model is selected for simulation of streamflow, following the proper calibration and verification. Third is selecting the future scenarios and incorporating that in the model for water resources assessment and decision making. For clarifying this, here all this three stages are explained.

In the first stage historical trend of climate along with the water resources are studied to distinguish changes between the past and present condition. The main indicator of climate is investigated in this stage such as temperature, evapotranspiration and humidity. The daily average temperature, minimum average and maximum average has analyzed and its trend is plotted. The evapotranspiration study due to nonexistence of gauged data Bleny criddle method based on the regional comparison and similar studies is used. This method is mostly relying on temperature.

In the second stage the analysis is focused on the hydrological modeling part which considered as a necessary part of this research for studying the future condition of streamflow respect to climate change scenarios. This part is necessary because incorporating the future scenarios will not be possible with ignoring this part. Base on extensive literatures the SCN loss method and temperature index along with HEC-HMS model is identified a suitable model used in this research work. The model runs in continuous bases following the requisite of different data and variety of parameters. This work performed by extensive search for the data and used accurate methods for parameter estimation. For carrying of calibration and verification the hydrologic and meteorological data has divided into the calibration and verification sets. For possibility of not getting results mainly two measures are undertaking, either changing the parameters or further, using another model.

Predicting future streamflow, temperature and precipitation based on changes on the climate and water resources factor are considered in third stage. This stage will justify the need of hydrological modeling as a requisite part of this study. In this stage, the future IPCC scenarios for the precipitation, evapotranspiration and temperature will be incorporated to the model. The scenarios are already existing for the Afghanistan context and especially for the Kabul province that downscaled for the study area. In the final stage the proper adaption options will be evaluated for mitigating the effect of climate change on downstream Kabul and especially for the Shah toot reservoir. Finally, the research work will end by discussion, conclusion and recommendation.

3.1 Methodology flow chart

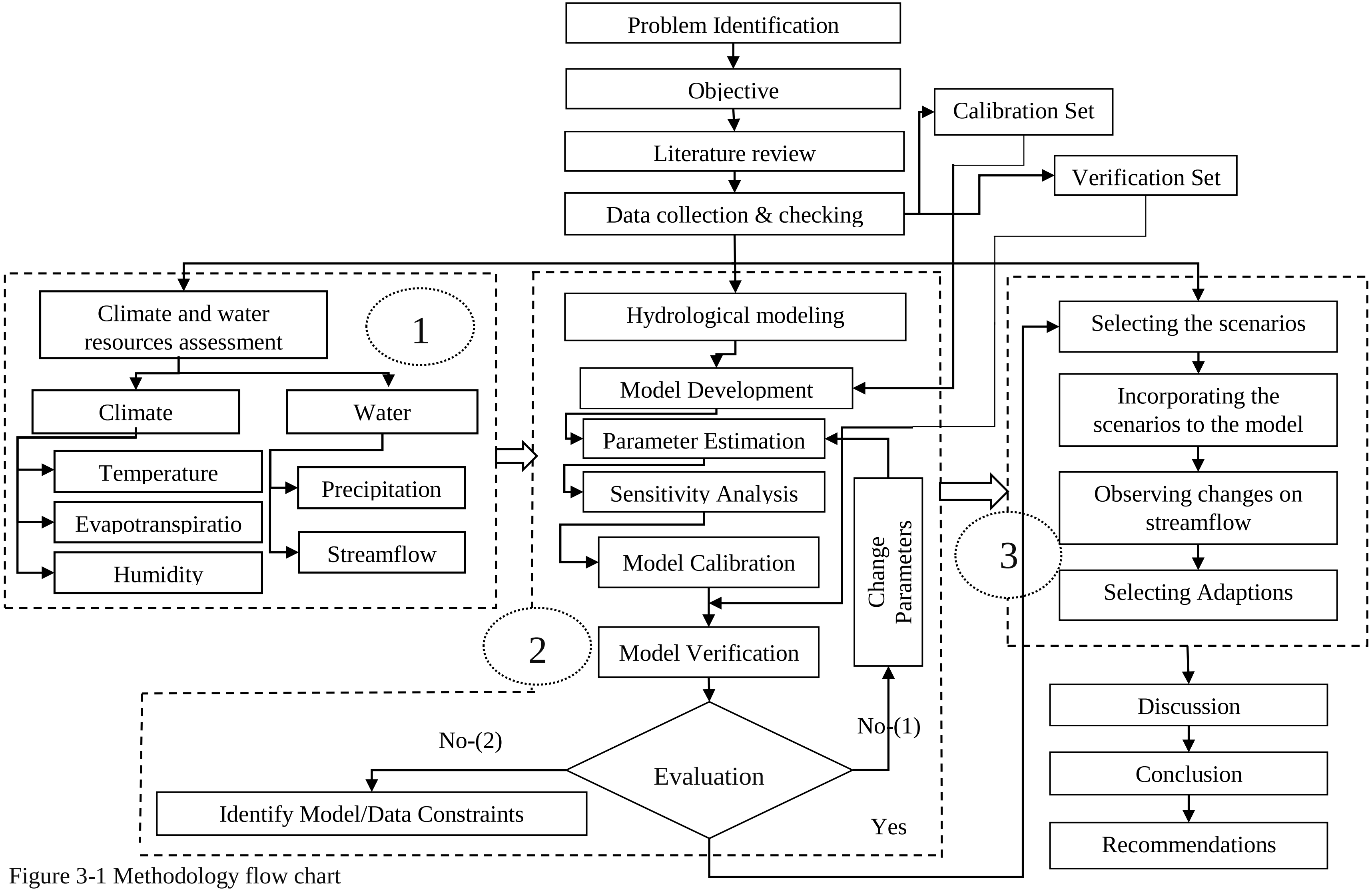


Figure 3-1 Methodology flow chart

3.2 Model selection

According to literatures and case studies carried out in the different part of the world, it’s found that HEC-HMS developed by the United States Army corps of Engineer successfully calibrated and verified for many cold and mountainous basins model around the world and the region. It is considered as a suitable model for this research work. For further proceeding this model, the canopy method, surface method, loss method, transform method and baseflow method is adjusted which will be explained in following:

1- Canopy Method: this method is idealized which initially falling of precipitation is on the surface of plants and vegetables to the edge of it filling prior to falling to the earth surface. In the HEC-HMS model three methods are exist for retrieving the canopy values which are simple canopy, dynamic canopy and gridded simple canopy. The simple canopy is selected based on the availability the data.
2- Surface method: In the HEC-HMS model for the purpose of depression storage similar to the canopy method the simple surface and gridded simple surface is provided. The surface storage is the amount of water which will be lost from the system through storing in the earth which will more depends on the topographic of the surface for initial estimation. In here, the gridded surface storage is used for the modeling of surface storage in the study area.
3- Los method: HEC-HMS model is providing many loss methods but out them based on the literature review the SCS Curve Number is selected because the climate of the region is dry climate and the streamflow is mostly concentrated in the month of April and May due to melting of the snow and most precipitation is in the form of solid (snow) during the season of the winter. The SCS Curve Number based on many studies and the nature of this model can simulate event better than continuous and the streamflow graph is more look like events because except of winter other season has very less precipitation which this will either evaporated or used for the irrigation purposes before any contribution to the main streamflow and reaching to the Tang-i-Saidan station. Therefore, except of several months this river is go to in dry condition.

4- Transform method: In the selected model (HEC-HMS) similar to other methods many choices is provided for simulation of water transforming through the main channel. The most prominent method is the Clark unite hydrograph, SCS Unite hydrograph which based on the number of studies, data availability and preciseness of the model, the Clark Unit Hydrograph is selected.

5- Baseflow method: similar to other methods, in the HEC-HMS model many methods is available for capturing the baseflow which the most prominent among these methods are recession and linear reservoir which linear reservoir is mostly using along with soil moisture accounting loss (SMA) loss model but the recession model is used with other loss methods. Therefore, we used the recession model in this study based on the nature of this method with SCS loss method, the method for estimation of the parameters and preciseness.

3.3 ArcGIS

The development of remote sensing (RS) and Geographic Information System (GIS) capabilities foster the usage of hydrologic modeling in the international context. GIS is a suitable tool for the efficient management of large and complex database. Through this software it is possible to provide a digital representation of watershed characteristics used in hydrologic modeling. It has added confidence in the accuracy of modeling by providing more practical approach toward the watershed conditions, defining watershed characteristics, improving the efficiency of the modeling process and ultimately increasing the estimation capabilities of hydrological modeling (Ghoraba, 2015).

In this study the ArcGIS 10.5 is used as a primary tool for extracting the values for different component of the model. The watershed is extracted using the 30m Dem and the stream network is also identified for the study area. The precipitation and streamflow gauging stations locations are visualized through this tool. For averaging of precipitation the thiessen method through spatial analyst tool is developed to the study area. Using the landuse map which developed by RS techniques different values for the canopy storage, surface storage, curve number and the impervious percentage is retrieved. The slope map is developed using Dem and following all the information by the HEC-GeoHMS tool exported to the HEC-HMS software.

3.4 Study area

The study area map is shown in Figure 3-2; it consists of the 2408.12 km^2 located in the upper of side of Kabul city. Its location is in the eastern region of Afghanistan; bordering Parwan to the northeast, Kabul and Logar province to the east. It's a mountainous area like the rest of the country with plains and many valleys. There are four precipitation stations which are: Qala-i-Malik, Payin-i-Qargha, Tang-i-saidan and Pul-i-Surkh that only the Pul-i-Surkh station is located inside the boundary and others are located outside of the boundary. All of the available stations is recording the temperature, wind and humidity but no stations recording the evaporation and also the evaporation stations are not existed. The streamflow is located at the outlet of the boundary at Tang-i-Saidan where the Shahtoot reservoir will be build. The study area is extracted using the 30m DEM through help of the ArcGIS software.

For the current study this area is selected due to availability of data, closeness for the Kabul city and locating of purposed Shahtoot reservoir at the outlet of this catchment. The meteorological and hydrological stations located in this area are continuously measuring the climate and hydrological data. Due to closeness to the capital and relevant government agencies all the stations are continuously monitoring which is more reliable for hydrologic modeling. In addition to that availably of historical data is benefiting in selection of this palace. In the downstream of this catchment, Kabul city is located that is under the threat of flooding incidents which during the past several years many flooding incidence are reported. Its purposed that Shahtoot reservoir is being built at the outlet of the study area which is very critical in recharging the groundwater and producing continuous water for the Kabul city for drinking and agriculture purposes.

The people living in this region mainly involves to trade in agriculture, livestock products and stone quarrying which four fifth of rural households own or manage agriculture land. Its population is estimated near to 60000 which 85% are Pashtuns, and rest of that are Hazaras and Tajiks. It has warm, dry summer and cold, snowy winters. July is the warmest month of the year with an average of 21.2 ℃ and the January is the coldest month with -6.4 ℃ with 2225 m elevation above the sea level.

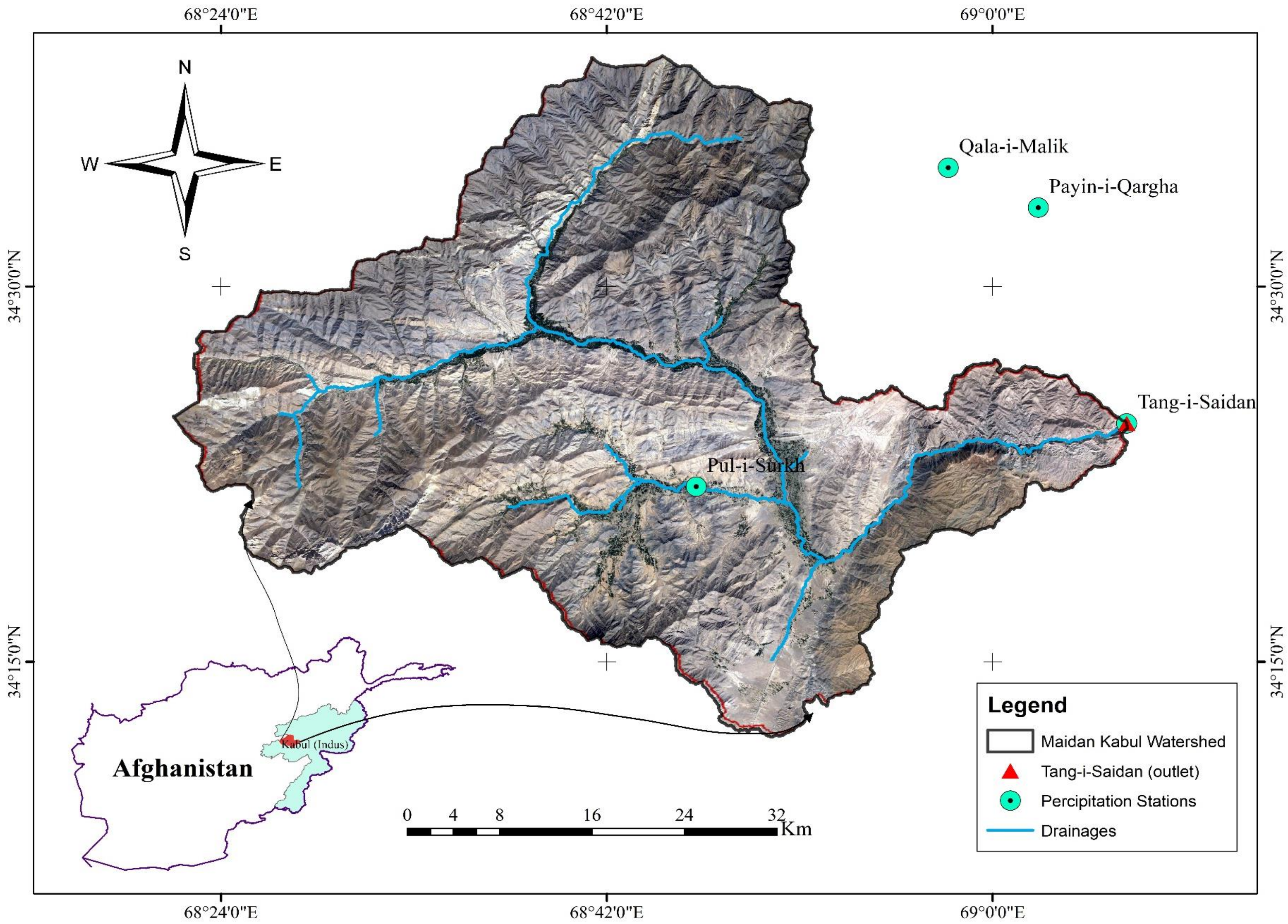


Figure 3-2 Study area map

3.5 Data collection

Base on the literature review and the objective of this research different kind of data are collected include of precipitation, streamflow, temperature, humidity, DEM (Digital elevation model), soil and landuse. Further, every individual data has checked for consistency and purified before using to the analysis part which will be explained under this section. The source, resolution and the data period of every individual data has showed in the below table 3-1.

Table 3-1 Data specifications

Data type	Spatial reference	Resolution	Data period	Source
Precipitation	Qala-i-Malik	Daily	2009-2017	Ministry of Energy and water
	Payin-i-Qargha	Daily	2009-2017	Ministry of Energy and water
	Tang-i-Saidan	Daily	2009-2017	Ministry of Energy and water
	Pul-i-Surkh	Daily	2009-2017	Ministry of Energy and water
Streamflow	Tang-i-Saidan	Daily	2009-2017	Ministry of Energy and water
Temperature	Qala-i-Malik	Daily	2009-2017	Ministry of Energy and water
	Payin-i-Qargha	Daily	2009-2017	Ministry of Energy and water
	Tang-i-Saidan	Daily	2009-2017	Ministry of Energy and water
	Pul-i-Surkh	Daily	2009-2017	Ministry of Energy and water
Landuse	Afghanistan	1:50,000	2016	FAO
Soil	Afghanistan	1:250,000	1992	FAO

3.5.1 Landuse

The landuse details of the study area is showed in table 3-2 and for clear illustration it showed in the Figure 3-3. The landuse map is collected from the WFO 2016 and according to that, 85.7% of the study area is covered by Rangeland and rain fed land made the lowest portion of it. The landuse properties which are listed in table 3-2 is derived from Landuse rater map showed in Figure 3-4.

Table 3-2 Landuse characteristics

Landuse type	**Area**	
	(km)	**(%)**
Rangeland	2063.58	85.7
Irrigated Land	103.82	4.31
Barren Land	91.78	3.81
Barren Land & Rangeland	67.68	2.81
Fruit Trees	52.08	2.16
Built Up	11.65	0.48
Rangeland & Barren Land	5.84	0.24
Water Bodies & Marshland	5.84	0.24
Forests & Shrubs	2.65	0.11
Forests, Shrubs and Irrigated Land	1.29	0.05
Irrigated Land & Fruit Trees	0.86	0.04
Vineyards	0.34	0.01
Irrigated Land & Forests	0.23	0.01
Fruit Trees & Irrigated Land	0.21	0.01
Rainfed Land	0.12	0
Rangeland, Forests and Shrubs	0.04	0

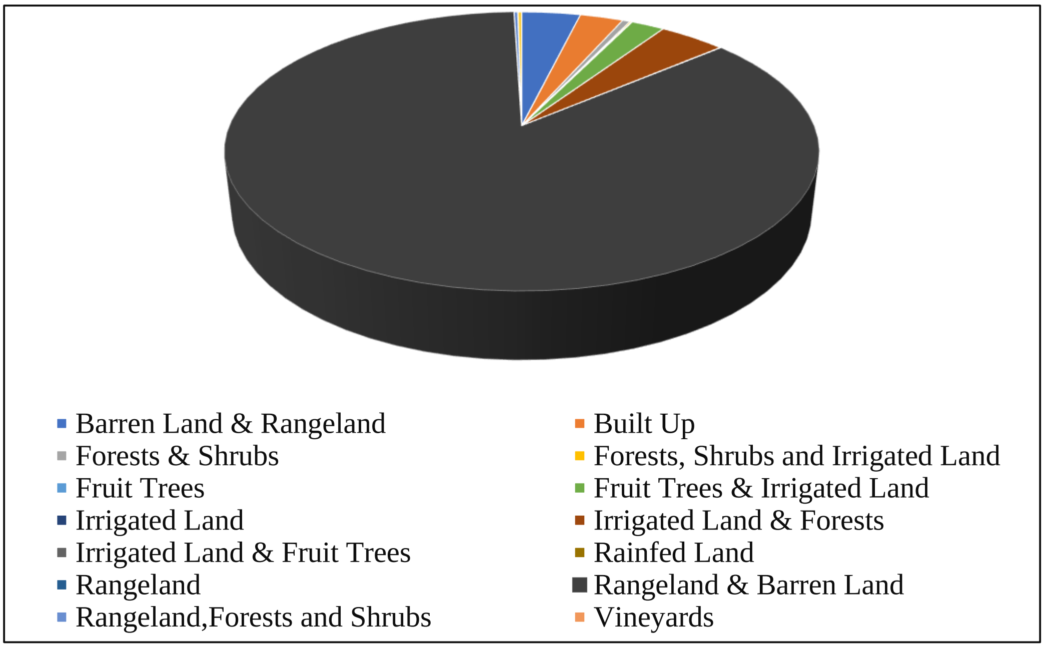


Figure 3-3 Landuse graphical representation

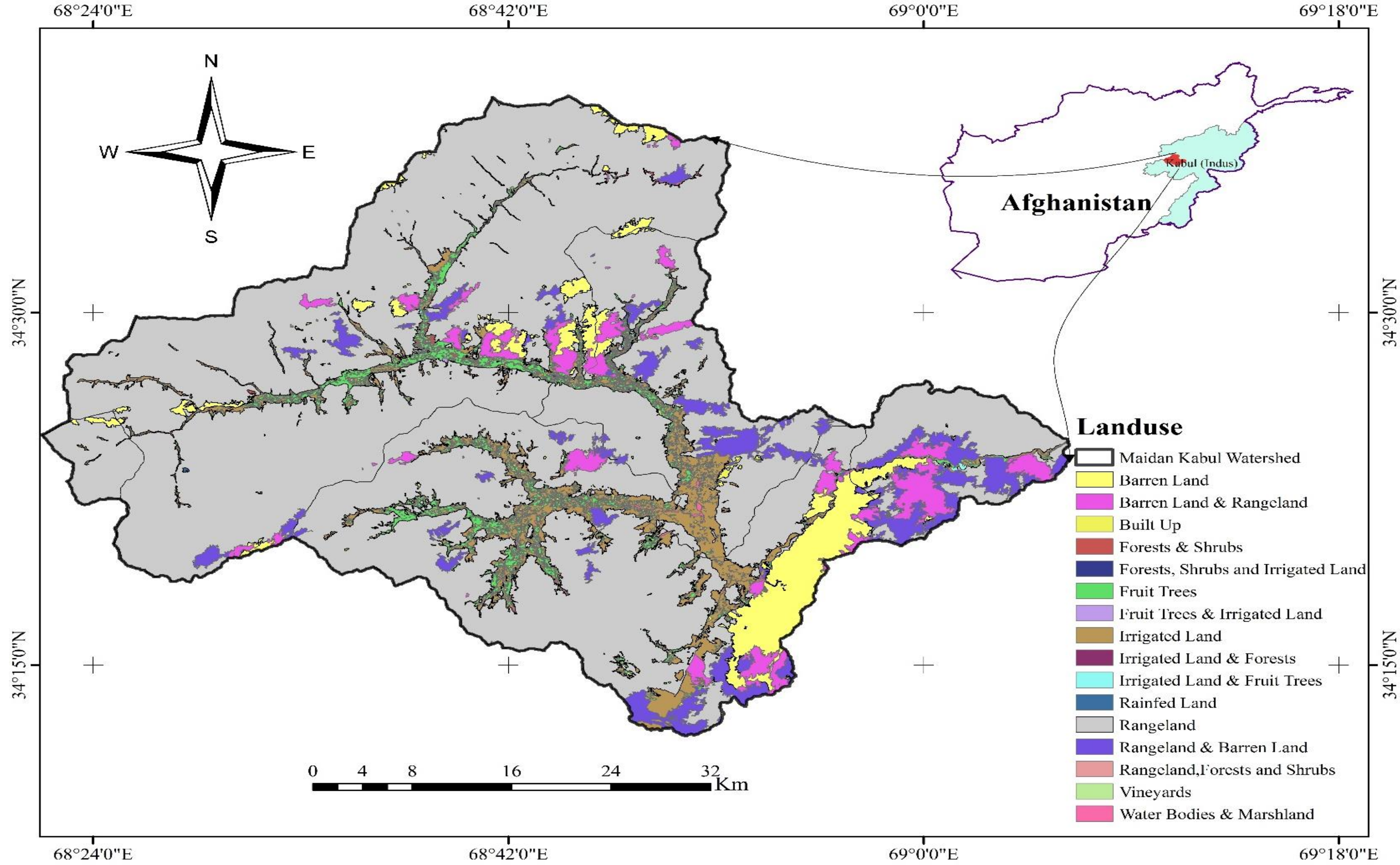


Figure 3-4 Landuse map

3.5.2 Soil Map

The soil map shape files are available for all over the Afghanistan available in the USDA-NRCS, soil science division in scale of 1: 250,000. For current study, this maps is clipped using the GIS tools for the study area and is showed in Figure 3-5. This map is consist of four major type of soil which Rocky land with Lithic Haplocryids is consist of 49% has the highest and the Hapclocambids with Torriorthents consist of 1% made the lowest area of the study area. The soil type characteristics in more details is illustrated in Table 3-3.

Table 3-3 Soil type characteristics

Soil Type	**Area**	
	Km^2	**%**
Xerochrepts with Xerorthents	1054.2	43.8
Rocky land with Lithic Cryorthents	149.1	6.2
Haplocambids with Torriorthents	24.6	1.0
Rocky land with Lithic Haplocryids	1179.5	49.0

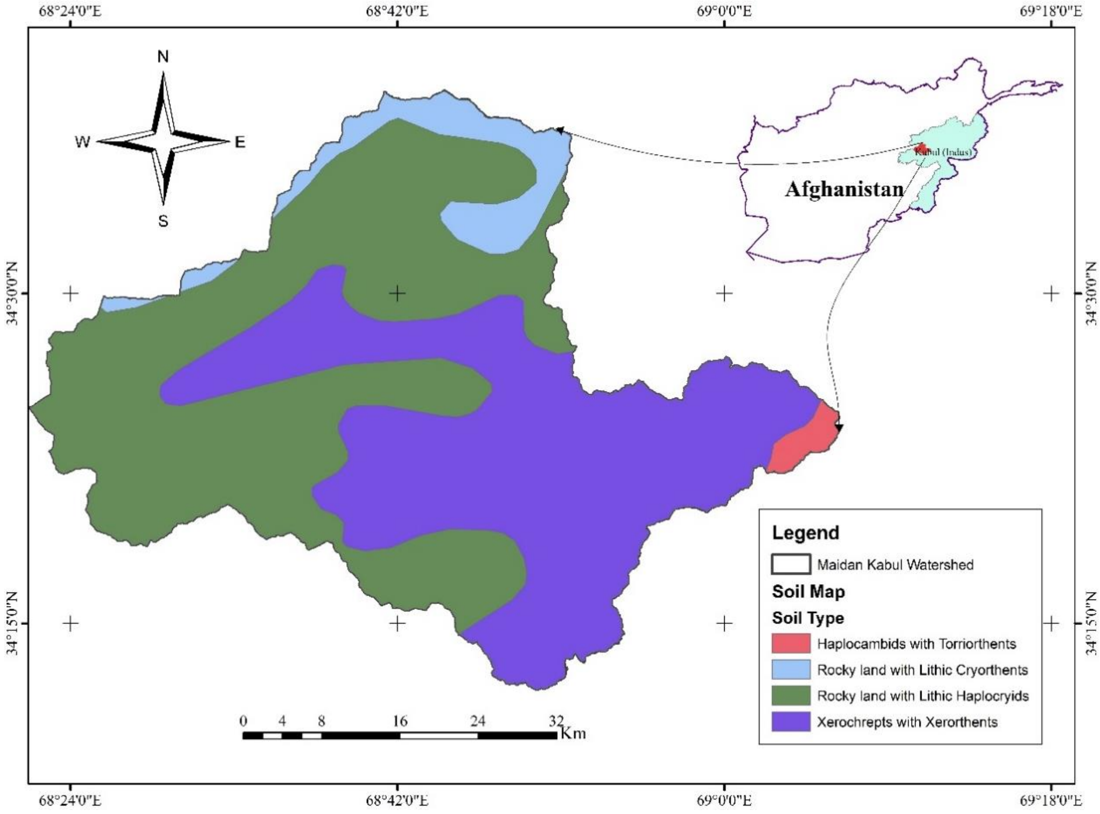


Figure 3-5 Soil map

3.5.3 Precipitation and streamflow

The precipitation stations along with the streamflow station is showed in Figure 3-6. More details on each precipitation and streamflow stations, including the coordinate, period of operation is mentioned in the table 3-4.

Table 3-4 characteristics of precipitation and streamflow stations

No	River basin	River	Stations type	Station name	Coordinate	Period of operation
1	Kabul	Kabul	Precipitation	Tang-i-Saidan	Lat=34.408975, Long= 69.10441111	2009-2019
2	Kabul	Maidan		Pul-i-Surkh	Lat=34.36684167, Long= 68.76965278	2009-2019
3	Kabul	Paghman		Payin-i-Qargha	Lat=34.55253889, Long= 69.03574444	2008-2018
4	Kabul	Paghman		Qala-i-Malik	Lat=34.5790833, Long= 68.9657222	2008-2019
5	Kabul	Kabul	Streamflow	Tang-i-Saidan	Lat=34.408975, Long= 69.10441111	1962-1980, 2007-2019

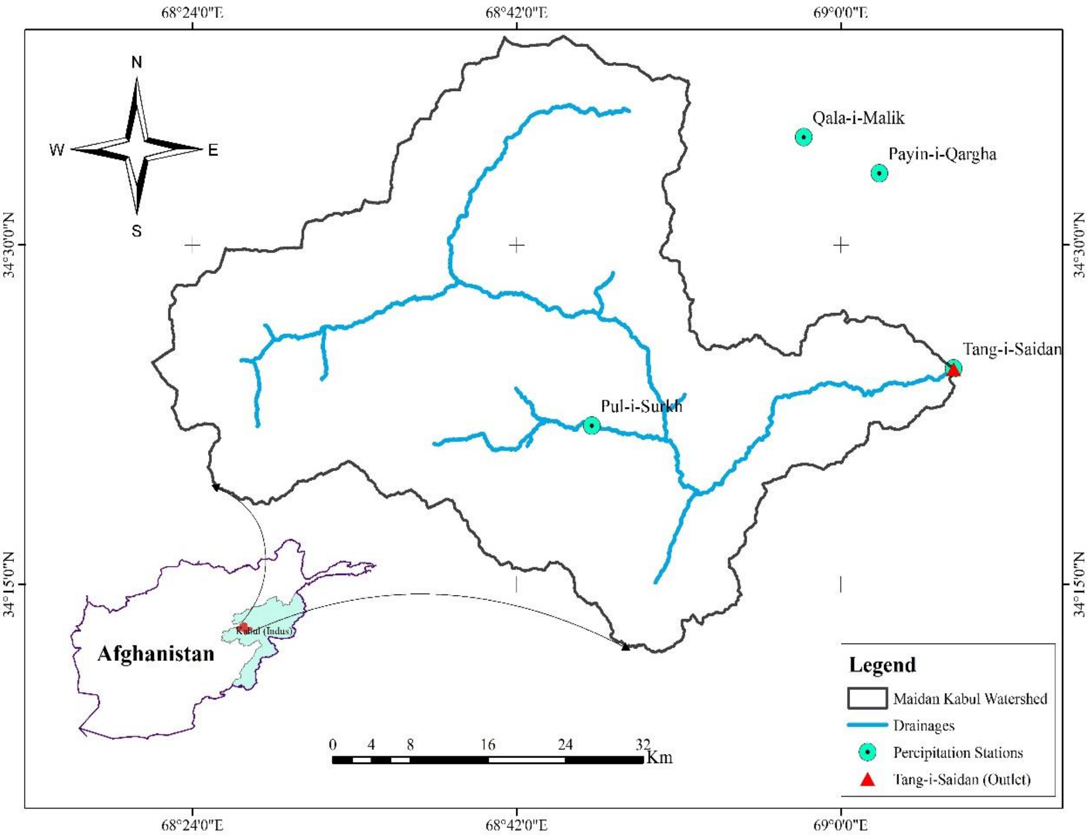


Figure 3-6 Location of streamflow and precipitation gauging stations

3.6 Data checking

All the data retrieved for this research is checked for the consistency using the different techniques prior to use in the analysis and further process.

3.6.1 Visual checking

Visual checking of the precipitation verses streamflow is one of the primary checks of the data. The main concept of this check is to investigate that precipitation has a good match with streamflow and if it observed in some time that precipitation is occurring specially in large amount but streamflow response is very low, it indicates that the data has some problems and need to be checked. In this study mainly two stations (Tang-i-Saidan and Pul-i-Surkh) has been selected for this checks, in here it shows in Figure 3-7 and 3-8 respectively for year 2011 and for rest of years is shown in Figure A-1, A-2, A-3 and A-4 in Appendix A which all the errors are marked with red circle.

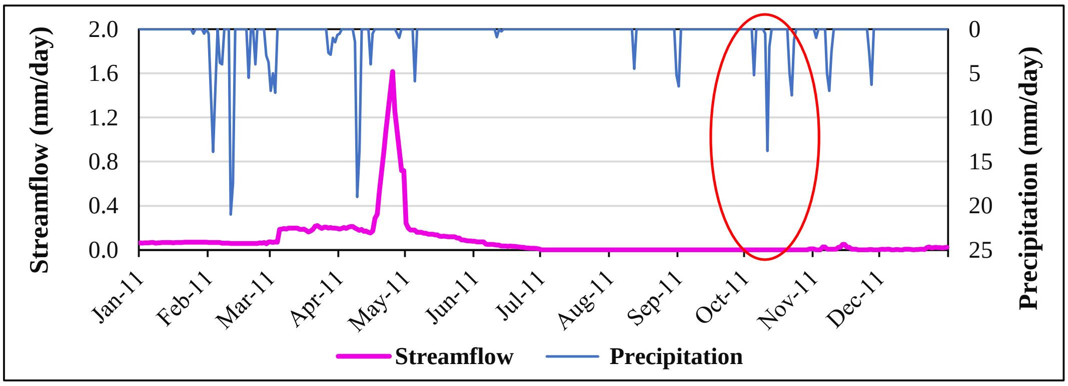


Figure 3-7 streamflow response of precipitation at Tang-i-Saidan station in year 2011-2012

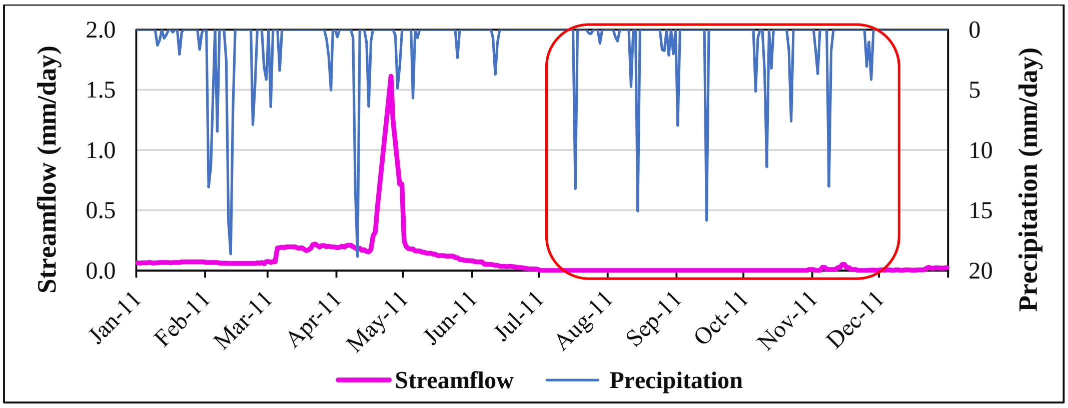


Figure 3-8 Streamflow response of precipitation at Pul-i-Surkh station in year 2011-2012

Similar to precipitation and streamflow the temperature (in daily scale) and evaporation in monthly scale has checked visually. During this checks only some less alteration is showing in some years and in some months which is marked in red lines. This check will lead us to inspect every single data and rectify that before using in any further analysis and process. Visual checks for precipitation data is shown in Figure 3-9 and for evaporation data is shown in Figure 3-10.

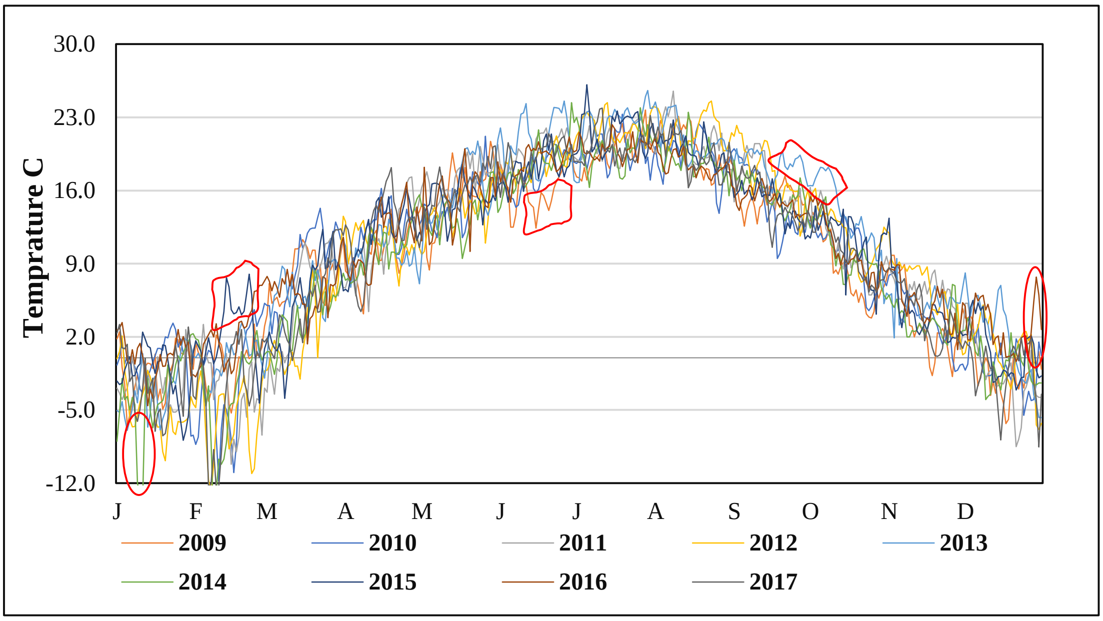


Figure 3-9 Daily temperature data from year 2009 to 2017

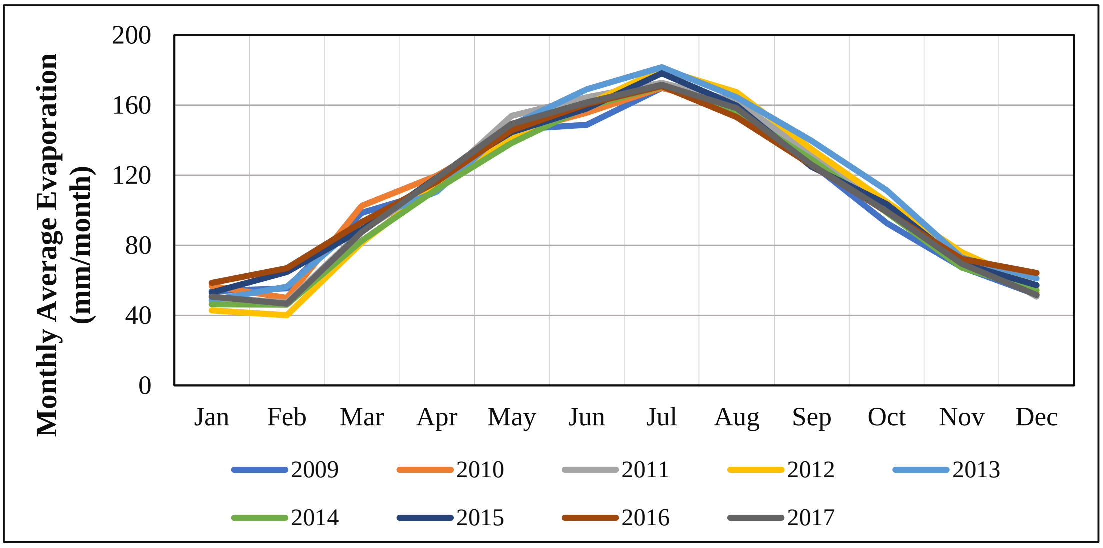


Figure 3-10 Monthly evaporation data form year 2009 to 2017

3.6.2 Comparison of annual precipitation

This is one of the primary check based to compare of annual precipitation of all the precipitation stations respect to each other. The goal behind this check is to find if the sum annual of a neighborhood station is different compare to other stations in a large scale. This check is carried for current study and all of four available precipitation stations is summed and the result of that is shown in Figure 3-11. According to this Figure, the Payin-i-Qargha station total sum of precipitation is highly different compare to other stations which is marked in red line.

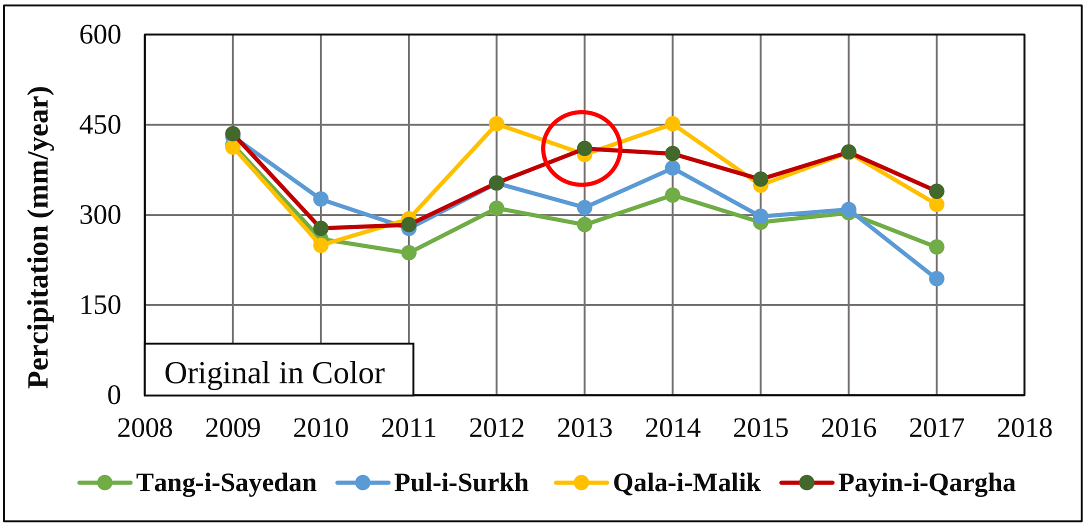


Figure 3-11 Annual sum precipitation data from year 2009-2017

3.6.3 Comparison of annual precipitation and streamflow

This is a main check in order to understand the response of every year precipitation to streamflow. Theoretically and practically when there is more precipitation more streamflow is expected. If in some years, there is a lot of precipitation but less streamflow response compares to the normal trend of precipitation the data has to be checked. In this study the thiessen average precipitation method along with streamflow at Tang-i-Saidan is used for comparison. As it shows in Figure 3-12 in year 2011, 2014 and 2017 the precipitation amount verses the streamflow is not following the normal trend of other years. This check will help to investigate on those mentioned years for finding out the problems and making data more purify.

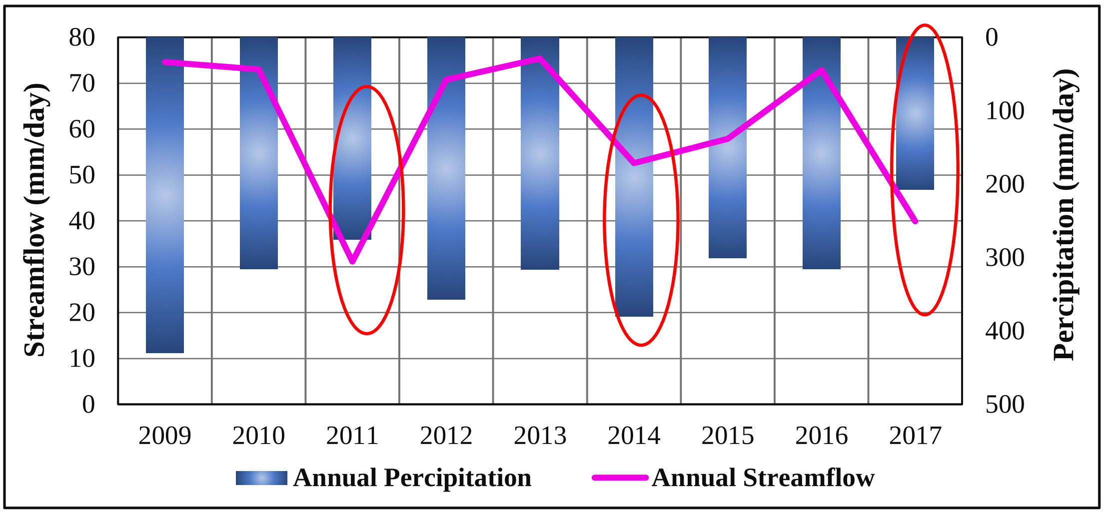


Figure 3-12 Sum of annual precipitation verses annul streamflow in year 2009-2017

3.6.4 Rectifying precipitation stations errors

After the visual and consistency checking of the data it has been observed that in some years and in some meteorological stations there are errors that has to be rectified. In response to this matter a method called cumulative against a station is used which base on this method the slope of the trend multiplied by all the values of the concern station. All the results are checked with coefficient of determination R^2, the range recommended for this is between 0-1, the closer to 1 is better. Its shown in Figure 3-13 and Figure 3-14 for all the available stations that R^2 is greater than 0.8, indicates a good fit.

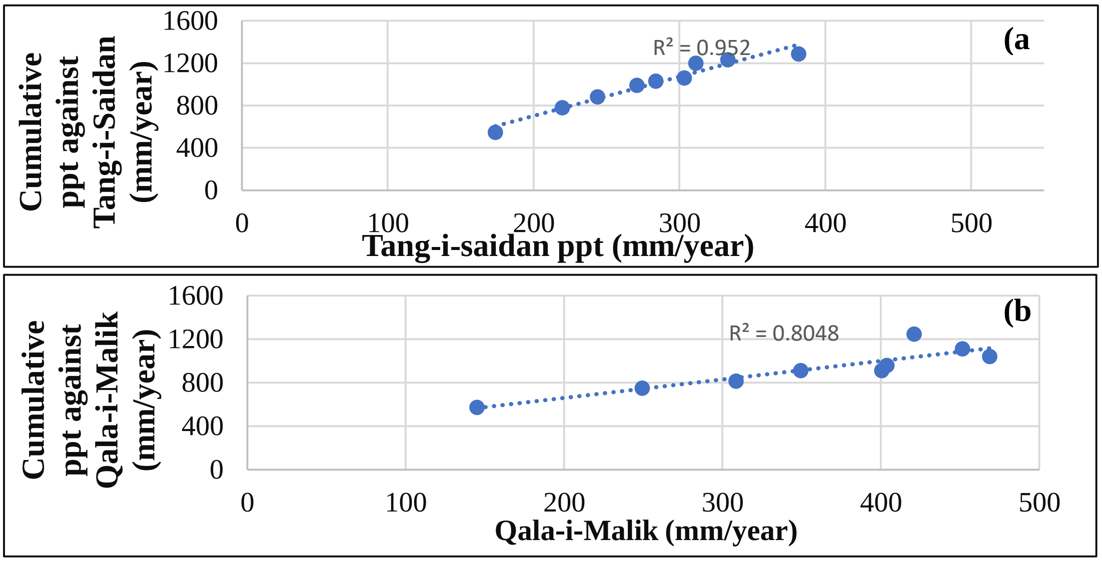


Figure 3-13 cumulative of precipitation stations for rectifying errors (a-b)

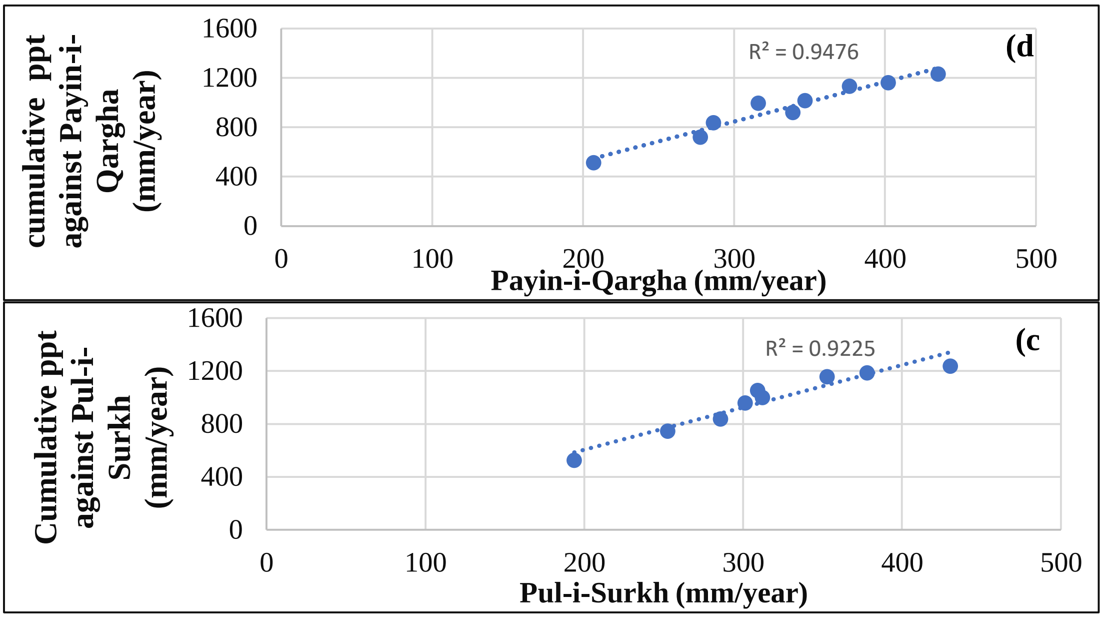


Figure 3-14 cumulative of precipitation stations for rectifying errors (d-c)

3.6.4.1 Double mass curve

The double-mass method is commonly used in the interpretation of precipitation records. Interpretation of double-mass curves frequently involves rejection or acceptance of indicated changes in slope (Weiss & Wilson, 1953). In many studies like in quantifying the impacts of precipitation variation and human activities on water discharge and sediment load in lower Xijiang, China, the double mass curve and linear regression methods is used (Zhang & Lu, 2009).

Double mass curve is one the wide technic for checking and rectifying of the data. in this method the data of a station is cumulatively summed against the accumulation of other stations presented in scatter graph. The result can be checked with the same graphs by the coefficient of determination (R^2) or visual checking. If the points go to the same trend means good match and if there is a miss movement of points that data need to be rectified. For this study the double mass curve is plotted for all of the precipitation stations (Tang-i-Saidan, Puli-i-Surkh, Payin-i-Qargha and Qala-i-Malik). For Tang-i-Saidan station is showed in Figure 3-15 and for other stations is shown in Figure (A-5) to Figure (A-7) in Appendix A. Based on visual inspection of every single stations it is not showing any miss direction of point. As result of this check the precipitation stations data are trustable for using in the analysis and further process.

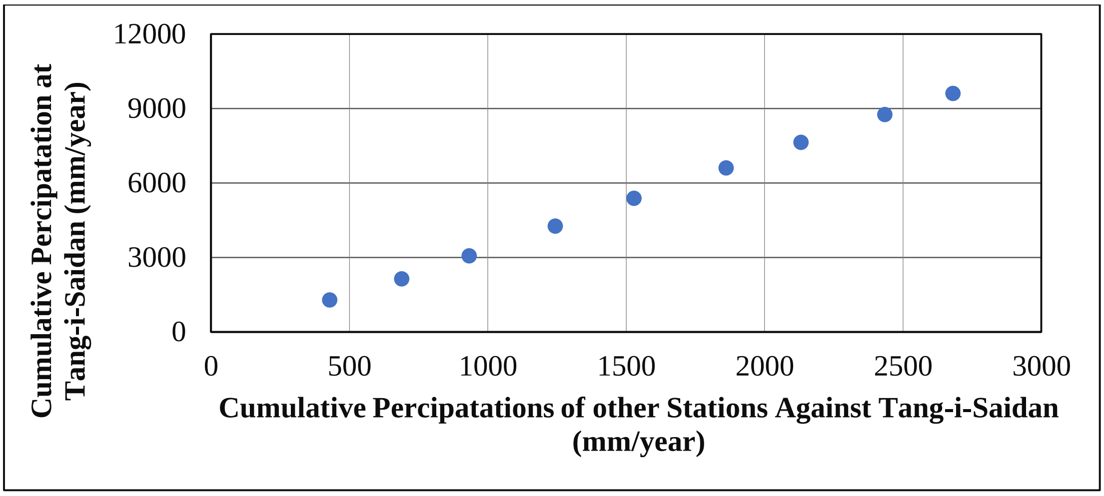


Figure 3-15 Double mass curve for Tang-i-Saidan precipitation station

3.6.4.2 Single mass curve

Single mass curve analysis is a graphical method for checking the data and it is widely used in hydrological modeling (Khandu, 2015; Sharifi, 2015). In this analysis, cumulative of every single station is plotted and is checked verses of another station. After carryout of data rectifying the single mass curve is plotted in this study for all the stations and it represented in Figure 3-16. According to this Figure for every single station form year 2009 to 2017 no any major miss direction has seen. As result of this check the precipitation data can be used in further process.

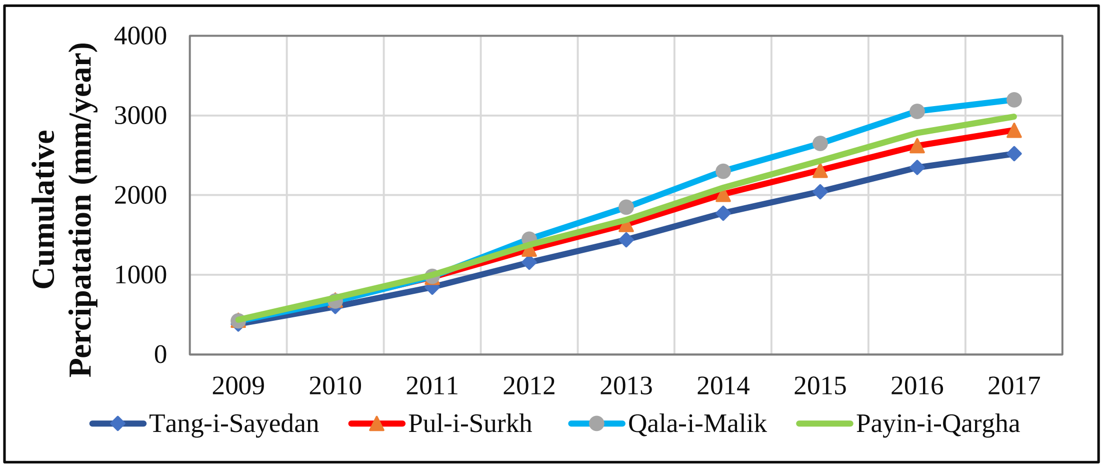


Figure 3-16 Single mass curve for precipitation stations

3.6.4.3 Annual sum of precipitation

Previously this check is carried and showed in Figure 3-11 which has many miss matching trend specially with Payin-i-Qargha precipitation station in year 2013 but looking to Figure 3-17 it shows that precipitation station is purified not only in year 2013 but thought every year.

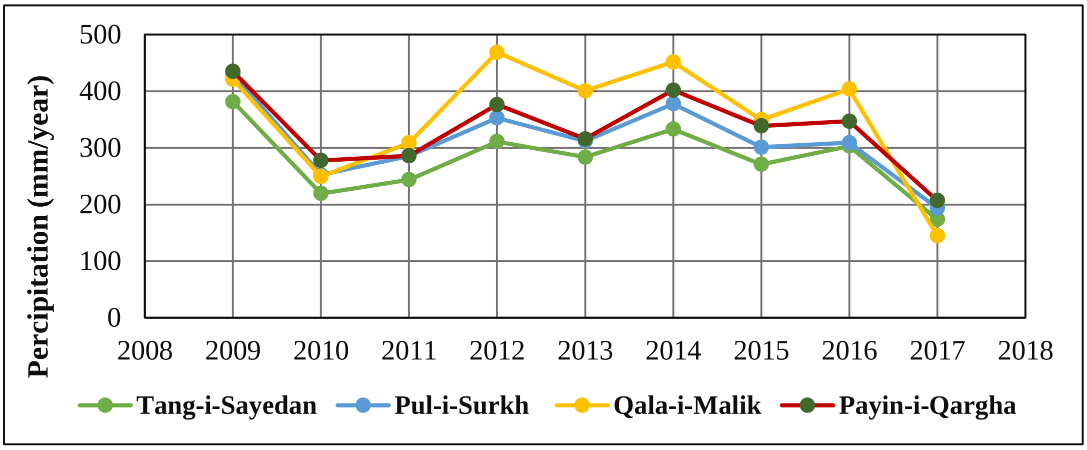


Figure 3-17 Annual sum of precipitation after data checking

3.6.5 Averaging Precipitation

GIS is a primary tools for interpolation of precipitation data and providing many methods like: Thiessen polygons, inverse distance weighted (IDW), thin smooth plate splines (spline), and ordinary kriging (Ruelland, 2008). The performance of every of these methods are different, corresponding to many factors like the model, number of gauging stations and topographic areas (Basistha, Arya, & Goel, 2007). The thiessen interpolation method is a simple method than any other methods mentioned and widely used around the world with hydrological modeling (Otieno, Yang, Liu, & Han, 2014) which is also used in this study. The gauging weights of precipitation stations is illustrated in table 3-15 and the map of thiessen polygon is shown in Figure 3-19.

Table 3-5 Thiessen precipitation stations characteristics

Precipitation station	Thiessen area	Station thiessen weight
Pul-i-Surkh	2032.83	0.84
Tang-i-Sayedan	191.05	0.08
Payin-i-Qargha	3.15	0.00
Qala-i-Malik	181.08	0.08
Total	2408.11	1.00

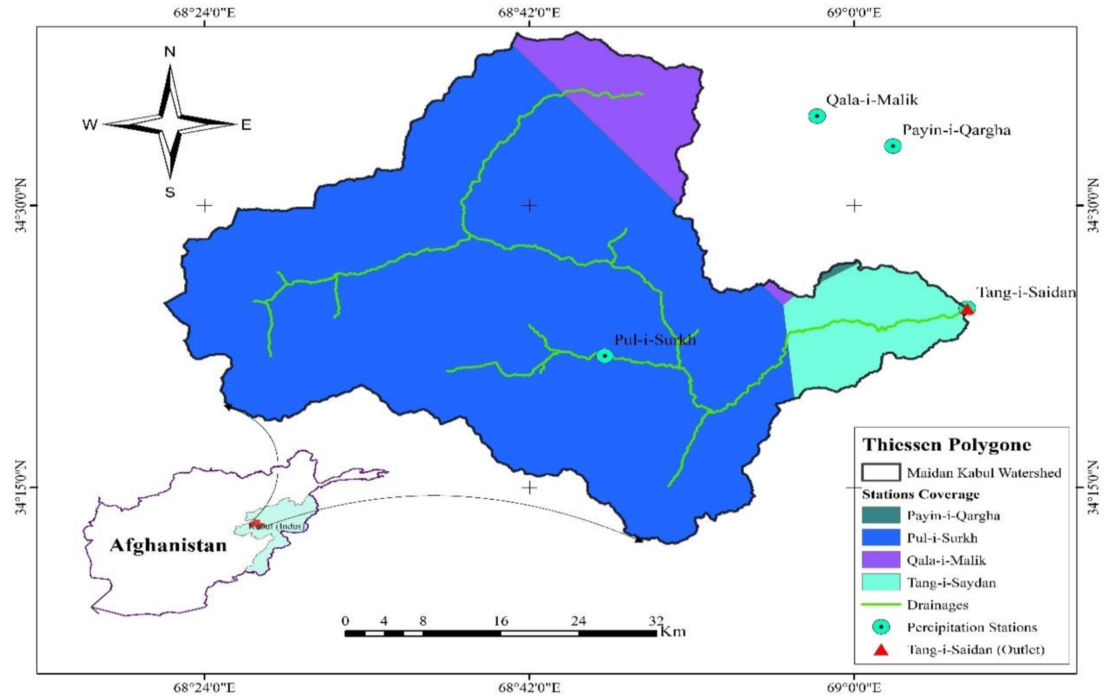


Figure 3-18 Thiessen polygon of Maida-Kabul Watershed

The response of Tang-i-Saidan streamflow station (outlet) to thiessen precipitation for year 2009 and 2010 is shown in Figure 3-19 and 3-10. Similarly, for other years are shown in Figure A-8 and Figure A-9 in the Appendix A of this thesis.

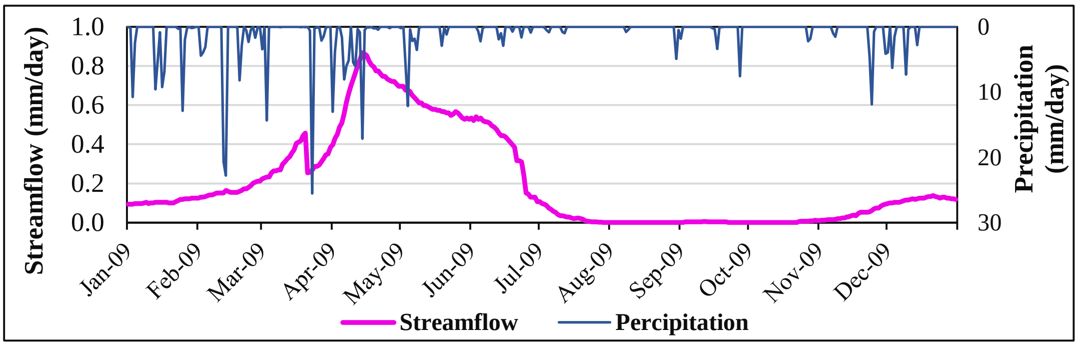


Figure 3-19 Streamflow response of Tang-i-Saidan to thiessen precipitation in year 2009

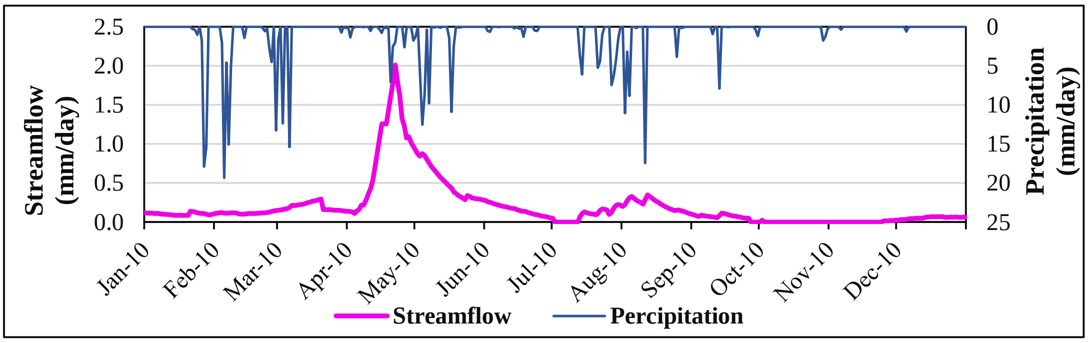


Figure 3-20 Streamflow response of Tang-i-Saidan to thiessen precipitation in year 2010

3.6.6 Monthly comparison of thiessen precipitation and streamflow

This check is carried out to investigate every single year monthly thiessen precipitation with the streamflow. In Figure 3-21 monthly comparison of precipitation with monthly comparison of streamflow in Figure 3-22 are compared. The streamflow in year 2009 in months of April to July is not in the same trend with other years but comparing to precipitation graph in the same year shows that precipitation is happened and it indicates that shift in streamflow in year 2009 is correct. Similarly, there is no any vivid error found to be considered in for checking.

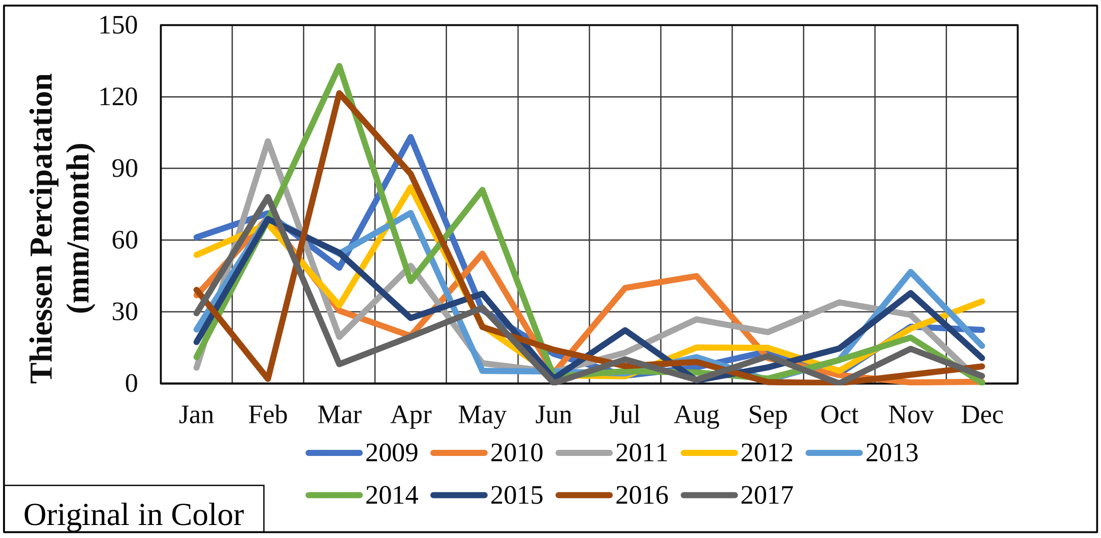


Figure 3-21 Monthly comparison of thiessen precipitation at Tang-i-Saidan from year 2009 to 2017

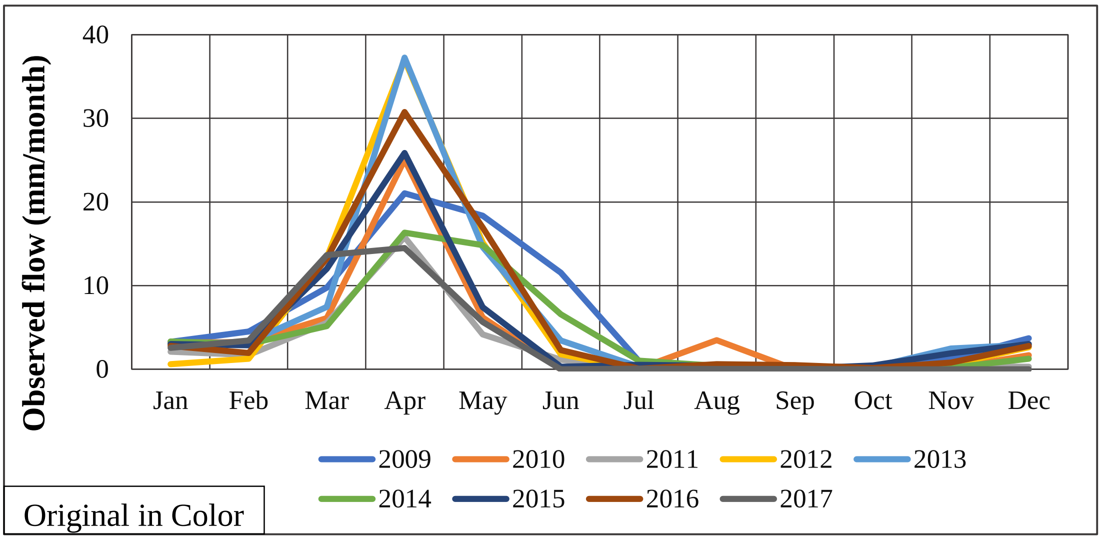


Figure 3-22 Monthly sum of streamflow at Tang-i-Saidan from year 2009 to 2017

3.6.7 Annual water balance for Maidan-Kabul River basin

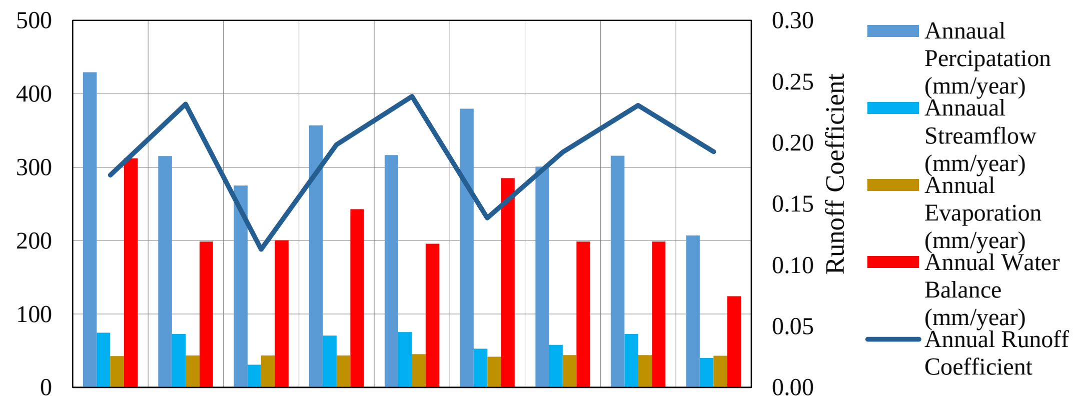
The water-energy balance for a catchment over a long-term timescale describes the relationship between the components of water and heat balances of land e.g., the partition of precipitation (P) into evapotranspiration (E) and runoff (R) controlled (Otieno et al., 2014). The simple water balance equation is describing in equation 3-1.

$$P=R+E+\Delta S \qquad (3\text{-}1)$$

Where P is precipitation, E is evapotranspiration (calculated by Blaney-Criddle), R is streamflow and ΔS is the change in storage (in soil or the bedrock/groundwater). In this study the annul water balance calculation is carried out in order to check the data. The result of that is shown in table 3-6 and Figure 3-23 which indicates that annual water balance in every year is less compare precipitations and the trend is following the same pattern for all years.

Table 3-6 Annual water balance values from year 2009 to 2017

Annual Water Balance of Maidan Kabul River basin					
Year	**Annual Precipitation (mm/year)**	**Annual Streamflow (mm/year)**	**Annual Evaporation (mm/year)**	**Annual Water Balance (mm/year)**	**Annual Runoff Coefficient**
2009	429.6	74.6	42.8	312.2	0.17
2010	315.2	73.0	43.5	198.7	0.23
2011	275.3	31.1	43.8	200.4	0.11
2012	357.0	70.8	43.4	242.8	0.20
2013	316.6	75.4	45.3	196.0	0.24
2014	379.9	52.6	42.0	285.3	0.14
2015	300.7	57.9	44.1	198.8	0.19
2016	315.8	72.9	44.3	198.7	0.23
2017	207.3	39.9	43.0	124.3	0.19
Average	321.9	60.9	43.6	217.4	0.2



Original in color

Figure 3-23 Annual water balance from year 2009 to 2017

3.7 Model Schematic

The model schematic is produced using the HEC-GeoHMS extension inside the HEC-HMS for lumped and distributed model. The lumped model is shown in Figure 3-24 and for distributed (Figure 3-25) five sub basin indicate good results in HEC-HMS (Nasimi, 2019) is used in this study.

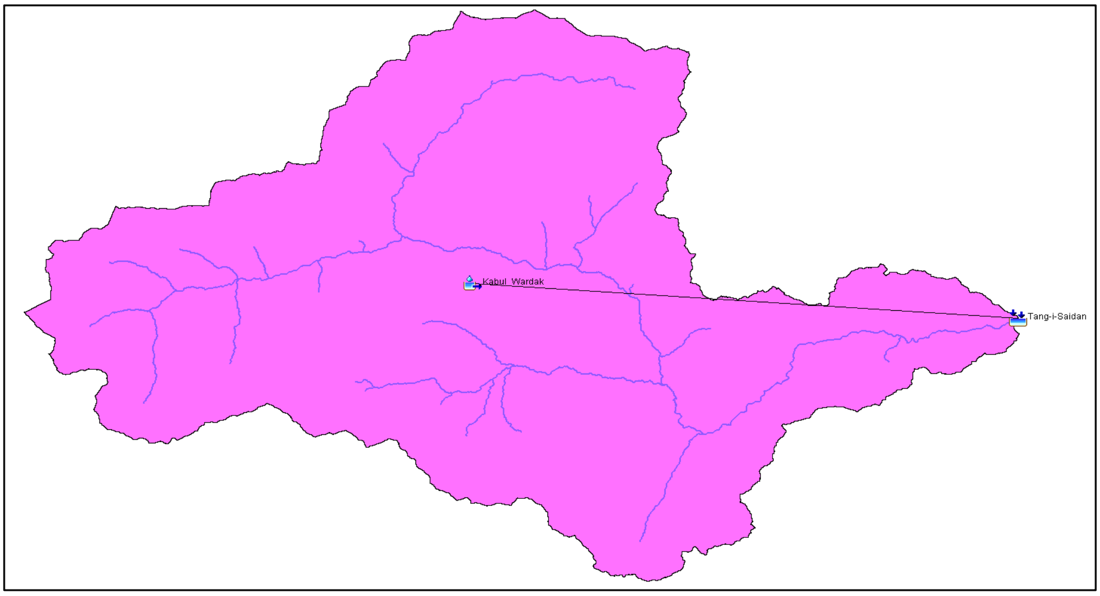


Figure 3-24 Lumped model schematic in HEC-HMS

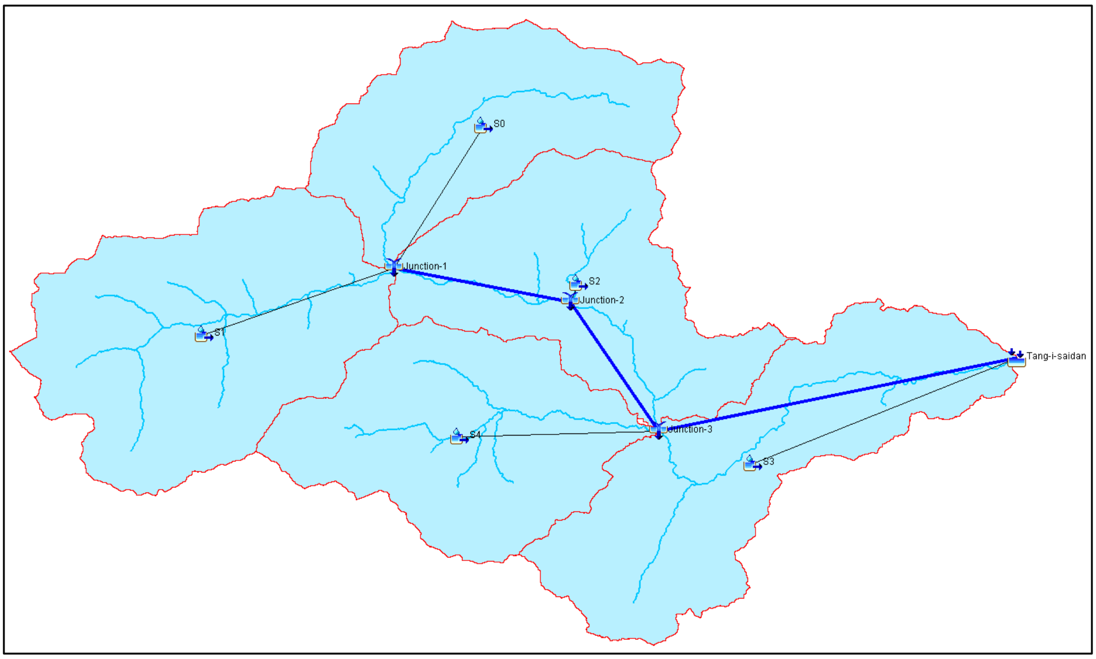


Figure 3-25 Distributed model schematic in HEC-HMS

4 ANALYSIS & RESULTS

The analysis part is combined of three parts which first part is concentrated on water resources and climate factors from historical perspective, second part is prediction the climate change scenarios of temperature and precipitation. Third part is hydrological modeling for analyzing the impact of climate change on streamflow. And, the las part is studying adaption measures to mitigate the impact of climate change.

4.1 Historical Analysis of climate and water resources

In this part the historical trend of climate and water resources are analyzed. The purpose of this part is to find the impact of climate change on streamflow, precipitation, temperature, evapotranspiration and humidity. The result of this part will illustrate the amount of impact and presents the needs of further studies respect to the future conditions in order to take adaptation measures. The data is used for this study is gathered from different sectors of Afghanistan government form year 2009 to 2017 except for streamflow which is available from 1962 to 1980. Although the nine years' data is not enough to study the climate change from the historical perspective but due to civil war in the country long historical data is not available. The simple statistical method which mostly rely on taking average along with considering trend line is considered for this study.

4.1.1 Impact on streamflow

Streamflow in Afghanistan context is mostly as a result of rainfall, snow and glaciers. Recent increased in temperature in past decades results in melting of glaciers and increased in surface area of the lakes. These change will lead to temporary increasing of the streamflow. As a result of increasing temperature and changing the climate factors melting early snow will happen that contribute in early forming of peak. In this study the climate change is only studied based on changes of streamflow peak as a vivid sign of climate change. Normally, in the study area the precipitation in snow pattern is falling during winter season which a respond of that melting process is starting during spring season (month of April and May). In this study based on available streamflow historical data from 1962-1980 and present data 2008-2017 the study is carried out. According to historical monthly streamflow analysis shows in

Figure 4-1, the peak of discharge is forming in month of April but in the present data in Figure 4-5, the peak of discharge is forming in month of March. As a result of this analysis, it indicates that the time of peak forming of discharge is shifted. When the peak of discharge is shifting in timely manner, it indicates that snow is melting earlier which is forming an early discharge. Increasing the temperature is the clear sign of climate change when the greenhouse gases is increased. Further, this study shows that peak discharge compare to past years is decreased and it shows that water volume is also slightly decreased.

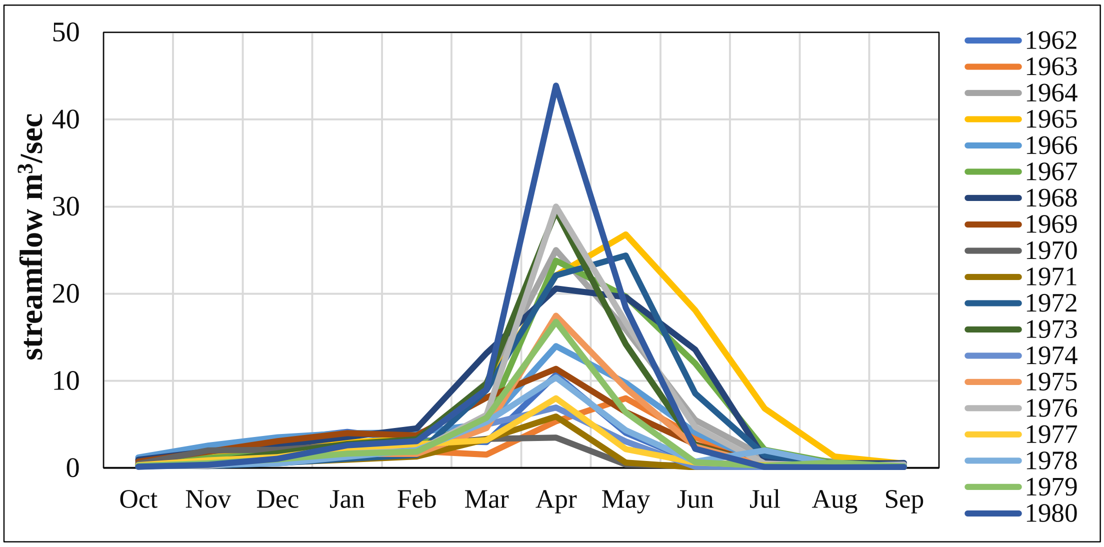


Figure 4-1 Mean monthly average streamflow from year 1962-1980 at Tang-i-Saidan

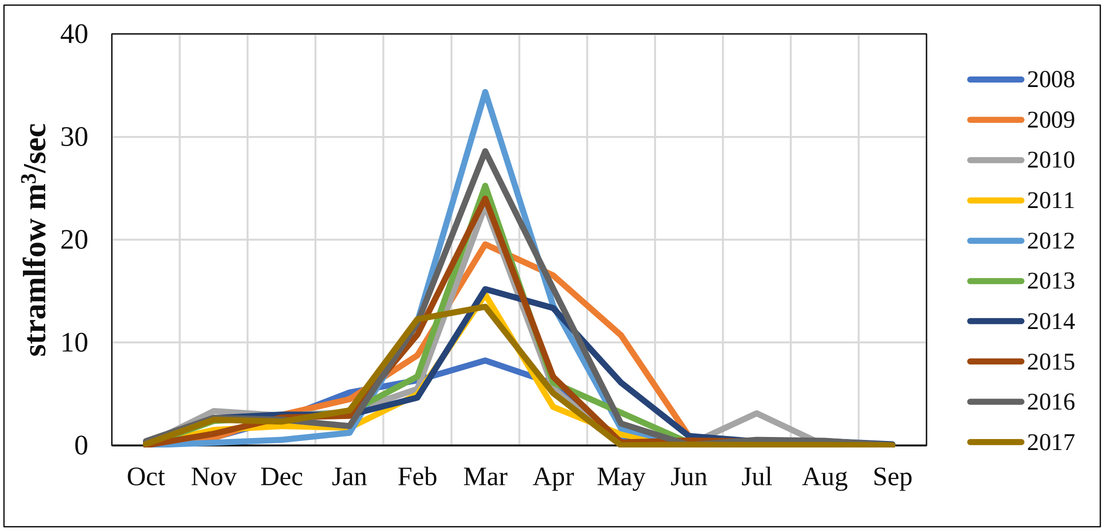


Figure 4-2 Mean monthly average streamflow form year 2008-2017 at Tang-i-Saidan

4.1.2 Impact on precipitation

Precipitation is the main source of water resources which is falling in kind of rainfall and snow. Studies around the world regarding the climate change indicates that precipitation is decreasing or increasing which is defer from region to region. In this study due to the limit of available data, only from 2009 to 2017 the precipitation data has analyzed which is shown in Figure 4-3. The trend of this analyzes clearly indicates that precipitation is following a decreasing trend. This analyze shows that the amount of precipitation is decreasing. This is a very simple analyses of climate change which many studies are carrying out in climate change studies.

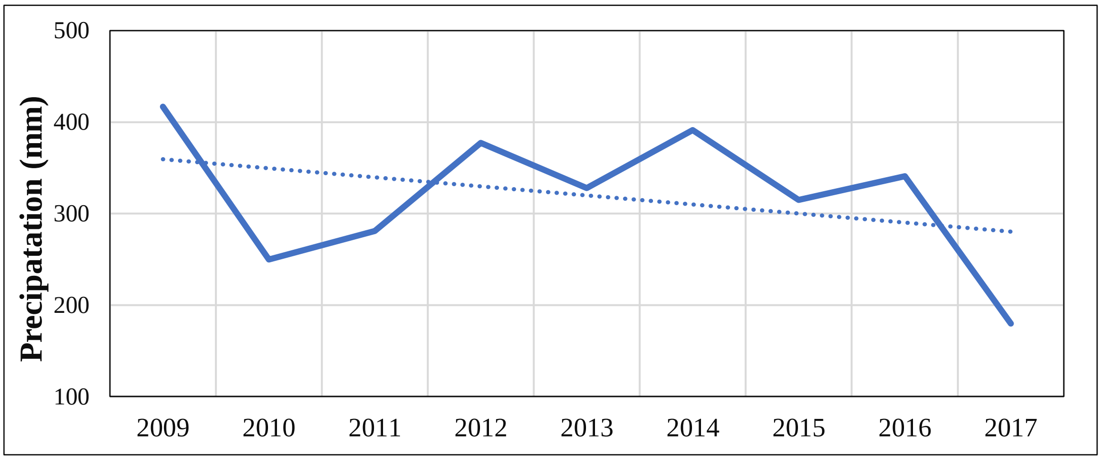


Figure 4-3 Annual precipitation trend from 2009 to 2017

4.1.3 Impact on temperature

Global climate change, caused by increased emissions of greenhouse gases increasing CO_2, and regional O_3 pollution are three important aspects of the changing atmosphere (Fuhrer, 2003).The presence of radiative active gases in the Earth's atmosphere (water vapor, carbon dioxide, and ozone) raises its global mean surface temperature (Mitchell, 1989). In this study temperature data has analyzed for every individual month in average manner for both winter and summer season from year 2009 to 2017. Due to lack of previous data, the comparison of historical data with the current data is not possible. Due to this limitation only for one recent decade this analysis is carried out. The temperature trend for winter season is shown in Figure 4-4 and for summer season shown in Figure 4-5. As a result of this analyses, it indicates that during the winter season the temperature is increasing in Pul-i-Surkh meteorological station. But in summer season the trend of temperature is little decreasing. This changes verified with people living in those areas that winter season temperature is changed more than summer season. They also explained that winter season is getting warmer compare to past years and the snow melting rate is increased soon after falling. Regarding the summer season, they noticed in recent year slight warmer but overall people are explained the sign of changes in temperature.

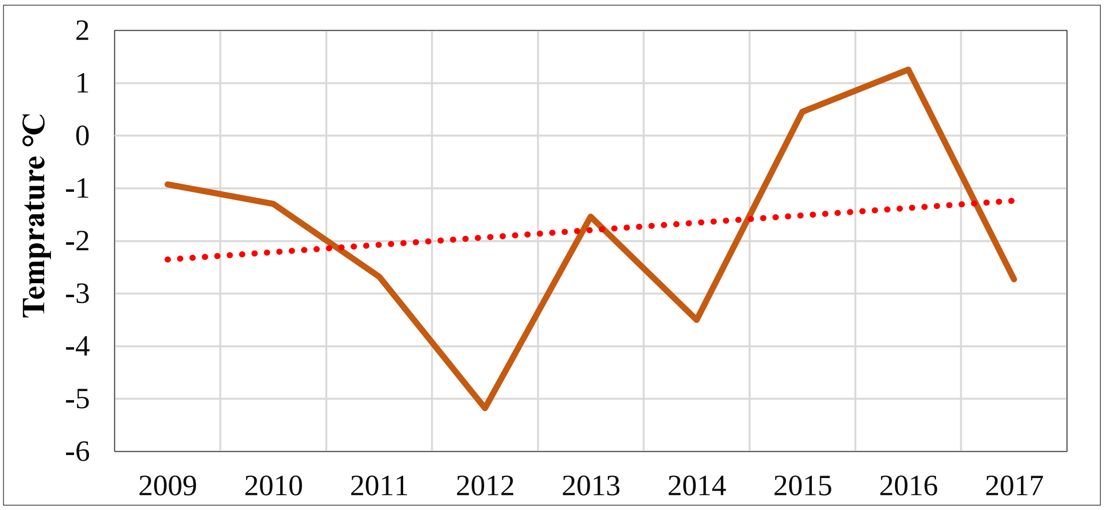


Figure 4-4 Trend of temperature in winter from 2009 to 2017

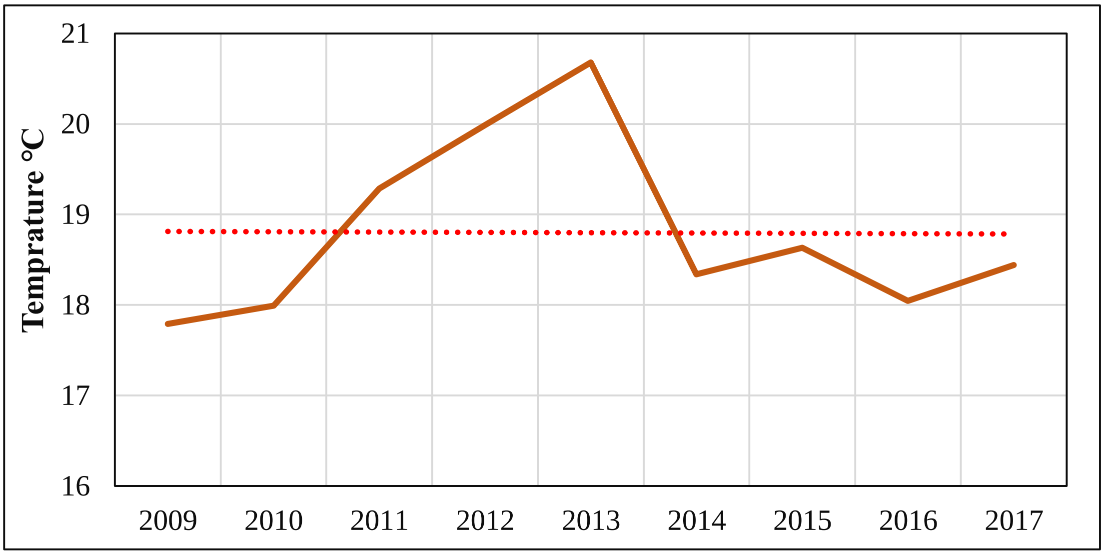


Figure 4-5 Trend of temperature in summer season from 2009 to 2017

4.1.4 Impact on relative humidity

The amount of water vapor present in the air is called humidity. The changes in the humidity of the air is the sign of climate change which its predicated to be increased in some part of the world. The scientists agree that increasing of humidity is a threat to life and make work environment difficult. In this study the humidity trend is analyzed base on the available data from year 2009 to 2017 for both winter and summer seasons. The average relative humidity though out this period for winter season (Figure 4-6) and for summer season (Figure 4-7) is showing an increasing trend. There is slight difference that this trend is increasing more in winter compare to summer season.

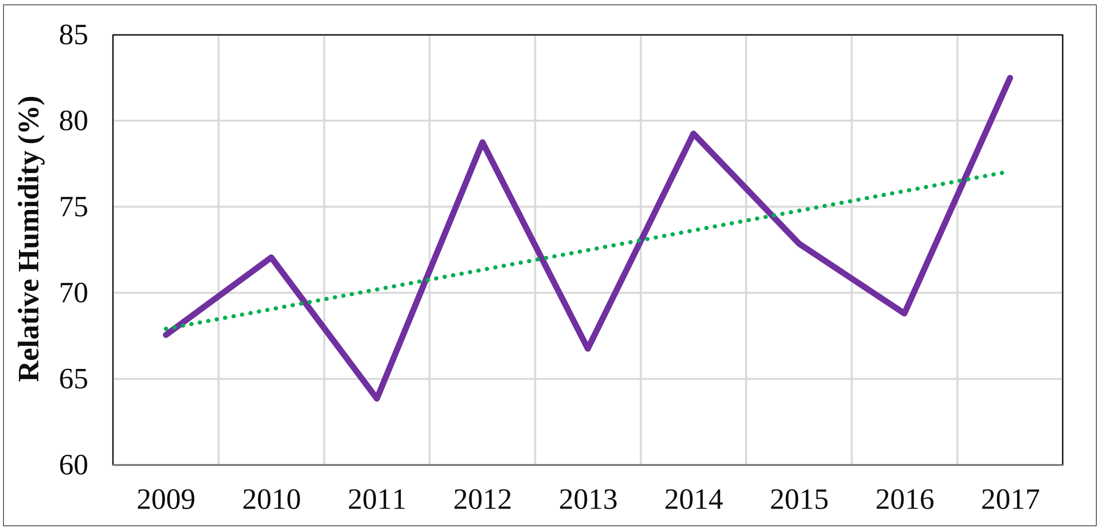


Figure 4-6 Trend of relative humidity in winter season from 2009 to 2017

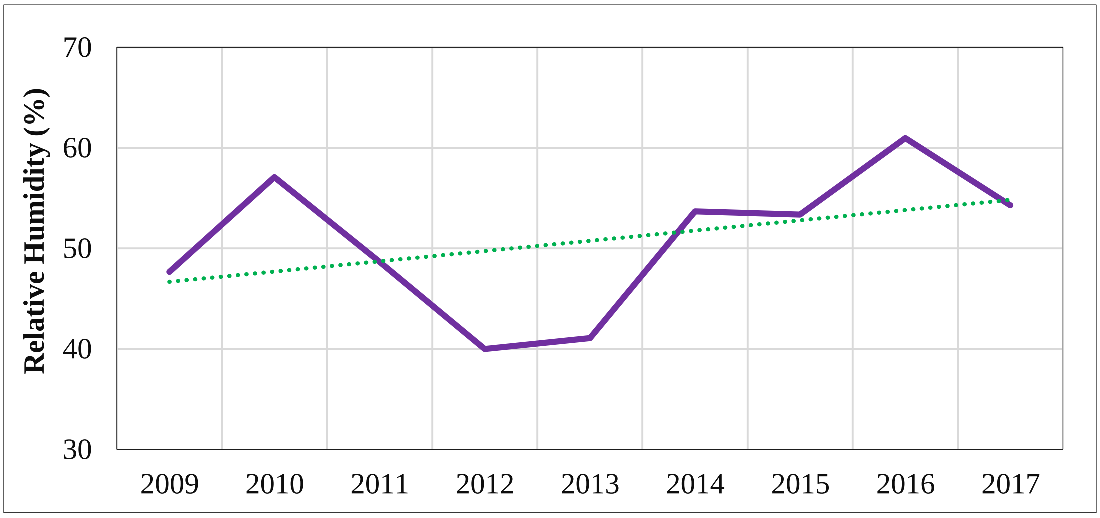


Figure 4-7 Trend of relative humidity in summer season from 2009 to 2017

4.2 Future analysis of climate and water resources

Future climate is studied based on changes of future temperature and precipitation in Maidan-Kabul river basin, Afghanistan. This river basin water resources are mainly based on solid precipitation which is highly vulnerable as result of alteration in temperature and precipitation to climate change. It is obvious that increase in temperature may cause decrease in snowpack volume especially in mountain areas and increases the evapotranspiration rate. In addition, warmer and drier climate will increase the sensitivity of the hydrologic cycle. The Maidan-Kabul watershed is located in arid region with fresh water resources of snow and ice which as a result of these changes the streamflow will severely be affected. The main objective of this analysis part is to study changes in future precipitation and temperature under climate change scenarios from three GCMs.

4.2.1 Global climate models (GCMs) and RCPs

Many studies around the world is studying the climate change in regional and global scales using these models with reference to the General Circulation Models (GCMs). There are uncertainties in prediction of climate due to sensitivity of the climate system to changes in the greenhouse gases (GHG) concentration. Which these uncertainties are causing them to project the climate differently under various GHG emissions. This can be addressed using the different statistical methods in order to establish an empirical relationship among GCM outputs. From the 39 GCMs built in the Coupled Model Inter-comparison project Phase 5 (CMIP5), 3 have been selected (Sidiqi, Shrestha, & Ninsawat, 2018). The reason for selecting is the finest resolution and widely usage in the region. Respect to the baseline (1961-1980) the two scenarios from which are RCP 4.5 (stabilizes radiative forcing at 4.5 W/m^2 in 2100 without ever exceeding that value) and RCP 8.5 (rising radiative forcing pathway leading to 8.5 W/m^2 by 2100) considered in forecasting the climate.

There are four scenarios base on their radiating forces which are RCPs (RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5) used by the IPCC. These four RCPs consist range of greenhouse emission scenarios with or without climate policies. RCP 2.6 illustrate low emission scenario which leads to very low forcing level. The happening of this scenario will be possible if proper mitigation policies and efforts are made to reduce greenhouse emission. RCP 4.5 and RCP 6 are the intermediate stabilization scenarios which can only be achieved if proper adaption strategies are implemented. RCP 8.5 pathway arises when very little or no effort is taken to reduce greenhouse gas emission.

In the Kabul river basin due to ongoing political crisis and less developing measure, it seems difficult that proper adaption will be considered in the future. Therefore, by consideration this and with less hope to the future two scenarios are selected which are RCP 4.5 if the adaptation is undertaken and RCP 8.5 if not, where no adaptation is considered. The Meteorological data for the future period was downscaled from the earth system grid federation (ESGF) website and used for climate change projections. The delta change approach is used for the downscaling and it considered a reliable simulate climate parameter changes in relative rather the absolute values. Further, this method uses differences between simulated current and future climate condition from GCMs added to observed (baseline) time series of climate variables.

$$T_f = \text{T (GCM simulated)}_f - \text{T (GCM simulated)}_p \tag{4-1}$$

$$P_f = \text{PPT (GCM simulated)}_f / \text{PPT (GCM simulated)}_p \tag{4-2}$$

Where p is used for the present and f is used for the future time period. The future scenarios are then generated using the eqs (3) and (4).

$$\text{F}_\text{s}\text{ (T)} = \text{T (baseline)} + \text{T}_\text{f} \tag{4-3}$$

$$\text{F}_\text{s}\text{ (PPT)} = \text{PPT (baseline)} \times \text{P}_\text{f} \tag{4-4}$$

Where F_s(T) is for future temperature, F_s (PPT) is for future precipitation and PPT is for precipitation. The GCM models for KRB were selected using statistical analysis. As statistical indicators, the coefficient of determination (R^2) and root mean square error (RMSE) offer the simplest and easiest method for mathematical calculation and used by many similar studies are shown in table 4-1 on below.

Table 4-1 Summary of the statistics for baseline and simulated temperatures, and precipitation at Kabul meteorological station in the Kabul river basin for baseline period 1961-1980 and after bias correction

Station	**Meteorological data**	**Before bias correction**	**After bias correction**
Kabul	Precipitation	$R^2 = 0.01$ $RMSE = 4.64mm$	$R^2 = 0.2$ $RMSE = 3.65mm$
	Maximum temperature	$R^2 = 0.69$ $RMSE = 6.54$℃	$R^2 = 0.92$ $RMSE = 2.84$℃
	Minimum temperature	$R^2 = 0.81$ $RMSE = 3.7$℃	$R^2 = 0.89$ $RMSE = 2.61$℃

4.2.2 Future projection of temperatures

For understanding the future changes in maximum and minimum temperatures, the projected values were considered in three future periods: the 2020s (2010-2039), 2050s (2040-2069), and 2080s (2070-2099) relative to the baseline period (1961-1980) under two emission scenarios (RCP 4.5 and RCP 8.5). The projected temperature for the RCP 4.5 Scenario both for the T maximum and T minimum is shown in Figure 4-8 and Figure 4-9, respectively. In the same manner the projected temperature for RCP 8.5 correspondingly for T maximum and T minimum is shown in Figure 4-10 and 4-11.

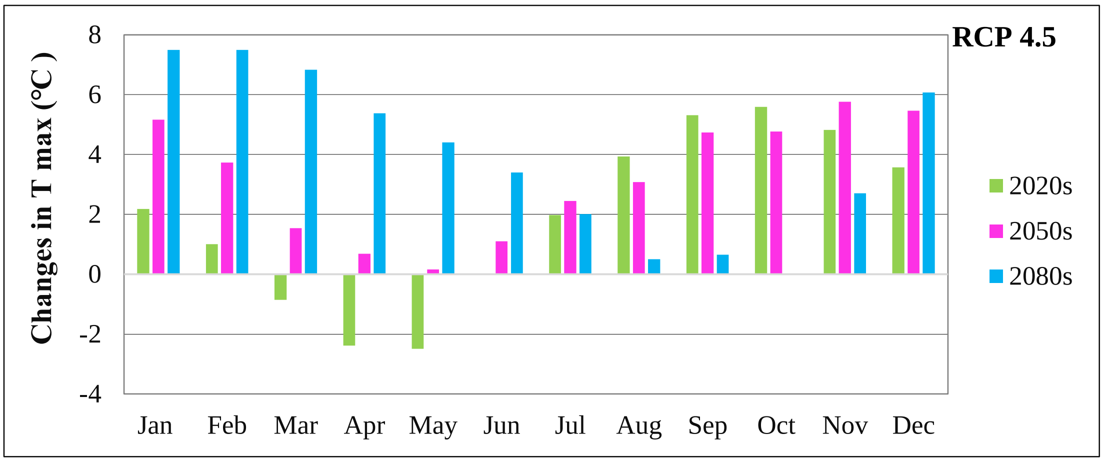


Figure 4-8 Future mean monthly changes in T_{max} relative to baseline period (1961-1980) under RCP 4.5 in the Kabul river basin

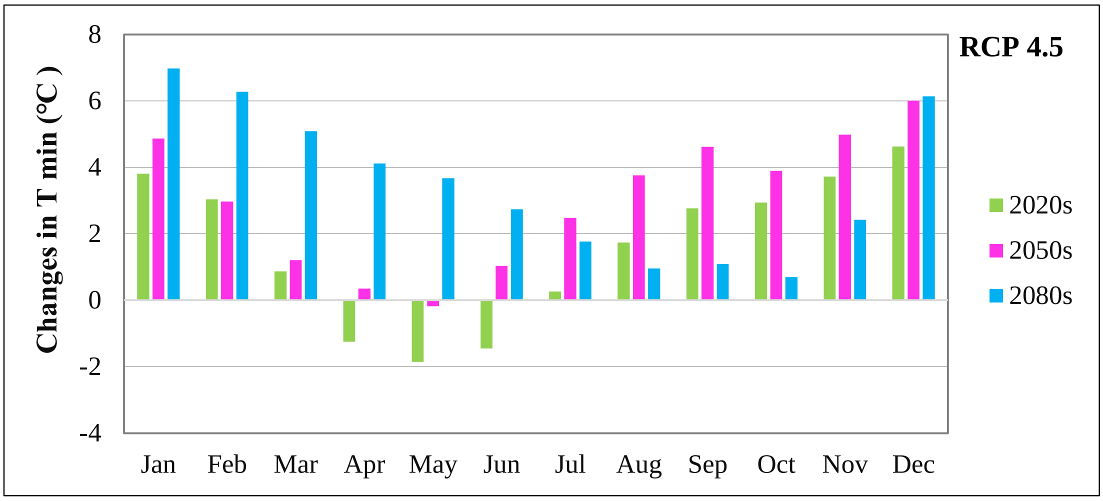


Figure 4-9 Future mean monthly changes in T_{min} relative to baseline period (1961-1980) under RCP 4.5 in the Kabul river basin

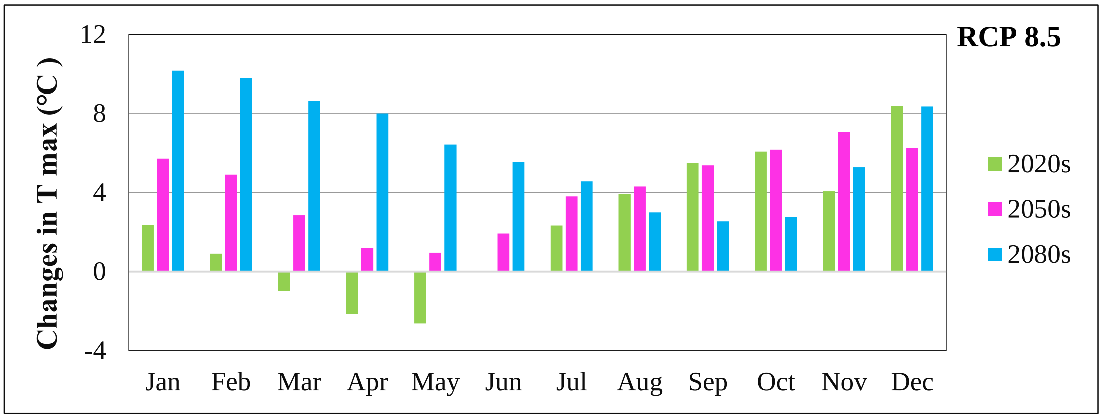


Figure 4-10 Future mean monthly changes in T_{max} relative to baseline period (1961-1980) under RCP 8.5 in the Kabul river basin

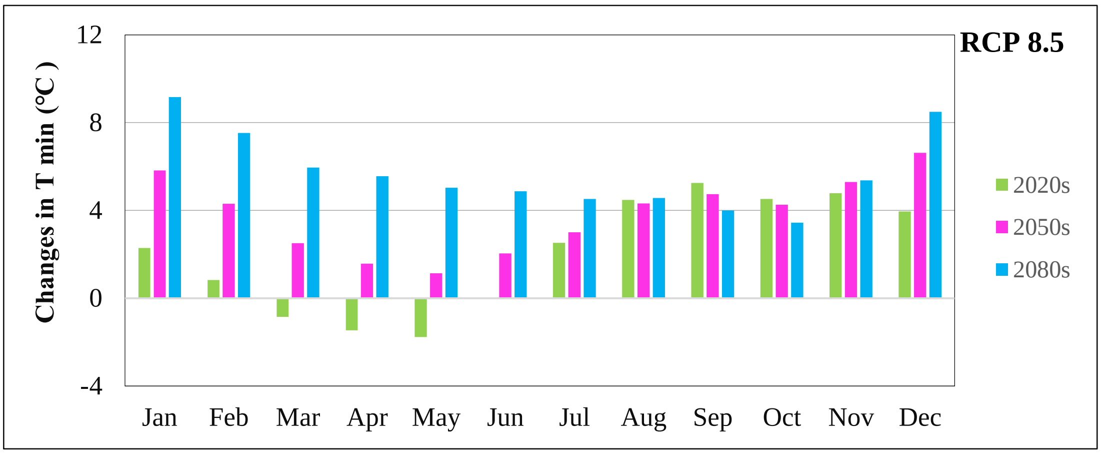


Figure 4-11 Future mean monthly changes in T_{min} relative to baseline period (1961-1980) under RCP 8.5 in the Kabul river basin

The projected values under the two emission scenarios indicates that maximum temperature increases for all months in all periods (2020s, 2050s and 2080s) except for the months of March, April and May for periods of 2020s under both scenarios. The comparison between the baseline and projected values shows that the maximum temperature will rise by 6.2 °C in the 2080s under RCP 8.5 and 3.9 °C under RCP 4.5 compare to the baseline period (1961-1980). It is observed that the hottest month at all stations is month of July. The coldest month in the historical period is January (-5.3°C) which this month simulation is also shows cold in the future. The mean temperature is expected to increase by 1.7 °C, 3°C and 3.7°C under RCP 4.5 and under RCP 8.5 up to 6 °C in the 2020s, 2050s and 2080s respectively.

In the meantime, projection in minimum mean monthly temperature indicates by the GCMs under both RCPs shows an increasing tendency. According to Figure 4-9 and 4-11 the minimum temperature increases for all months expect for months of March, April and May for the 2020s. Beside of that, months of December and January are more affected by changes in minimum temperature. Compare to the baseline, projected values shows that the minimum temperature will raise by 3.4°C under RCP 4.5 and 5.7 °C under RCP 8.5 by the 2080s.

4.2.3 Future projection of precipitation

The changes in monthly precipitation over the Kabul river basin under RCP 4.5 and 8.5 scenarios are shown in Figure 4-12 and 4-13 respectively. The wettest month was shifted from April to March. Besides, under both scenarios, the decreasing change is seen in January, February, March, April, October and December.

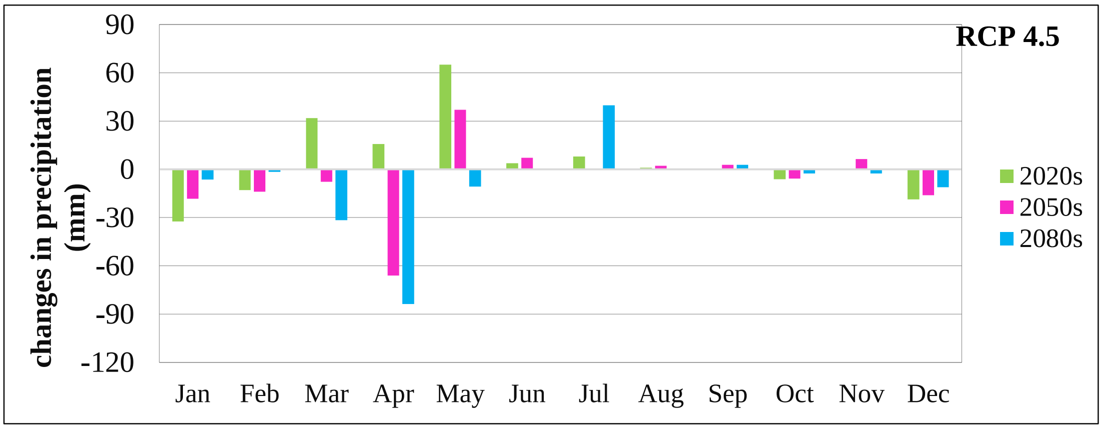


Figure 4-12 Future mean monthly changes in precipitation relative to the baseline period (1961–1980) under RCP 4.5 in the Kabul River Basin

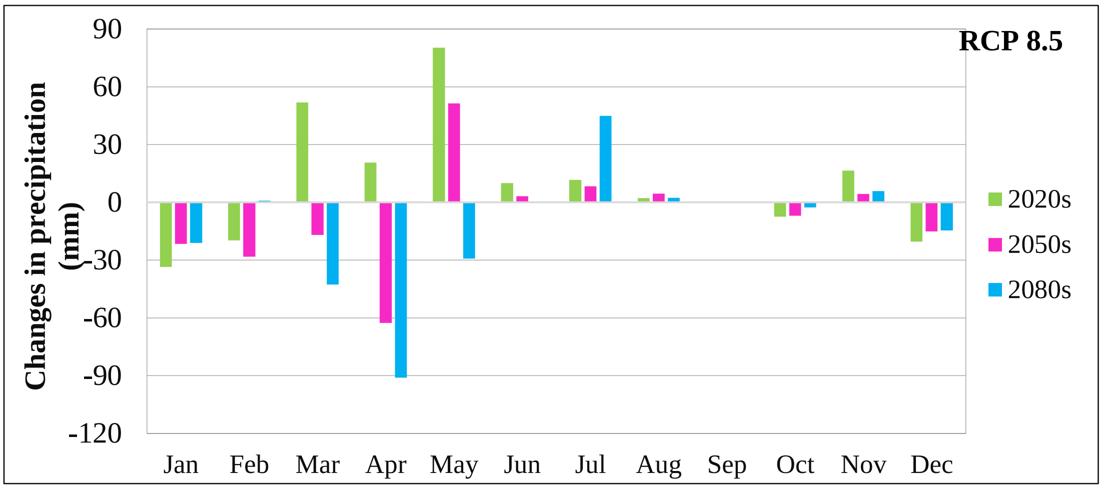


Figure 4-13 Future mean monthly changes in precipitation relative to the baseline period (1961–1980) under RCP 8.5 in the Kabul River Basin

4.3 Hydrological modeling

Watershed and basin management requisite hydrological models to properly simulate the runoff. Without the hydrological modeling studying different aspect of water management such as floods and droughts seems impossible. With development of computer technology and advances in science different models and technic are exist which defer from watershed to watershed. In addition, applying different models requires different data and techniques for parameter estimation that is not clearly mentioned in the guidance of most models. Rather to that, hydrologist by conducting different researches found different methods for estimation of the hydrologic model parameters. This case is also applicable with the HEC-HMS model respect to the SCN loss method and temperature index.

The main usage of the hydrological models is to simulate the movement of water through surface and groundwater layers for incorporating expected scenarios that explored through different researches for decision making process. Respect to this theory the climate change scenarios that were developed for the Kabul river basin is incorporated in this model to study the respond of runoff respect to these scenarios. It’s been clear that studying the climate change without hydrological modeling seems very difficult and impossible. The main component of climate that can be changed due to climate change is the temperature that directly affect the evaporation and it increases the rate of it. In addition, increasing of temperature will add to speed in early melting of snow and glaciers which contribute in early forming the peak. Respect to the study area, changes in the date of the peak can affect the water resources management and agriculture sectors.

Another climate factor that can be impacted due to climate change is precipitation. According to analysis of historical trend of precipitation, it shows decreasing trend over the country. In addition, climate projection of precipitation indicates that by 2020s it increases and by 2050s and 2099s the precipitation will be decrease further compare to baseline. It also indicates that under both scenarios the type precipitation will change from the liquid to solid particles. It also shows disorder in the precipitation falling compare to present in each months. The result this of changes will not lead to natural disasters such as floods and drought but millions of peoples will suffer.

The main objective of the hydrologic modeling is not only incorporating the future precipitation and temperature scenarios but also studying the behavior of the data. Through hydrological modeling, it will be possible to discover the exactness of the acquired data and find out the relation between the captured precipitation and streamflow. In this part beside of incorporating the scenarios studying the relation of the data is expected to study. The procedure for this is starting from the parameter estimation, sensitivity analysis, calibration and verification periods which each of them will be studied separately under this section.

4.3.1.1 Parameter estimation

The HEC-HMS model is used in this study due to number of benefits such as accessing to required data, its suitability in cold and mountainous condition and free access availability. This model is structured in such a manner that has to be close to the reality and capture the physical parameters like canopy, surface storage, loss, transform, routing and temperature index. These methods are required variety of method for extracting the relevant parameters that will be studied individually in this section. Different tools such as GIS, remotes sensing, excel and mathematical calculations are used for extracting the parameters.

4.3.1.2 Canopy method

Water through the process of falling to earth is initially reaching to the surface of plants before approaching to the earth surface. In the study area where it covers mostly with mountains, canopy loss has very low impact on the hydrological modelling part. But considering this loss method can increase the model accuracy and help in the calibration process. There are mainly three methods for canopy values estimation which are simple canopy if there will be single plant, dynamic if the plant is shifting from season to season or gridded simple canopy considering every individual single plant. For the study area base on table 4-2, the landuse map is classified (Figure 4-14). The extracted values for both lumped and distributed model is shown in Table 1-B, Appendix B.

Table 4-2 Canopy storage values for Maidan-Kabul Watershed

Vegetation type	Canopy interception (mm)
General vegetation	1.27
Grasses and deciduous trees	2.032
Trees and coniferous trees	2.54

Source: (Bennett & Peters, 2000)

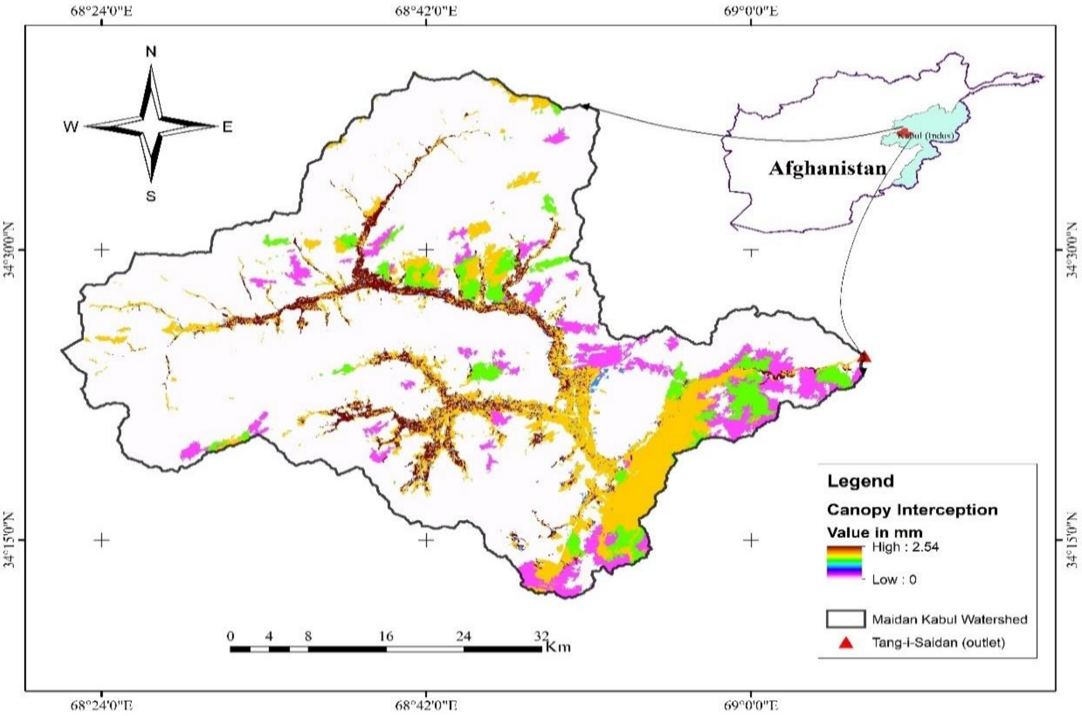


Figure 4-14 canopy storage raster for Maidan-Kabul watershed

It can be concluded from Figure 4-14 that values are in the range between the 0 to 2.54 according to Bennett and Peters (2000) suggestion. For this study the vlues are ectracted in average using the simple cnopy gridded mehtod. The GIS software is used for developing the canopoy raster and extrating the relevant amounts.

4.3.1.3 Surface method

When water is falling through precipitation to the earth, theoretically after filling the canopy surface its falling to the earth. The surface storage is defined as the amount of water that is directly falling after the precipitation and due to topographic of the land surface is accumulating to the surface based on the slope. Then it is contributing to the evapotranspiration and groundwater storage and after some time it gradually taking part to the runoff. Based on many researches and according to Bennett al. (2000), the surface storage corresponds to slope and landuse is classified and showed in table 4-3.

Table 4-3 Surface storage values for Kabul-Maidan watershed

Description	Slope %	Surface storage (mm)
Paved impervious areas	NA	3.2-6.4
Steep, smooth slopes	>30	1.0
Moderate to gentle slope	5-30	12.7 -6.5
Flat, furrowed land	0-5	50.8

Source: Bennett al. (2000)

Based on the table 4-3 the study area is classified in three categories in an average manner. If some palace in study area have 1mm storage values, it indicates where the sloop is very steep and all the water is falling down after precipitation. Some places where it has moderate slope has approximately an average of 9mm storage capacity of precipitation and palaces where is all flat has the capacity of 50 mm surface storage. According to the satellite map and landuse of study area, it’s clear that most of study area is covered by mountains with steep slope which as result of that very less precipitation is being stored. It also need to be mentioned that surface storage is applicable for precipitation both in form of solid or liquid. The surface storage raster maps are developed according to table 4-3 is shown in Figure 4-15. Surfaces storage values are extracted based on for lumped and distributed model as shown in Table 1-B in Appendix B.

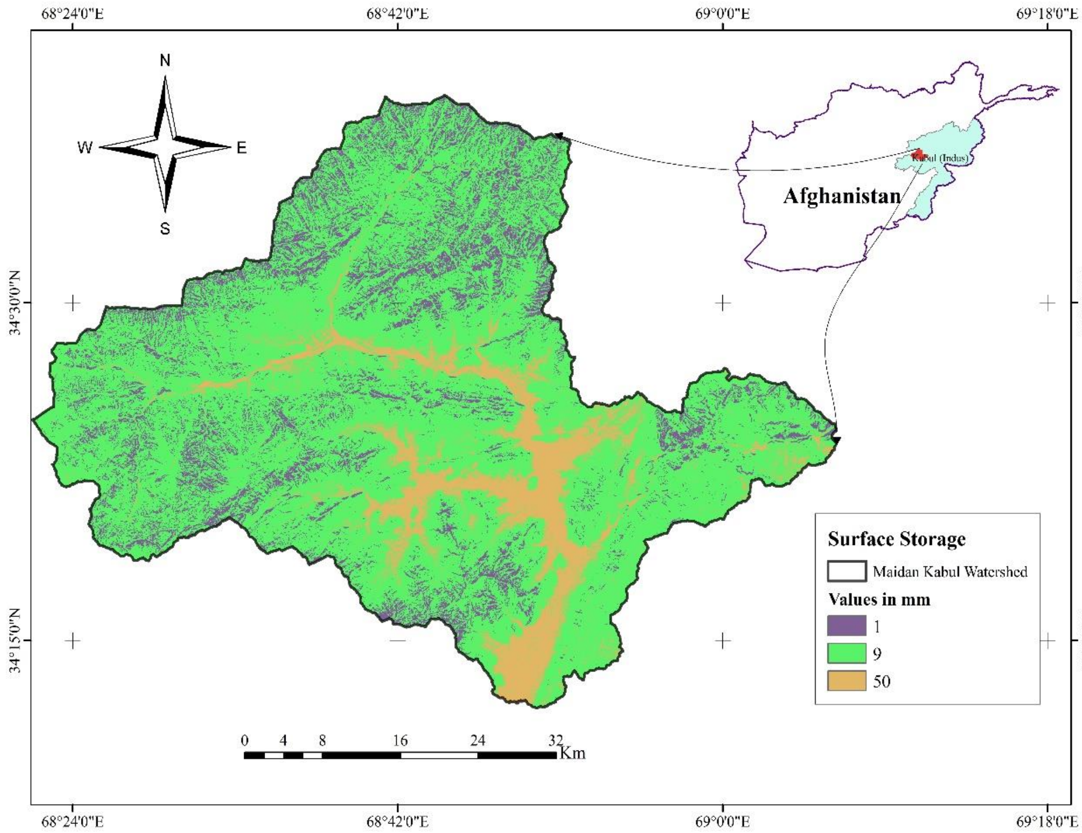


Figure 4-15 Surface storage raster map for Maidan-Kabul watershed

4.3.1.4 Loss method

Base on the observation from the streamflow data which is forming the peak discharge is only during the months of April to May, the SCS curve number is used for this study in loss method.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (4\text{-}5)$$

$$CN = 1000/(S+10) \qquad (4\text{-}6)$$

Where in the above equations Q is direct (surface) runoff, *P* is the total precipitation, *S* is the potential maximum retention and CN is the curve number. According to this method two important constant values are required for the input which are curve number (CN) and impervious percentage. Besides Infiltration and effective net precipitation could be obtained with the Curve Number method (CN), given by the Soil Conservation Service (Mckeever, 1972).The impervious percentage and the curve number needs to be insert to the model for both lumped and distributed model. The impervious percentage is developed for individual landuse according to the landuse coefficient attached in table 2-B, Appendix B of this thesis work. Similarly, the curve number is also developed based on the HEC-HM manual (HEC, 2000) suggests for different landuse. The impervious percentage raster and curve number are shown in Figure 4-16 and Figure 4-17 respectively and the optimized values are shown in Table 1-B in Appendix B.

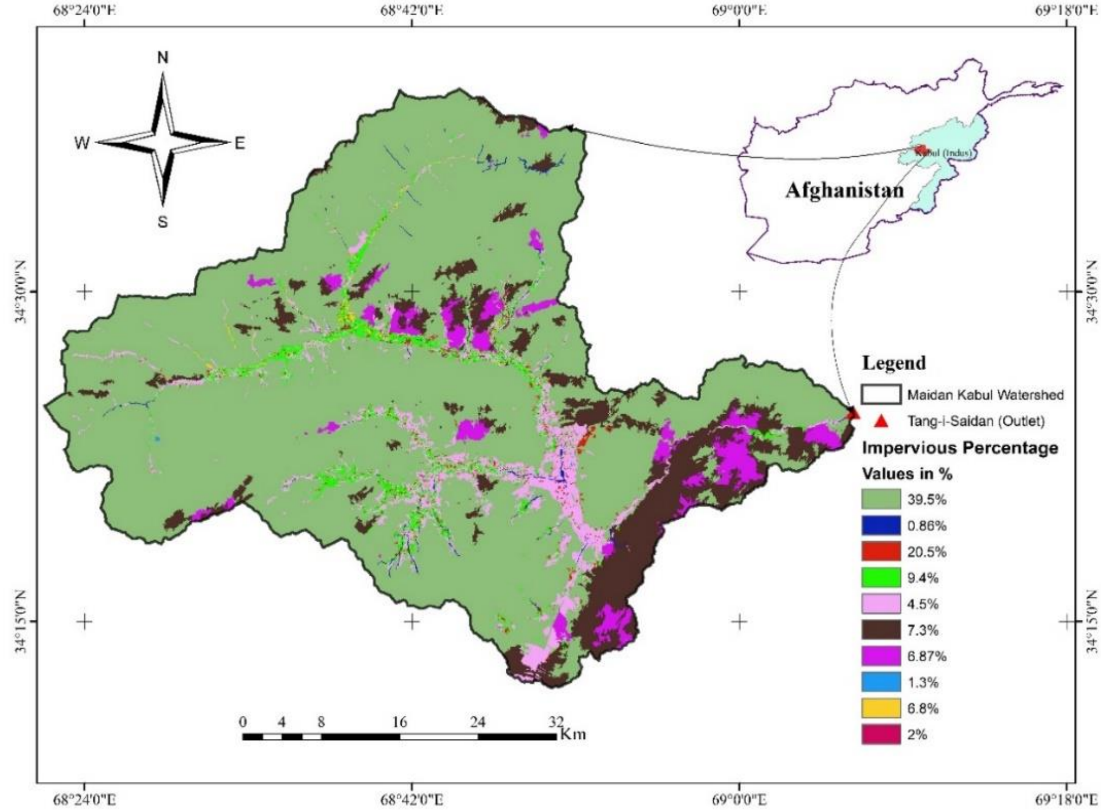


Figure 4-16 Impervious percentage raster for Maidan-Kabul watershed

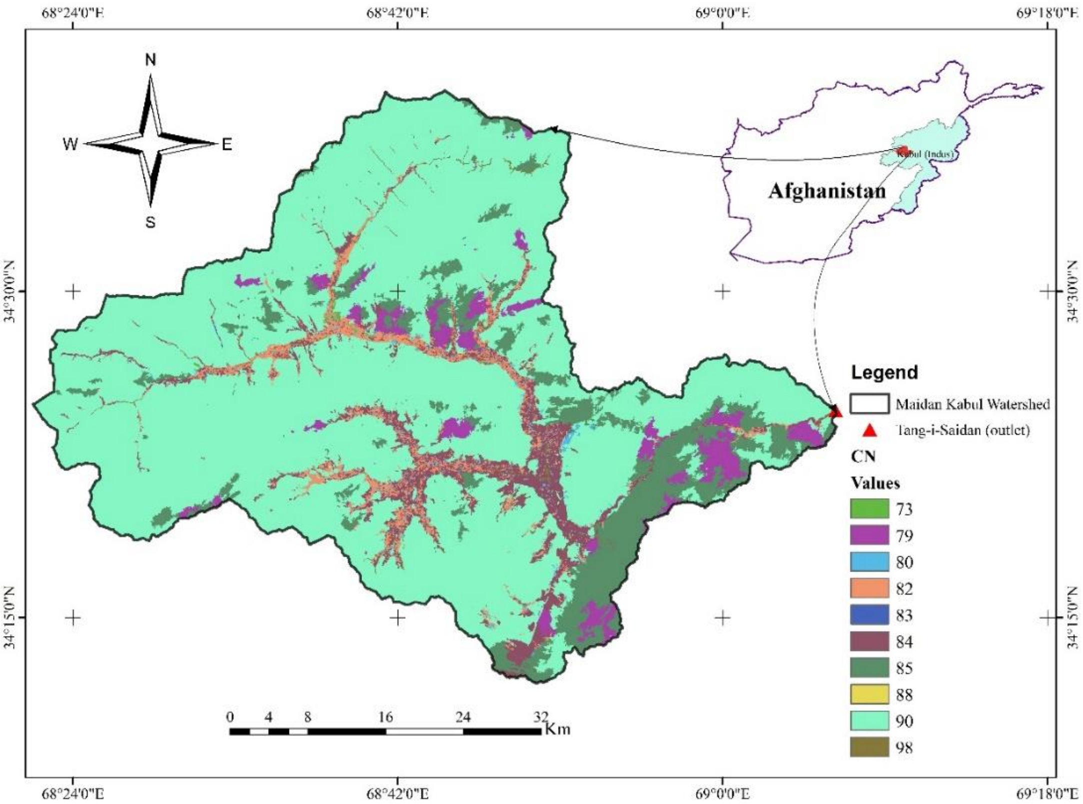


Figure 4-17 CN (curve number) raster map for Maidan-Kabul watershed

It can be find from the landuse map that most of landuse is covered with mountains which because of that the impervious percentage and curve number has high values in those areas. Where water is less infiltrate to soil and instead of that either it stored in ice form during winter or directly contributing to runoff in spring and summer season when earth temperature is increasing.

4.3.1.5 Transform method

The model that simulate the process of direct runoff of excess precipitation on watershed refers to transformation of precipitation excess into point runoff. In this model many transform methods can be supported but the Clark Unit Hydrograph Transform method which is a synthetic unit hydrograph method is used for the current study, due to it is common usage and easiness of parameter estimation. It requires two parameters which are time of concentration (HR) and storage coefficient (HR), these two parameters are calculated through NRCs formula written in below:

$$T_c = \frac{L^{0.8}(\frac{100}{CN} - 9)^{0.7}}{1140S^{0.5}} \quad (4\text{-}7)$$

In the above formula, the Tc is the time of concentration in hour, CN is the curve number, L is the longest length in foot and S is the slope in percentage.

The relationship between the time of concentration and storage coefficient is defined in equation 4.8 suggested in the NRCS method.

$$\frac{T_C}{R} = 1.46 - \frac{0.0867 * L^2}{A} \quad (4\text{-}8)$$

In the above formula the Tc is the time of concentration, R is the storage coefficient in hour, L is the longest length in mile and "A" is the drainage area in mile square. The watershed area and Longest stream length has calculated automatically using the ArcGIS software. Curve number is retrieved based on the Landuse from Figure 4-17 and the slope is retrieved from the slope map from Figure 4-18 in below. The optimized values for time of concertation and storage coefficient is mentioned in table 3-B in Appendix B.

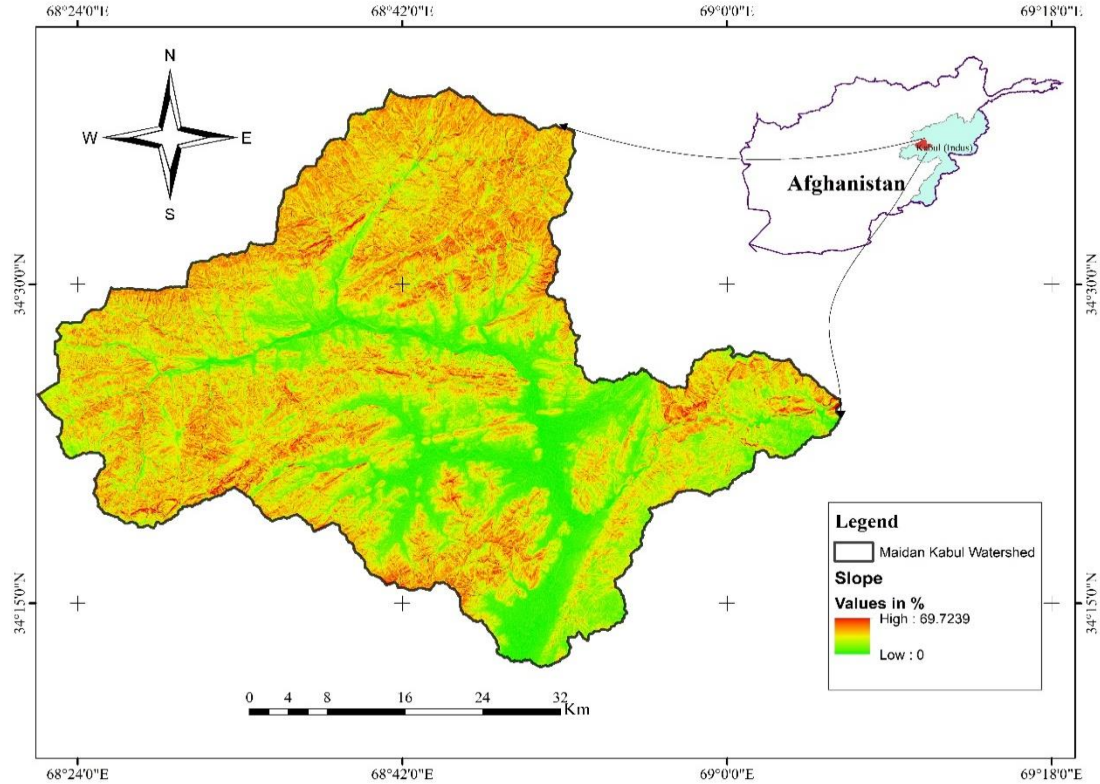


Figure 4-18 slope raster map for Maidan-Kabul watershed

4.3.1.6 Baseflow method

In a simple definition base flow is the sustained runoff, prior to precipitation that was stored temporarily in the watershed, plus the delayed subsurface runoff from a storm. Mainly three alternatives models exist as baseflow: constant, monthly-varying value, exponential recession model and linear-reservoir volume accounting model that out of all, the exponential recession model is selected based on the applicability of this model along with the SCN curve method. Baseflow parameters includes of initial discharge, recession constant and ratio to peaks are calculated through streamflow analysis. According to HEC (2000) it is calculated through this formula:

$$Q_t = Q_0 K^t \quad (4\text{-}9)$$

In the above formula, Q_0 is initial baseflow; K is the exponential decay constant which defines as the ratio of the baseflow at time “t” to the baseflow one day earlier and Q_t is the baseflow at any time of t. For calculating these parameters an event is selected which then optimized values are retrieved from the calibration process. The event is selected from month of April to May in year 20010 which is shown in Figure 4-19.

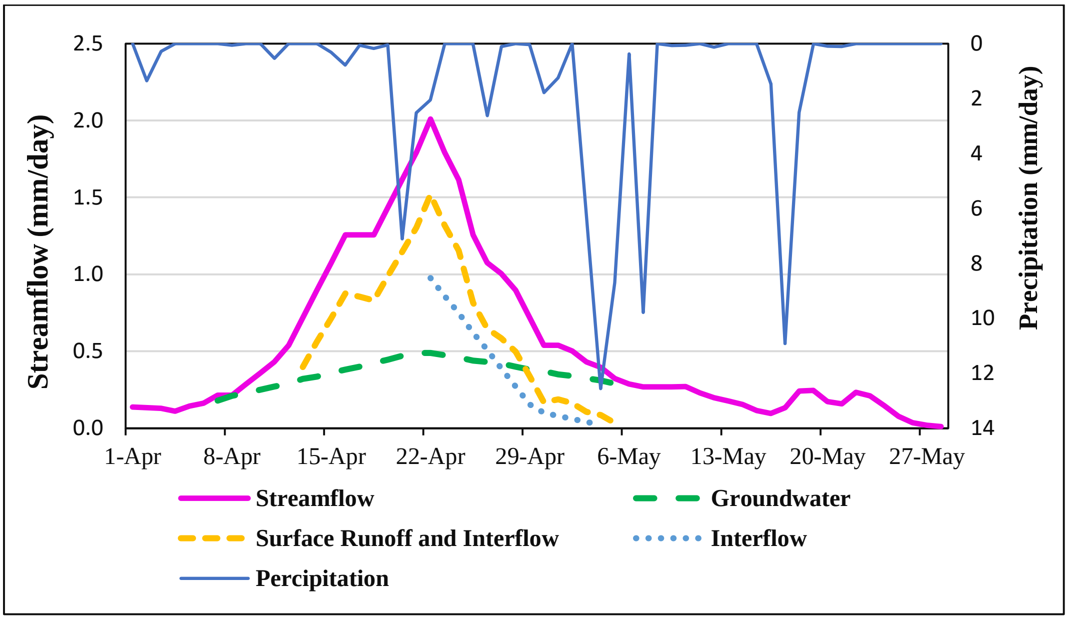


Figure 4-19 Water flow component separation for streamflow recession analysis

In the Figure 4-19 the groundwater (baseflow) and interflow is subtracted from the runoff. Based on the equation (4-9) those parameters are calculated as follow according to selective event in Figure 4-19.

Q_0 = 0.14mm/day (1st April 2010); Q_t = 0.22 mm/day (8th April 2010) and t= 8 days which these values are incorporated in the above formula for retrieving the K value:

$$0.22 = 0.14K^8$$

Which finally the K =1.058, this parameter has to be further calibrate based on the observed streamflow for retrieving the optimized value. Another parameter which is threshold discharge is written according to this formula:

Q_{tr}= 0.22 mm/day and the Q_{peak} = 2.01 mm/day, which the ratio to peak is calculated:

$$Ratio\ to\ peak = \frac{Q_{tr}}{Q_{peak}} = \frac{0.22}{2.01} = 0.11 \qquad (4\text{-}10)$$

The recession constant and ratio to peak optimized parameters are mentioned in table B-4 in Appendix B.

4.3.1.7 Routing method

Modelling of the channel flow is possible through routing methods, the available routing methods in HEC-HMS are: Lag, Muskingum, storage routing, Kinematic-wave and Muskingum cunge. For this study the Muskingum method is used which requires two parameters the are Muskingum K (HR) and Muskingum (x). The X parameter range is between (0-0.5) and the final values of these parameters are optimized based on the calibration. The optimized values are mentioned in table B-5 in Appendix B for the distributed model which consist of three reaches. But for the lumped model there is no reach and it assume that all water through catchment is falling to the outlet in Tang-i-Saidan.

4.3.1.8 Temperature Index

Snow and ice melting are computed considering the degree day approach (Rango & Martinec, 1996).The precipitation is falling in pattern of rainfall when the temperature is higher than zero and it is considered as a rainfall and when the precipitation is below to zero it is considered as a snow type and that will be saved in the mountains and earth surface. The respect basin is considered as a cold basin which mostly receives precipitation in terms of snow during the winter season. The temperature index method requires some parameters that are estimated base on the HEC (2000) manual reference. The optimized para meters for lumped model is mentioned in Figure 1-B in Appendix. Similarly, for the distributed is shown in Figure 2-B in Appendix B and the ATI-Meltrate function is mentioned in Table 5-B in Appendix B for both lumped and distributed model.

4.3.2 Sensitivity analysis

Sensitivity analysis is an important analyzes for determining of sensitive parameters that can effect to the calibration period. This effect can be changes on peak, time to peak, baseflow, raising limb and falling limb. As result of that in the all scenarios the volume of runoff is changing. In this study the sensitivity analysis is carried to for identifying the sensitive parameters that has play crucial role in calibration process. The sensitive analysis carried out in this research work is presented in Figure 4-20 which shows the sensitivity of each parameters respect to change in runoff volume in percentage. As a result of this analysis it was found that impervious percentage is the most and water capacity is among the least sensitive parameters.

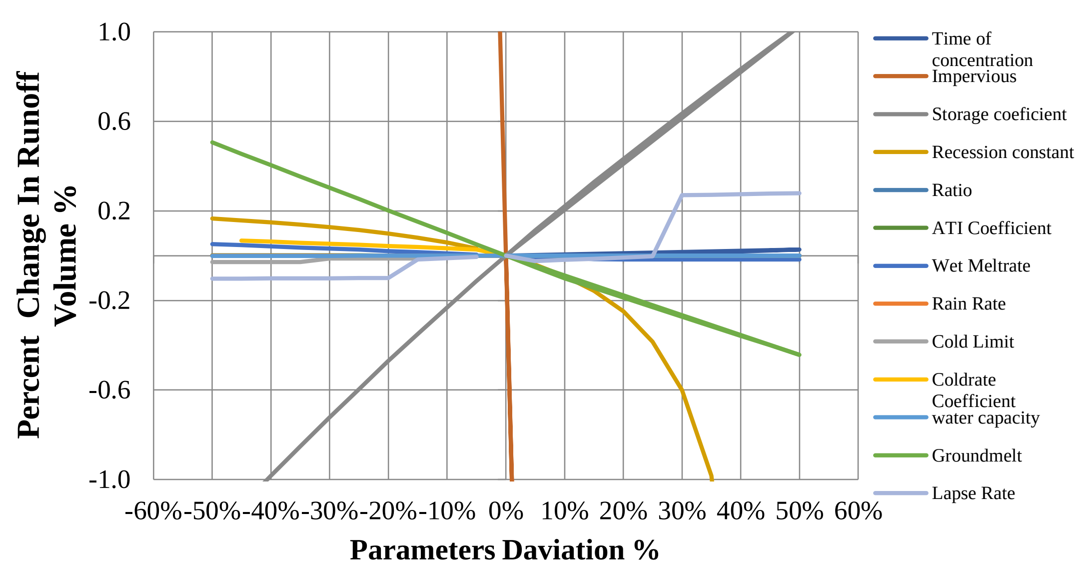


Figure 4-20 Sensitivity Analysis for Maidan-Kabul river basin (2009-2017)

4.3.3 Results (Lumped model)

The results of calibration are compared base on the hydrograph, flow duration curve, water balance and objective functions. Five-years data has been selected for the calibration period, which will be explained in below:

4.3.3.1 Hydrograph (outflow)

The hydrograph result for the calibration period is presented in Figure 4-21 and for verification period in Figure 4-22. In addition, for every individual year is shown in Figure 1-C and 2-C in Appendix C for both calibration and verification periods.

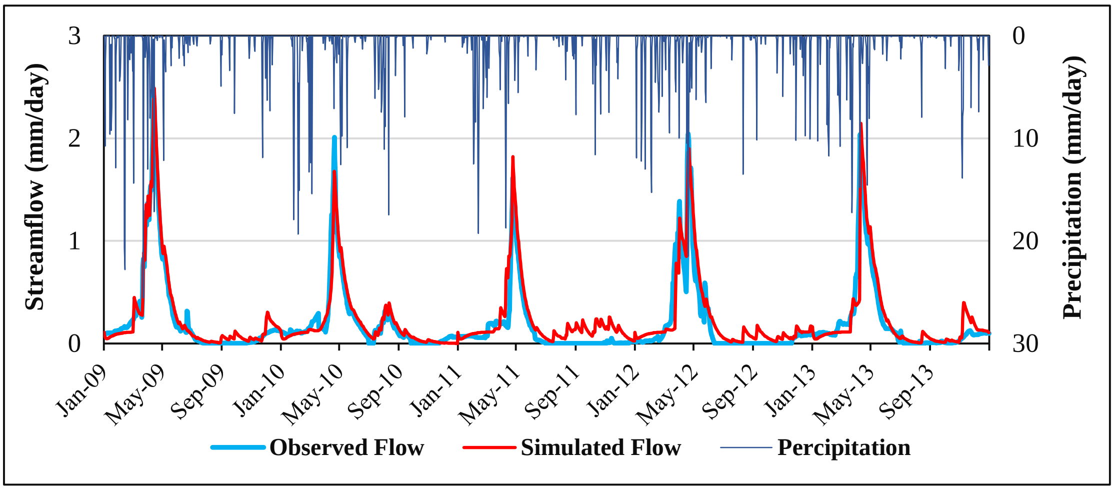


Figure 4-21 Hydrograph result for calibration period (Lumped model)

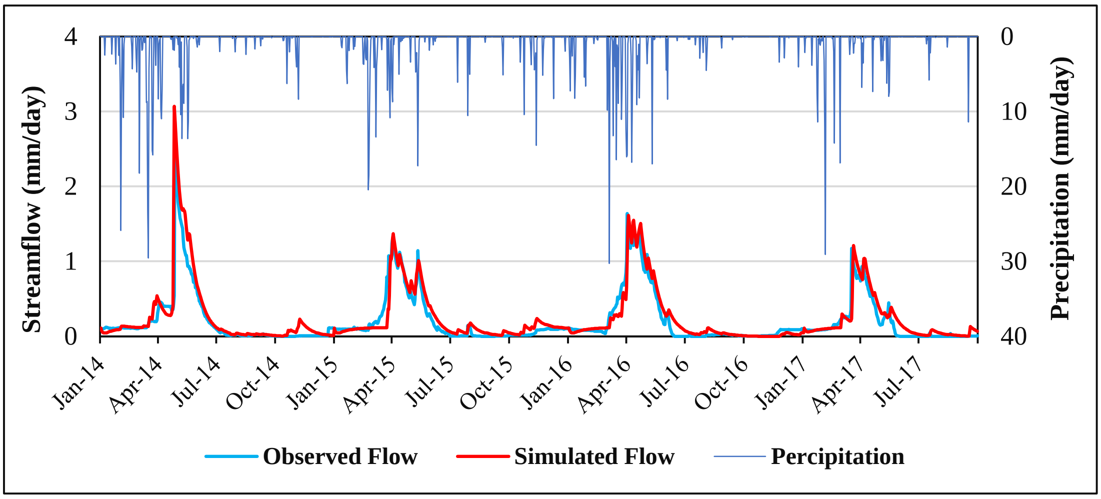


Figure 4-22 Hydrograph result for verification period (Lumped model)

4.3.3.2 Flow duration curve

The result of lumped model for the calibration period in semi-log and normal graph is presented in Figure 4-23 and similarly, for verification period the results indicated in semi-log and normal graph in Figure 4-24 respectively.

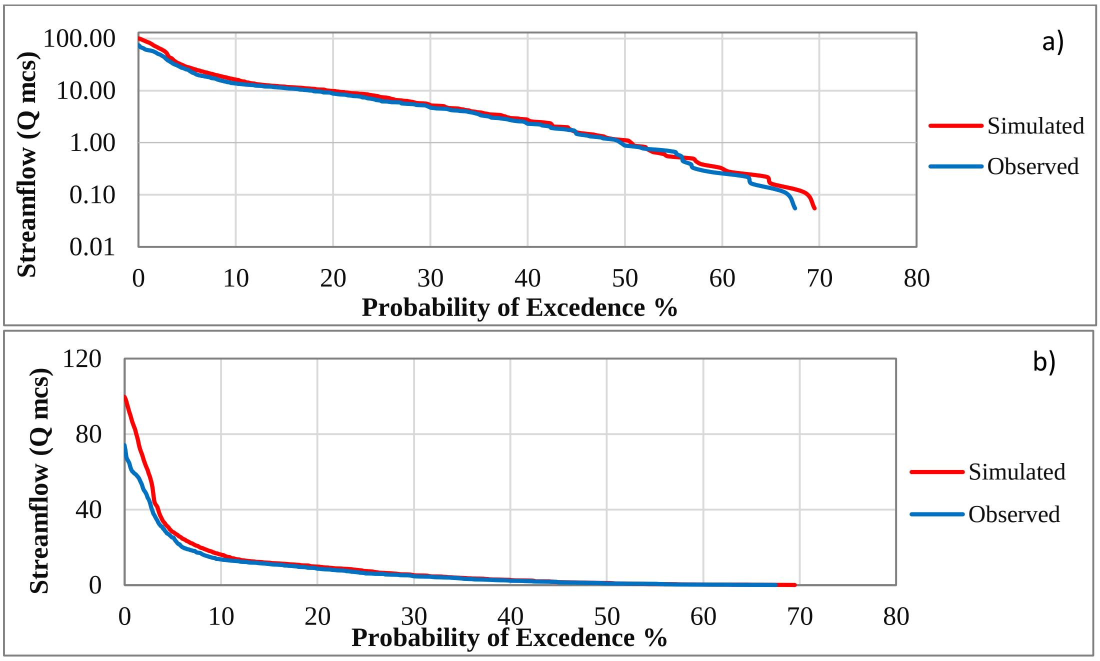


Figure 4-23 Flow duration curve result for lumped model (a, b)

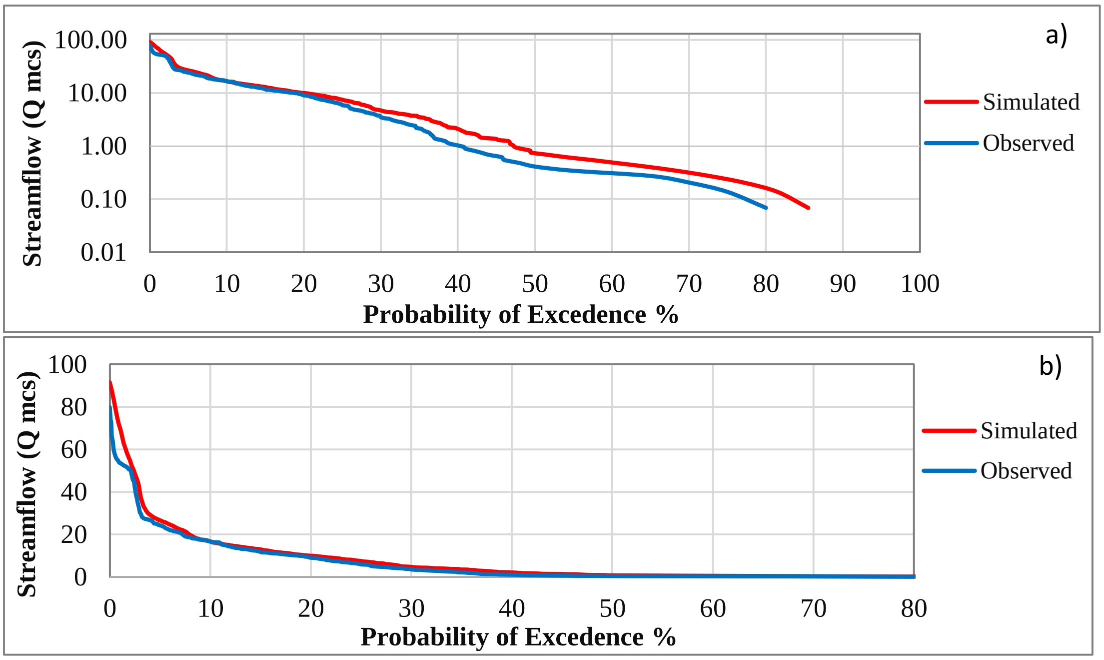


Figure 4-24 Flow duration curve result for verification period (a, b)

4.3.3.3 Water Balance

The lumped model calibration results are compared and shown both for the calibration and verification period respect to water balance computation in Figure 4-25 and Figure 4-26 respectively.

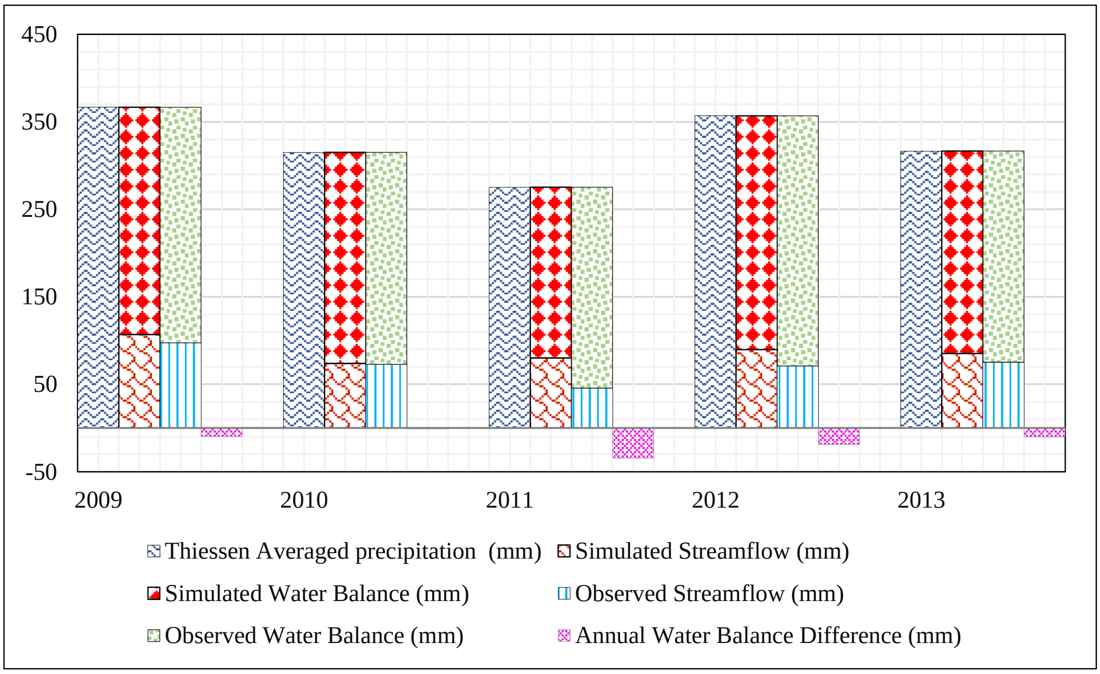


Figure 4-25 Annual water balance result for calibration period for lumped model

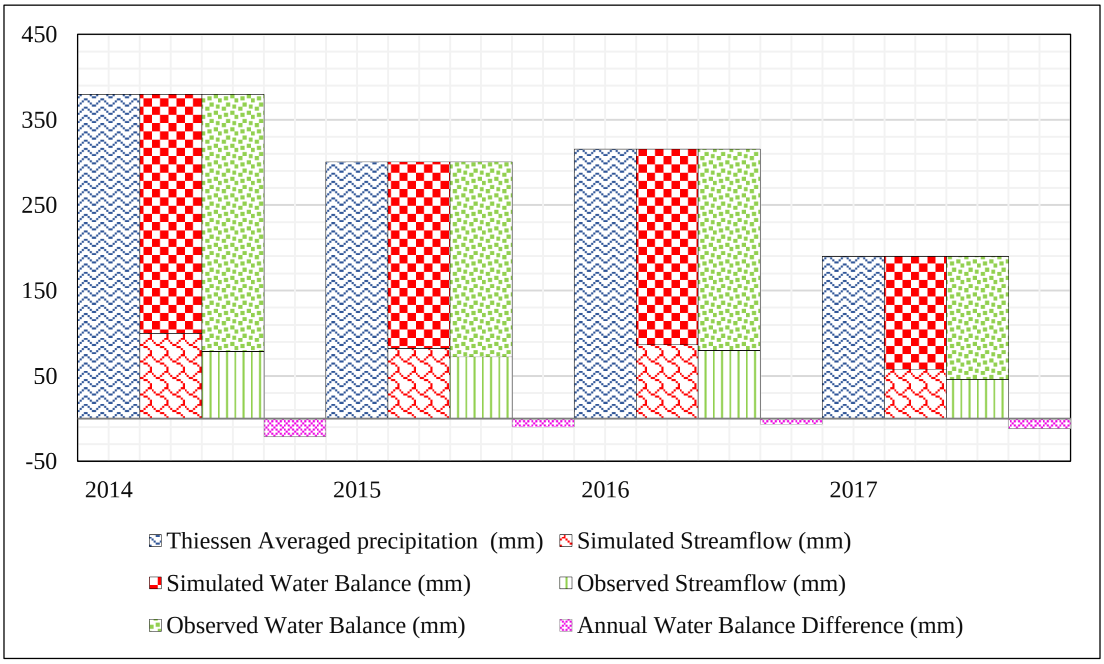


Figure 4-26 Annual water balance result for verification period for lumped model

4.3.3.4 Statistical results

The performance of the model results are checked respect to objective functions (NSE, PBIAS, R^2) and the results of that is shown for both calibration and verification period in Table 4-4. In addition, the relation between simulated and observed streamflow is plotted for both calibration and verification period as illustrated in Figure 4-27 and 4-27 respectively.

Table 4-4 model performance for lumped model

Calibration Period			Verification Period		
NSE	PBIAS	R2	NSE	PBIAS	R2
0.88	7.77	0.90	0.84	9.25	0.88

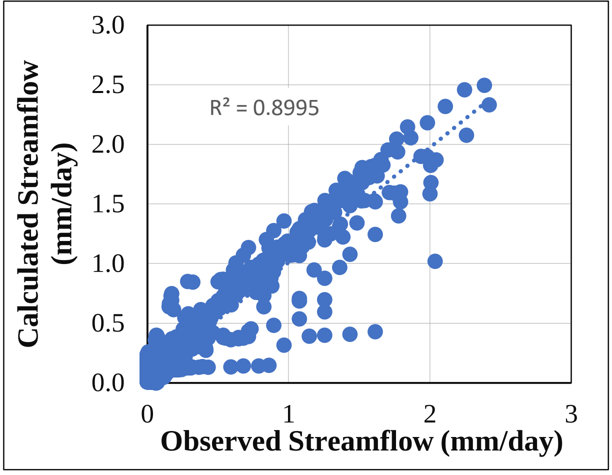


Figure 4-27 Relation between observed and simulated runoff values in scatter plot for lumped model in calibration period

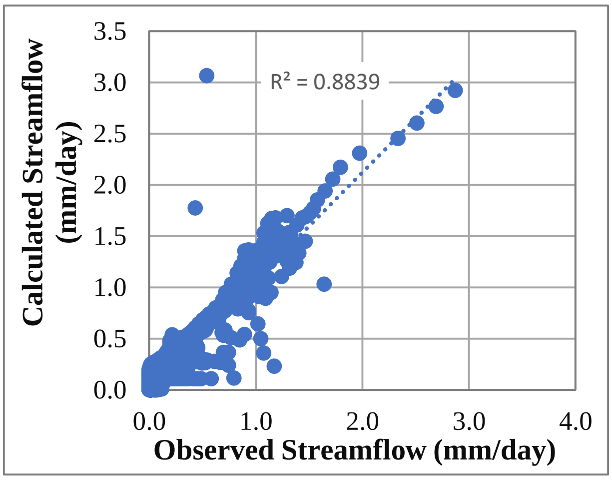


Figure 4-28 Relation between observed and simulated runoff in scatter plot for lumped model in verification period

4.3.4 Results (distributed model)

In addition to the lumped model the calibration and verification procedures is carried out for the distributed model in order to check the accuracy for aim of achieving better results. The results in this section similarly to lumped model is compare through hydrographs, flow duration curves, water balance and statistics.

4.3.4.1 Hydrograph (outflow)

The results of the model are shown respect to hydrograph for both calibration and verification periods in Figure 4-29 and Figure 4-30 respectively. Also for every individual year are shown in Figure 3-C and 4-C in Appendix C.

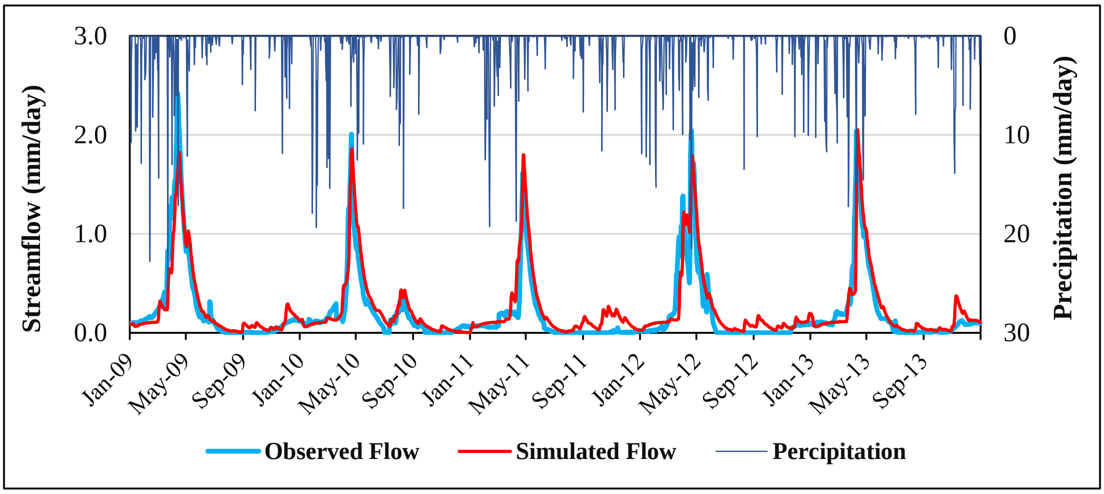


Figure 4-29 Hydrograph results for calibration period (distributed model)

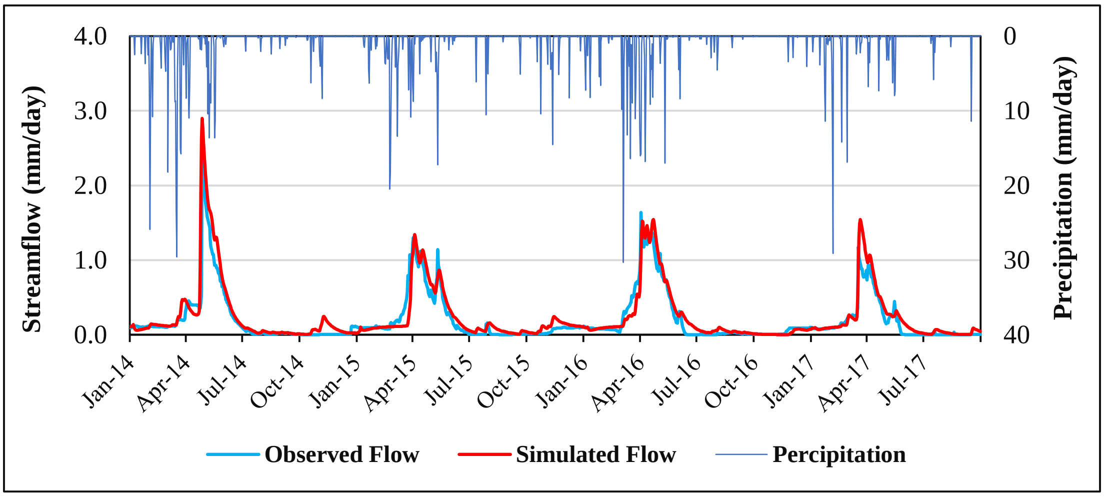


Figure 4-30 Hydrograph results for verification period (distributed model)

4.3.4.2 Flow duration curve

The result of distributed model for the calibration and verification periods in semi-log and normal graphs are shown in Figure 4-31 and 4-32 respectively.

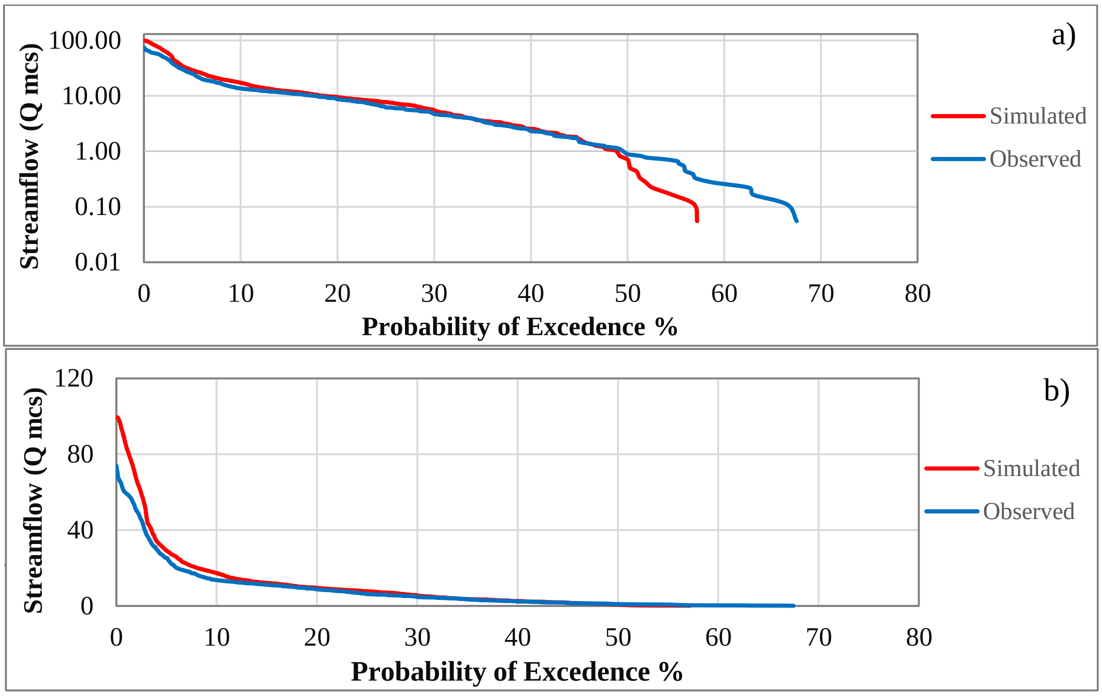


Figure 4-31 Flow duration curve result for distributed model (a, b)

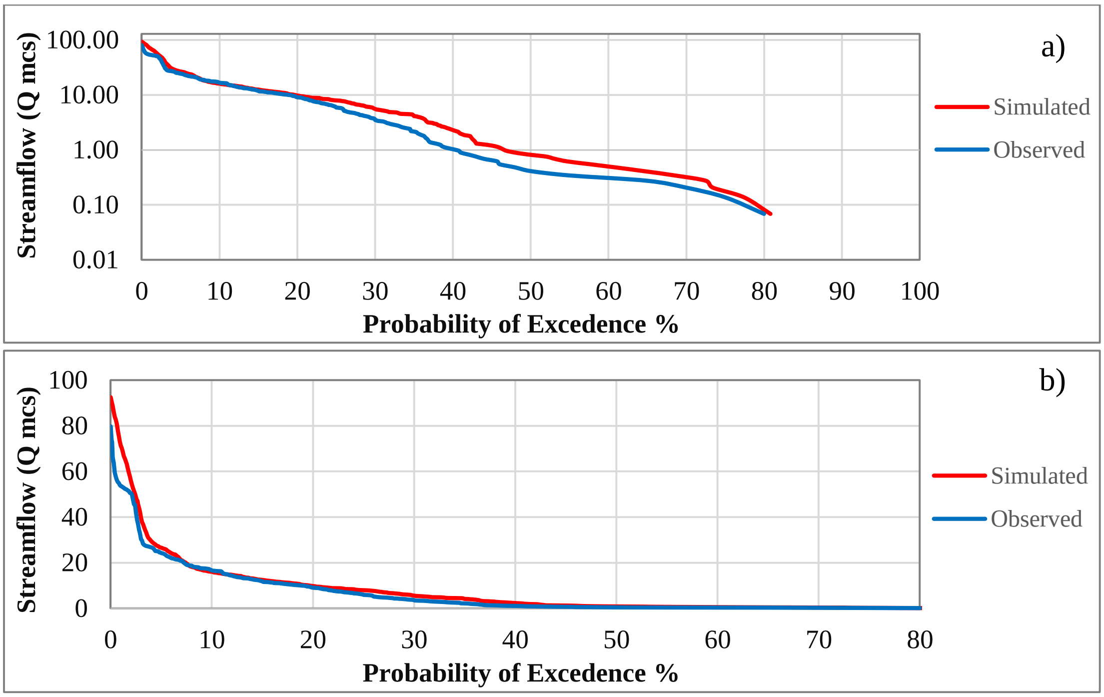


Figure 4-32 Flow duration curve result for distributed model (a, b)

4.3.4.3 Water Balance

The distributed model results are compared for both the calibration and verification periods respect to water balance computation, presented in Figure 4-33 and Figure 4-34 respectively.

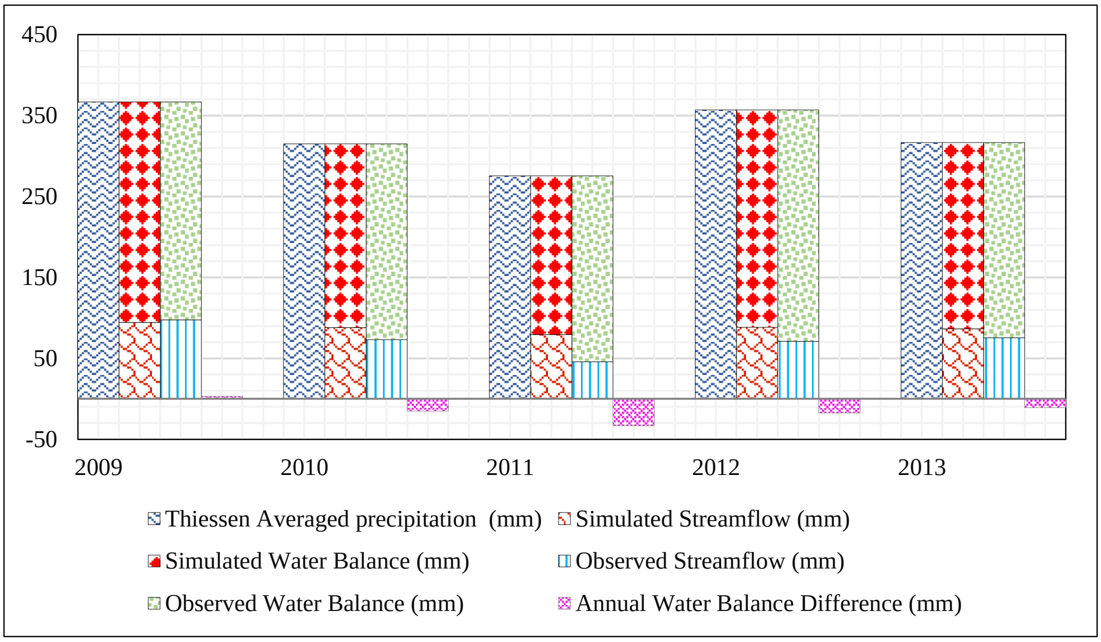


Figure 4-33 Annual water balance for calibration period (distributed model)

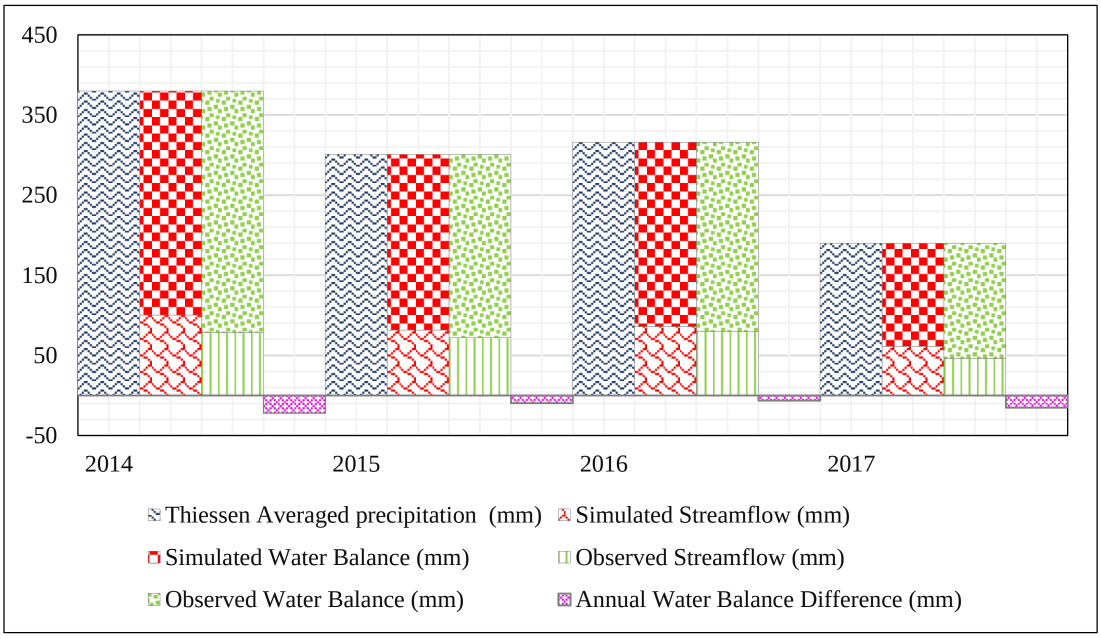


Figure 4-34 Annual water balance for verification period (distributed model)

4.3.4.4 Statistical results

The performance of the model results is checked respect to distributed model with objective functions (NSE, PBIAS, R^2) for both calibration and verification periods presented in table 4-5. In addition, the relation between simulated and observed streamflow is plotted in scatter graph for both calibration and verification period and it shown in Figure 4-35 and 4-36 respectively.

Table 4-5 Model performance for distribute model

Calibration Period			**Verification Period**		
NSE	PBIAS	R2	NSE	PBIAS	R2
0.84	10.71	0.85	0.85	8.82	0.90

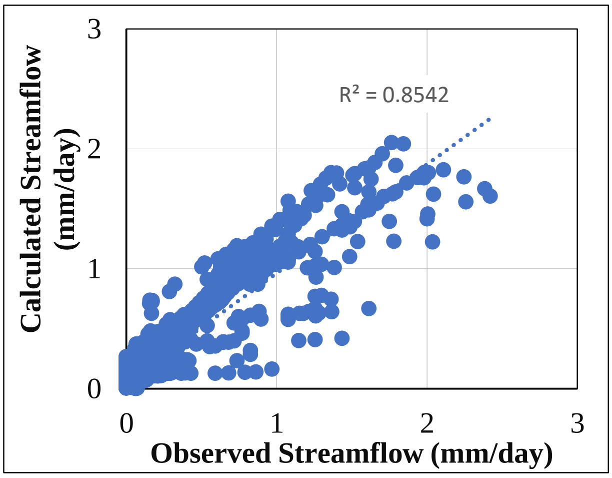


Figure 4-35 Relation between observed and simulated runoff values in scatter plot for distributed model in the calibration period

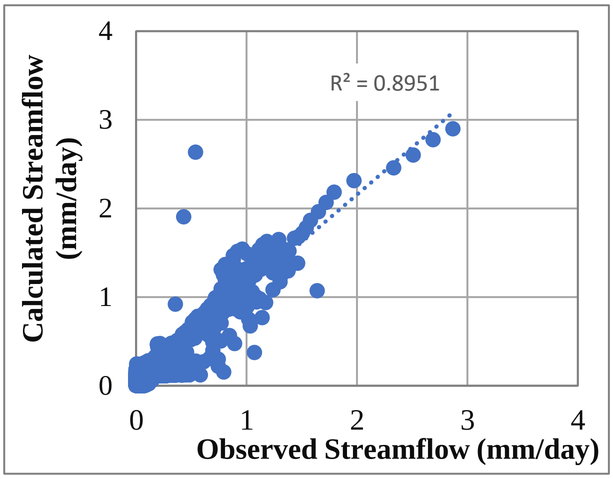


Figure 4-36 Relation between observed and simulated runoff values in scatter plot for distributed model in verification period

4.4 Future impact of climate change

The two selected scenarios (RCP 4.5 & RCP 8.5) for year 2020s, 2050s and 2080s were selected and downscaled for the study area which are showing changes in precipitation and temperature. These future scenarios are in monthly scale which are changed to daily scale both for precipitation and temperature. The year 2012 is selected to incorporate the scenarios because of less errors shows under the data checking part. In addition, the observed and simulated flow is matched very well respect to this year. This model is daily based model then the changes are incorporated to the model based on that for investigation of on streamflow. In conclusion for this section, first changes investigated on precipitation and temperatures, following the changes are applied in the hydrologic model for investigating the streamflow alteration.

4.4.1 Impact on precipitation

The impact on precipitation is presented in Figure 4-37 compare to baseline. It shows that for both scenarios for year 2020, the precipitations are increasing from month of February to mid-May compare to present. But for 2050s and 2080s in both scenarios the precipitation is decreasing and irregular precipitation is happening during some months.

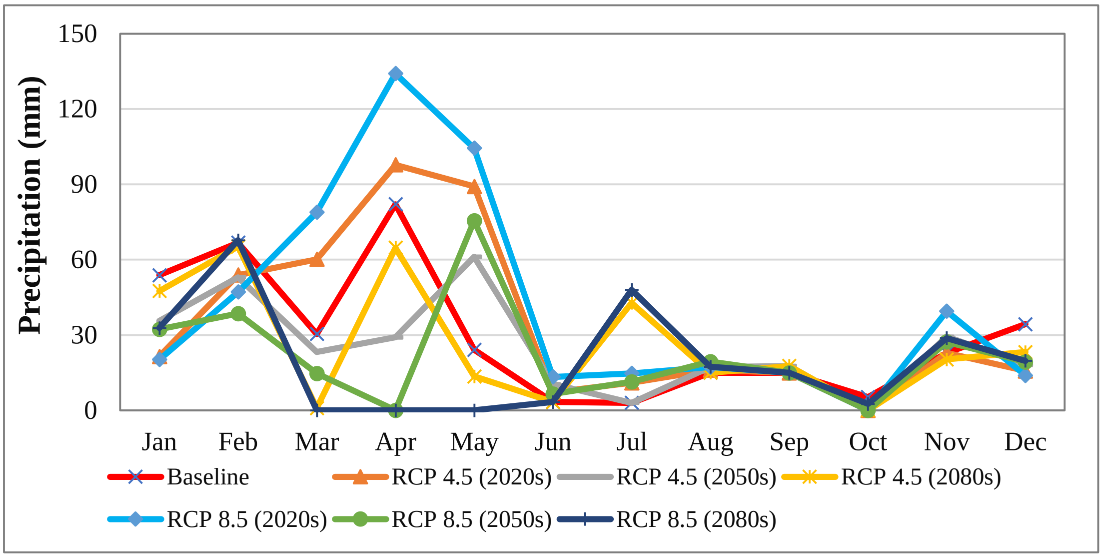


Figure 4-37 Changes in monthly precipitation for the year 2020s, 2050s and 2080s relative to baseline (2009-2017)under RCP 4.5 and 8.5 scenarios in Maidan-Kabul watershed

4.4.2 Impact on temperature

The main indicator of climate change is increase on temperature that within this study in both scenarios it is showing increasing trend especially in month of December, January and February (Figure 4-38). But for year 2020s under both scenarios the temperature is decreasing during month of April and May compare to baseline. This change is exception only for 2020s as presented in Figure 4-38 in more clear manner.

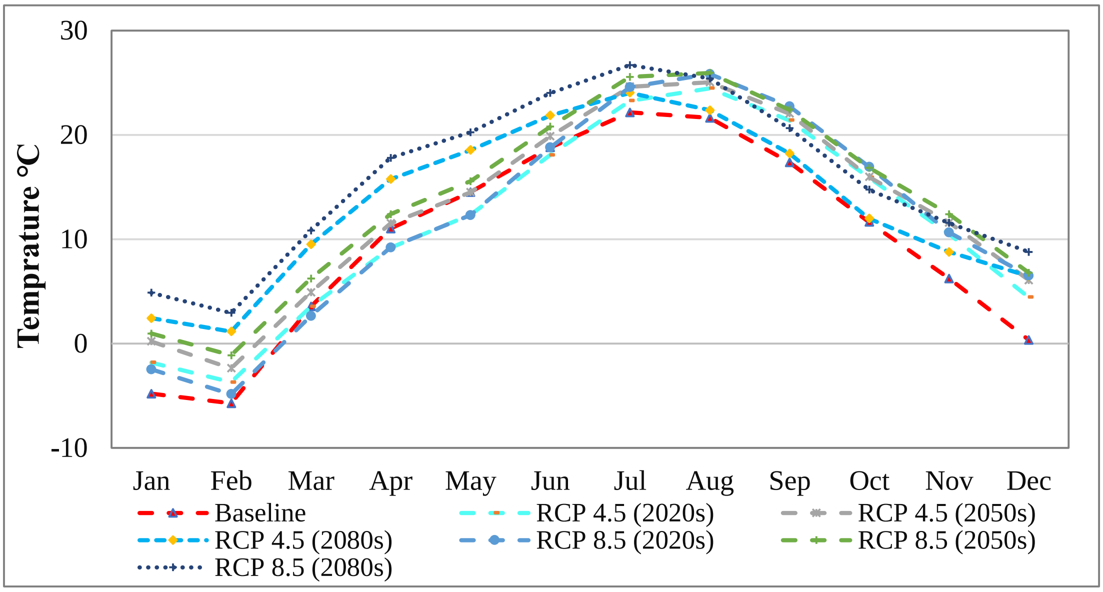


Figure 4-38 Changes in monthly temperature for the 2020s, 2050s and 2080s relative to baseline (2009-2017) under RCP 4.5 and 8.5 scenarios in Maidan-Kabul watershed

4.4.3 Impact on Streamflow

The main aim for carrying out the hydrological modeling is to incorporate the concern scenarios of climate change on streamflow. Building the Shahtoot reservoir and locating the Kabul city in the downstream of this river increased the importance of studying the climate changes and hydrological modelling. For the current study the precipitation, temperature and evaporation scenarios respect to RCP 4.5 and RCP 8.5 for 2020s, 2050s and 2080s are incorporated in the acquired model and compared further with baseline. The results of that are shown respect to hydrograph, flow duration curve and water balance which will be explained separately in following:

4.4.3.1 Future streamflow results on hydrograph

The results of future streamflow are illustrated on hydrographs and compared to baseline for investigating changes on streamflow responding to the forecasted precipitations in Figure 4-39. According to this Figure (4-39) the upcoming decades respect to both scenarios the time of peak is shifted form may to end of March and mid of April and also it shows increases in water amount. But for 2050s and 2080s shows draught and significantly decrease in the peak discharge. Further it shows that all the precipitation will be in pattern of rainfall other than snow which precipitation directly after falling contributes to the runoff.

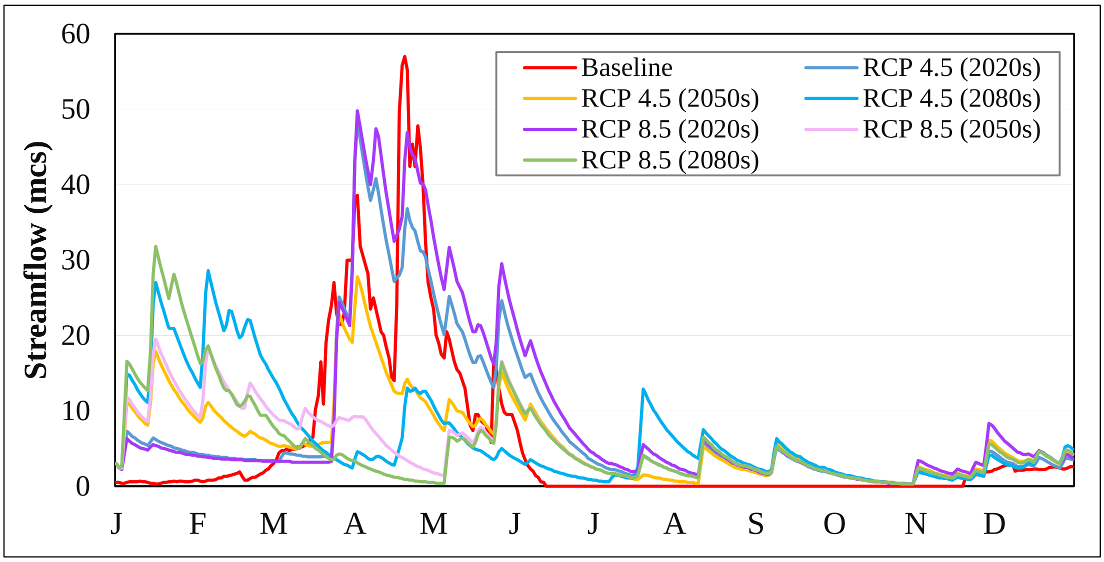


Figure 4-39 Changes in monthly streamflow for the year 2020s, 2050s and 2080s relative to baseline (2009-2017) under RCP 4.5 and 8.5 scenarios in Maidan-Kabul watershed

4.4.3.2 Future streamflow results respect to flow duration curve

In addition to the hydrograph, the impact of climate change on streamflow is depicted on flow duration curve as it shown in Figure 4-40. The main of this presentation is to clearly differentiate the increase in amount of water compare to baseline. Which distinguishing the streamflow is more vivid respect to high, medium and low flows. Further, streamflow duration curve is helping in determining the amount of water correspond to its frequency. Form Figure 4-40, it can be illustrated that for 2020s for both scenarios streamflow is increasing compare to baseline but for 2050s and 2080s it showing decrease in water for both scenarios. In the meantime, it shows that the low and intermediate flows are improving for the both scenarios.

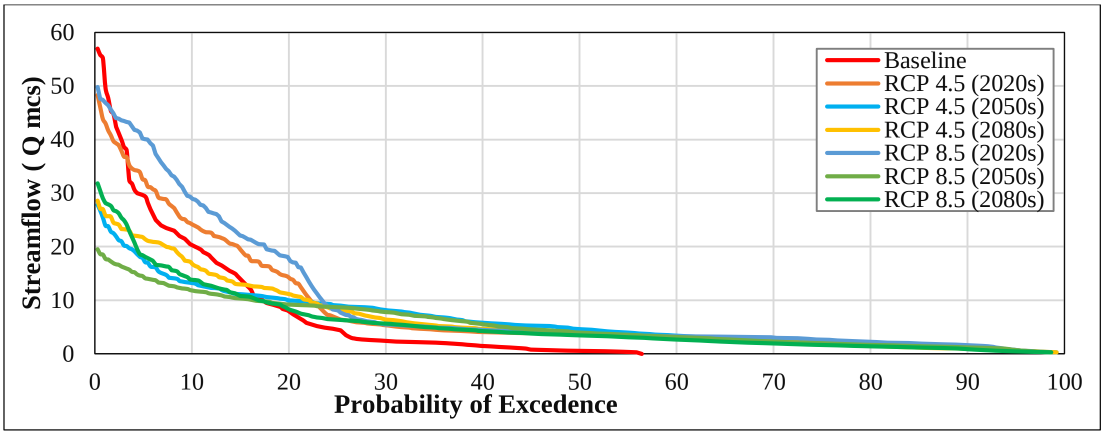


Figure 4-40 Changes in flow duration curves for the year 2020s, 2050s and 2080s relative to baseline (2009-2017) under RCP 4.5 and 8.5 scenarios in Maidan-Kabul watershed

4.4.3.3 Future streamflow results on water balance

The main purpose of this presentation is to seek the increases on streamflow and it shows that the water is less infiltrating and incorporating to groundwater. The results of water balance are presented in Figure 4-41 and from that it can be concluded that for both scenarios in the 2020s the water amount is increasing. But for 2050s and 2080s the amount of water is decreasing compare to baseline but the streamflow volume against the base line is increasing. This changes shows that due to less precipitations in type of snow, more volume of precipitation is adding to direct runoff or evaporating and less water is contributing to groundwater.

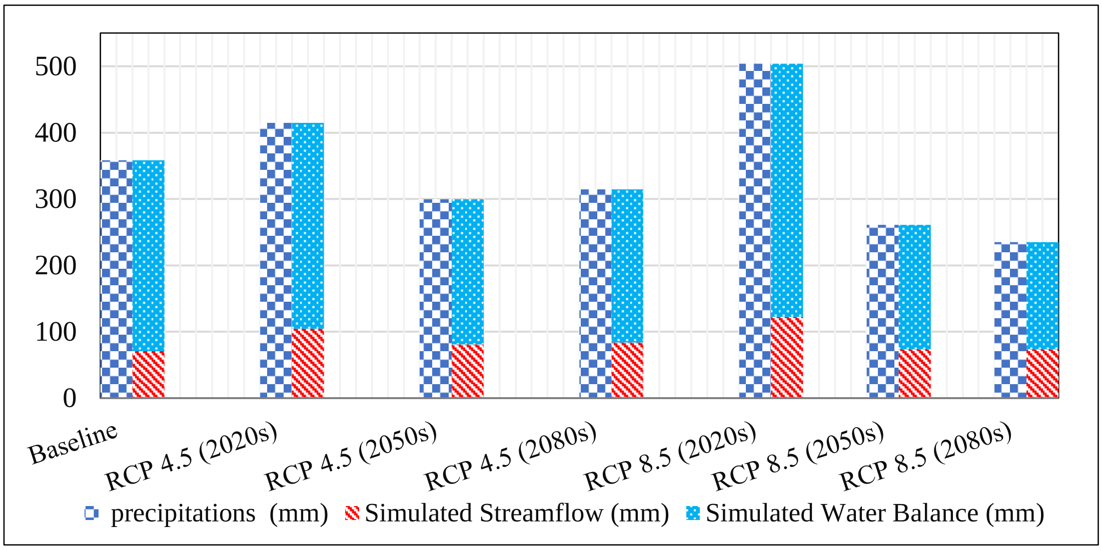


Figure 4-41 Changes in water balances for the year 2020s, 2050s and 2080s relative to baseline (2009-2017) under RCP 4.5 and 8.5 scenarios in Maidan-Kabul watershed

4.5 Adaptions strategies development

Adaptation to climate change for maintaining sustainable production systems is need to assure food security, nutrition security, and income for mountain people. Increased climate variability is already affecting water availability, ecosystem services, and agricultural production, and extreme weather is causing flash floods, landslides, and debris flow. While the climate change is acting as a natural driver of change, there are several other forces such as population change, economic growth and globalization causing rapid socioeconomic transformation in these mountains. Adaptation priorities, based on a review of UNFCCC documents submitted by Afghanistan (NAPA, national communications, NDCs), commonly identify agriculture, water, health, forests, biodiversity and disaster management as key sectors for intervention is shown in table 4-6.

For majority of people living in this sub-basin the crop-livestock agriculture has long been the source of livelihood. Their livelihoods are highly vulnerable to the impact of climate and environmental change. Mountain farmers have continuously adapted their farming systems to a risky and changing environment. Field studies show that farmers are adopting to climate change by altering sowing dates, although many others strategies are not considered due to the lack of access to information and sites. It has also been reported that many springs are dried up and the reoccurring of droughts for a very long time lead to substantive yield reeducation. It is also being reported of new pests, diseases, flash floods, thunderstorms, hail, and other disasters are becoming more unpredictable, irregular and fierce.

In response to the climate change effects adaptation policies and practices must intensify in the respect mountains, local-level autonomous responses to climate variability and extreme events must be systematically studied, documented and validated. In addition of that, inside the country, the river basin institution must work together to build mechanism and fora to debate and negotiate key challenges, such as data sharing. This cooperation’s are needed to harness relevant opportunities, expertise and experience.

Table 4-6 Afghanistan Adaptation priorities

Country	Adaptation vision/goal	Status with respect to NAPA & NAP (or other (sub)national policy frameworks)	Adaptation priorities (in terms of sectors or actions)	Cost of adaptation measures	Target years	Date of INDC submission to UNFCCC
Afghanistan	"to protect the country and its population by enhancing adaptive capacity and resilience, effectively respond to the vulnerabilities of critical sectors, and efficiently mainstream climate change considerations into national development policies, strategies, plans" (p. 4)	NAPA and NCSA completed in 2009. NAP process under way	• Development of the CCSAP and vulnerability monitoring and assessment system • Mainstreaming of adaptation technologies • Regional and international cooperation for adaptation technology transfer • Meteorological and hydrological monitoring networks and services • Water resources infrastructure and irrigation systems • Community-based natural resources management • Selected species and habitat conservation • Alternative and renewable energy • Regeneration of degraded forests and rangeland areas	USD10.785 billion (of a total financial need of USD17.405 billion)	2020–30	13 October 2015

Considering the above table, it requires that government should start to integrate mainstream climate change in their development planning and budgeting systems. For taking adaptions measures base on the field visits and literature reviews the adaptions measures in this study are focusing on eliminating droughts, minimizing floods impacts, strengthen the institution and support of climate information.

4.5.1 Mitigation of droughts impact

In the study area, normally people are suffering from the meteorological drought rather than infrastructure drought because most of their livelihood and irrigation system is based on the normal regime of flow. According to the field visits, the water storage infrastructure is not existing and people by using the traditional methods changing the direction of the flow to their farms. The main objective of this part is to identify some common measures to mitigate the effect of drought. It is being observed through this study that respect to both scenarios (RCP 4.5 and RCP 8.5) for the year 2050s and 2080s the amount of precipitation is decreasing and it leads to drought specially during the spring seasons. In this study some common methods based on studies around the globe is considered for mitigating the effect of droughts. Although it requires more broad and extensive study and grants to purpose specific measures. Mainly two adaptations are purposed for controlling the drought impacts which are crop and land management and water management measures.

4.5.1.1 Crop and land management

In the Maidan-Kabul watershed normally people cultivating wheat, tomato, onion, potato and vegetables. In addition, there are different kind of fruits mostly apple, peach, apricot and other fruit trees. The vegetables and wheat are mostly vulnerable to drought which requires consistent water. Similarly, all the plants are in need of water for their livelihood and decreases in the amount of water will impact to the yield of fruit trees. People in this area is using wheats, vegetables and other crops for their internal use but exporting the fruits like apple to market for commercial purposes. Decreasing in the amount of water will directly affect the people livelihood and incomes which contribute to food scarcity and other social problems. The anticipating problems can be solved by taking early suitable measures.

A very common and wide method is used for mitigating the effect of drought is by shifting the crop type into a new type which requires less water. This can be possible by conducting a research for identifying alternate cultivars to expected thermal and hydrological conditions. The experience from Humalia region of Nepal on planting drought-resistant crop varieties is good example. This requires studies to introduced new crop that would suitable for the climate and habit of people. Furthermore, based on this study precipitation and streamflow normal regime is changing and it requires for famers to adjust the timing of seeding and harvesting. In aim of taking the maximum advantage from their farms.

4.5.1.2 Water management measures

Water is a crucial element for sustain of live, agriculture and ecosystem, without water there will no life. Meteorological droughts will cause less water in terms of precipitation and it is effecting to drying up of springs, rivers, and decreasing in ground water level. Normally people in the Maidan-Kabul sub basin is converting the water from the river and using it for the agriculture and other livelihood purposes. Climate change could affect the normal regime of flow and type of precipitation. Saving water and using this precious element in right manger has an important value in all situation specially, in drought condition. Water management in such situation means that using water without wasting. Normally, when water is converting to the land and using by stakeholders due to exist of knowledge on water governing, it wastes through many ways. In this study, it is forecasted that in 2050s and 2080s for both scenarios Afghanistan will suffer from severe droughts. This requires to seek for water management solution to use from less water maximum advantage.

Through many years of research and experiences, it was found that by use of water management techniques, it is widely possible to mitigate the impact of droughts. The experience from the Himalayan mountains in Nepal, farmers are pumping the groundwater for agriculture purposes. Using the potential of groundwater is possible in the study area, only through recharging it when there is enough water in the river. Storing water through different techniques and harvesting of rain waters during the peak season will make this possible to use from that during necessity and using it in the shortage of groundwater resources. Based on the field visit from the area, it was found there are many palaces exist for building temporary reservoirs through natural ponds and earthen embankment.

In addition to the mentioned techniques investing on micro irrigation techniques, roof water harvesting is also a good technique of increasing the efficiency of water usage. It’s been common in the Maidan-Kabul river basin that farmers know only one kind of irrigation system which is through filling the ground with water without understanding the exact amount of water that is requisite for individual crop and plants. Sprinkler, drip irrigation or direct on farm irrigation are among the potential techniques which possible through understanding the exact requirement of every plant to prevent excess water waste. Rainwater is a very good source that saving it through creating barriers in the land is a great help for both using that directly and by recharging to the ground water. In addition, techniques of roof water harvesting is giving household freedom on more dependence on other resources. This technic of water harvesting is possible by using a simple tank as shown in Figure 4-42 and 4-43 they people can get benefit of roof water for their domestic purpose.

Figure 4-42 Water tank for domestic use

Figure 4-43 Water tank for domestic use

4.5.2 Mitigation for minimizing floods impacts

Flood is defined when water is exceeding form the channel embankment due to heavily precipitation, early melting of snow, bursting of glaciers and breaking of dam and reservoirs. In the Maidan-Kabul watershed its expected of increasing the precipitation for both scenarios in the coming decades. It is also identified through streamflow future analysis, flow duration curve and water balance that water amount is increasing. This is a good news for farmers but ignoring proper adaptation can cause catastrophic events and this has the potential to destroy the lands, increase soil erosion and other events that threat the life and economy. In addition to that, locating the Kabul city in the downstream of Tang-i-Saidan and building of houses in surrounding of the main channel without taking proper measures could end to catastrophic incidents.

Engineering through years of research has broad solutions for mitigating the impact of flood which requires proper study of the fields, anticipant risk, information and budget. Based on the field visits carried out in this research there are a lot of options exist for mitigating the flood impact with structural and none structural measures for avoiding the catastrophic events. The study area is a mountainous area which has many potentials for building the temporary reservoirs and dams for storing and saving water before reaching to the main channel. It is being observed that Maidan-Kabul watershed could support many multipurpose reservoirs in cascade system up to Tang-i-Saidan station that could support agriculture, groundwater and even in producing electricity. Creating barriers in the high steep slope of mountains by wood, earth and rocks could mitigate the impact of floods. Trees planting, harvesting water, deepening the main channel and watershed management are among the most common methods for mitigating the effect of floods. Beside of structural measures considering the non-structural measures such as developing the early warning system will be a great help in mitigating the flood incidents.

4.5.3 Structural measure for mitigating the flood and drought impacts

Watershed management is very difficult with ignoring the engineering techniques of taking structural measures. Water resources engineering field has many solutions regarding the structural measures for mitigating the flood and drought impacts. It has been observed through this study that for both scenarios to the end of this century the flood and drought incidents will happen. Near future is forecasted with floods and increasing in temperature further will cause flood and droughts. In this study through combining of field visit and literature reviews some techniques are purposed that is suitable for the study area.

4.5.3.1 Sand Dams

Sand dams are small impermeable barriers constructed across the bed of seasonal streams. Sandy riverbeds are required for a sand dam to work properly. Sand dams vary in size according to the riverbed. It is a very simple technology and inexpensive since construction materials are locally available. In most cases, the labor required to build the barrier comes from the local community. Sand dams are very low in construction costs. All that is needed to build them is wood to form the barrier, reinforcing material, and concrete or masonry as shown in Fig 4-44. Being a simple structure, there are minimal to zero maintenance costs associated with sand dams. This sand band is both has benefits in flood and drought situation and in recharging ground water. Further, it is continuously providing water and support the livelihood of livestock.

Figure 4-44 Sand dam at Makueni County

4.5.3.2 Zai Pits and Negarims

Zai pits were traditionally invented by farmers in Burkina Faso (NDMA 2011). In Kenya, they are referred to as planting pits and are boxlike structure in cross section as shown in Figure 4-45. They are constructed by excavating the soil and returning the rich top soil with organic mulch, while the subsoil acts as an embankment behind the pit. A tree crop or several plants like maize and beans are then planted in the pit.

Figure 4-45 Zai pits at Makueni County

The mulch soaks up the water and stores it throughout the dry season. Similarly, negarims act in the same way except that they are mostly used for tree crops and involve a formation of square embankments. Some of the advantages of using Zai pits and negarims are the fact that they can be reused for up to four crop seasons or two seasons without the need to add more manure. In addition, they increase crop yield and enable better crop survival in drought condition, promote ease of weed control, conserve water through reduction of soil erosion, as well as improve soil fertility and environmental conservation.

4.5.3.3 Rock Catchment

Rock catchments are systems which mainly use natural rock surfaces to divert rainwater to a central collection area (Figure 4-46). The collected rainwater passes through sand and gravel before storage in a water reservoir or tank. The sand and gravel act to filter and make the water clean.

Figure 4-46 Rock catchment

During the field visits it is observed many palaces are suitable for being a rock catchment which is not only cleaning the water, but helping in recharging the groundwater and storing the water for a duration of time. Diverting water to the rock catchment need a system of drainage and also technical expertise. The big disadvantage of such kind of catchment in infiltrating water through holes from the catchment which requires to be filled by the sedimentation techniques.

4.5.3.4 Bunds

Bunds are large earth banks on the contour that trap runoff (Figure 4-47). Bunds are varying in shape. They are usually built to prevent runoff and conserve water. Bunds are simple to build, improve productivity, and keep water in the soil. Despite this, bunds use a lot of land, may create temporary logging, and may interfere with farm operations if the bunds are too close to each other. However, they are labor intensive (Yongon 2008). Bunds can be made of local material and by using of technical measures helping largely in preventing floods, saving water, farming and recharging groundwater.

Figure 4-47 Trapezoidal bunds

4.5.3.5 Water Pans and Ponds

Water pans and ponds are excavations or embankments that are constructed on the path of natural rainwater catchments and used as water reservoirs (Figure 4-48). To create a leak proof water reservoir, it is necessary to use an impervious layer of soil or line the reservoir with plastic material to form the plastic-lined dam. A recent innovation in Kenya used by farmers that lack a large catchment area is the diversion and collection of rainwater from road drainage, a method commonly known as road runoff harvesting. This method has become so popular along some roads; some farmers have conflicts as farmers up the road divert all the water.

Figure 4-48 Water pans

4.5.3.6 Small Farm Reservoir (SFR)

A small farm reservoir is a water impounding structure with a maximum height of embankment of 4 m and average pond area of 1,500 m^2. It serves limited areas no more than 2 ha and is designed to become an integral part of individual rainfed farms with catchment area not exceeding 10 ha. Its advantages are as follows: (1) less capital intensive, (2) easy to construct and maintain, and (3) empower farmer cooperation and production capability (Figure 4-48). In 1989, the Philippine Government embarked on a national program called the Small Farm Reservoir (SFR) project. This program aimed to accelerate rural development through the adoption of on-farm reservoir technology and to boost farm income by intensifying land use in rain fed areas (Bhuiyan & Zeigler, 1994)

The reservoir is owned and managed by individual farmers and is typically built using a bulldozer (Figure 4-49). It consists of an earthen dam that traps harvest and stores rainfall and runoff. The embankment is not more than 4 m high, the surface area averages about 1,000 m^2, the depth is 2–3 m, and the storage capacity is some 2,000 m^3.

Figure 4-49 Picture of a small farm reservoir

4.5.4 Shahtoot reservoir

Shahtoot reservoir is a purposed dam is located in the Chahar Asiab district of Kabul, on a tributary of Kabul river, the Maidan, after the Tang-i-Saidan station in outlet of the study are. The feasibility study is completed by an Iranian company with the cost of USD 1.86 million. The total cost of this project is near to 236 million USD that supposed to be built by India in near future according to Tolo news report in July 2018. Shahtoot dam is multi propose dam expected to hold 146MCM of potable water for 2 million Kabul residents, including water for a new city on the outskirts of Kabul called Deh Sabz and irrigating of 4000 hectares of land in the district of Charasiab and Khairabad. In addition, it will provide environmental flow in the river following in Kabul city, protecting against flood, recharging the ground water aquifer that is using for drinking water, contributing to the national food security (more corps, fisheries and industry promotion), tourism industry, increasing the job opportunities and income. The Shahtoot reservoir purpose location is shown in Figure 4-50.

Figure 4-50 Location of purposed Shahtoot reservoir

Shahtoot reservoir has important role in the economy of the country and vital role for sustain of life in Kabul city. Due to this reason the volume of water in the river is investigated for acquiring assures in filling of the reservoir. The result is showed in Figure 4-51 which indicate that based on all anticipated scenarios the current volume of the reservoir will be filled.

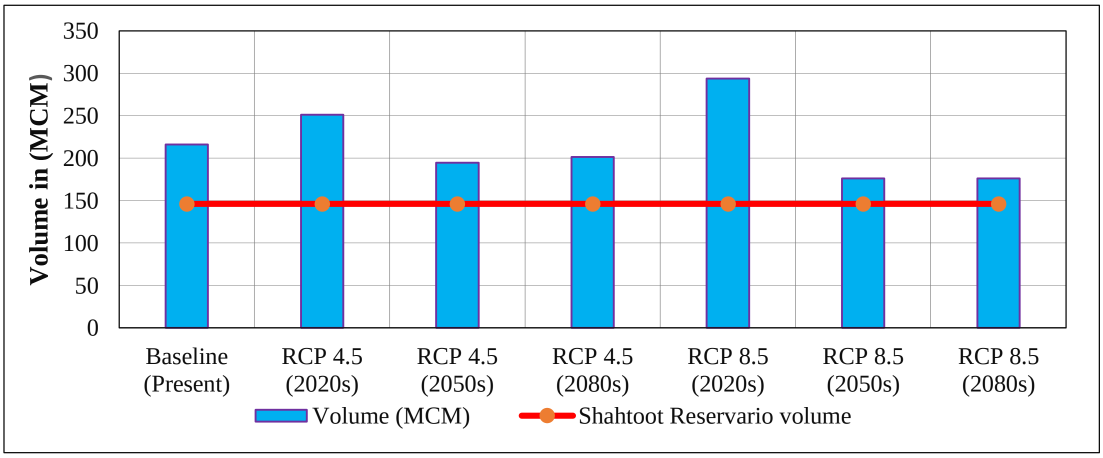


Figure 4-51 Shahtoot reservoir volume comparison under different scenarios

4.5.5 Institutional Strengthen

Responses to the climate change impact under the United Nations Framework Convention on Climate Change (UNFCCC) and the National Adaptation Plan (NAP) process establishing in 2012, emphasizes that countries in order to reduce vulnerability and build resilience they should integrate the climate change adaptation into development planning. Weak institutional capacity at the governance level along with social and economic barriers and poor infrastructure for development are major barriers for implantation adaptation measures.

Weak institutional links hinder farmers from adopting technology that can contribute to adaptive capacity. For poor and marginalized groups, deep and pervasive structural inequalities make climate change adaptation even more difficult (Wester, Mishra, Mukherji, Shrestha, & Change, 2019). Base on the interview with the authorities in the ministry of water and energy, they aware of the urgency to act on adaptation but they face substantive challenges. Some of these challenges are lack of reliable and long duration data (in terms of quality and quantity especially in localized scale) about the climate change impacts. Another challenges are come out during the implementation process between government and non-state actors are hindered by large constraints on institutional capacity which leading to major gaps between policy goals and actual implementation of adaptation programs.

According to assessment of different literatures and studies conducted in many parts of the world indicates that there are large potential enhanced opportunities through investments for generating science-based climate information and knowledge services, as well as incentives to promote policy experimentation through adaptation pilots. Greater country base and regional sharing information mechanism and integrating adaptation with national development plans and programs is urgently requisite. The network of hydro meteorological stations is need to be strengthened to increase national capacity to provide early warning for various climate-induced disasters. Public consultation and stakeholder engagement in adaptation is has to be considered in broad manner.

Maidan-Kabul sub basin is governing by the ministry of water and energy with the assistant of the its local headquarter in center of Maidan. It urgently need as mentioned before the local authority capacity should strengthen in different manner that they understand the climate change, have forecast models. Survey for taking adaption is required that has to be done by local engineering which familiarizing of them with the engineering techniques is highly necessary. The meteorological stations in the study area is not enough which requires to extend the current meteorological stations. Farmers and household has to be trained in taking necessary measures for mitigating the impacts.

4.5.6 Climate Information support

The Maida-Kabul river basin is mostly covered by the mountains which it originates from the Hindukush mountains. Increasing the climate change is projected by 2050 causing to increase temperature beyond 2 ℃ on average according to the researhc work and other such as Wester et al.(2019) at higher elevations. Due to poorly served by life-saving and livelihood-supporting infrastructures, mountain communities-especially remote ones are more vulnerable than non-mountain areas. The current level of understanding of adaptations needs and interventions specific to mountain situations continues to be highly limited because of inadequate knowledge of climate. It should be among the duty of the policy makers on emphasizing generating science-based climate information, knowledge, and services to enhance the resilience of climate-sensitive sectors and vulnerable households.

The Myanmar and Bhutan is identified in lack of locally usable knowledge and information on weather and seasonal forecasting to assist farm production operations. In the china the government has attempted to reduce climate vulnerability and impact by adopting adaptation options of early planting, fixing variety growing duration, and late planting. Also in India the Integrated Agro Meteorological Advisory Service Programme has provided climate information services to farmers (Tall et al. 2014). In order to reduce the effect of climate change in needs to support the locals with climate information and introducing in taking proper measures.

5 DISCUSSIONS

In this part, it’s been discussed regarding the important findings of this study in sequence manner.

5.1 Model selection

Model selection is one of the difficult part in every hydrological modeling. Advancement in hydrology and computer programmes made the modeling part very tough which requires many parameters and data though the results are more reliable and close to the reality. The study area is a snow dominant catchment which precipitation is not directly converting to runoff similar to rainfall dominant catchment. This special case in this catchment makes modeling procedure very tough because precipitation in type of snow is saving to the earth in ice form and by gradually increasing the temperature the melting process is starting and slowly contributing to the runoff. In the selection of the model several criteria are considered which are applicability to the climate of the study area, data and accuracy. Considering these criteria, the HEC-HMS model is selected for the current study. This model due to number of studies around the world recognized suitable for the snow dominant catchment which ended with good results.

It is also the palace of question that many other models are exist which is also presented acceptable results like J2000, Mike, SWAT but due to the mentioned criteria is not used in this study. A very common problem with these mentioned models are requires very huge number of data include snow parameters that are not accessible in the study area context. In addition to that, preparing of these models requisite many parameters and data like in SWAT model the soil data is needed which preparing of that is very difficult time and budget consuming. Some of the models are not free accessible and needs to purchase the license which is very expensive and costly. Despite these models many other mathematical models are exist that is not considered in this study. This is because that many number of mathematical models such as 2p,3p, abcd and other models are mostly empirical and applicable in the rain dominant catchments. Although many other models are existing like HBV models that are not considered in this study which using of such model could increase the efficiency of the modelling that needs a separate study.

5.2 Data collection

The landuse map used in this study is from 2016 which is acquired from the FAO and it not verified with the field in this current study. Further the landuse map resolution is very low which could affect the model in terms of capturing the exact landuse components. The soil map used in this study is in a very large scale and not in finer resolution cause of this issue the SCN curve loss method is selected which requires only curve number (CN) and impervious percentage. For the climate change study wide range of data including the sunshine, wind, soil moisture and land cover is widely used which in this study due to limitation of these data is not used. The study area is large and limiting it with only precipitation seems difficult to capture all precipitation.

Theoretically, with increase in temperature the evaporation is also increasing which existing of this data is not only helping in finding the historical trends but can be very beneficial in modeling purposes. Without this data the modeling procedure seems very tough because it is one of the loss component that has to be calculated during the modeling procedure. Using the HEC-HMS model needs particularly to enter the evaporation which without this the modeling procedure isn’t be successful. Because of this limitation only blaney criddle formula is used for calculation of evapotranspiration. This is an empirical formula which requires to be verified with the field measurement and other empirical methods. The reason for selecting this method is the existence of the necessary data and its widely usage in the neighborhood countries such as Iran with the clime condition same to the Maidan-Kabul river basin. Due to this limitation using of blaney criddle formula could not illustrate accurately the evapotranspiration.

5.3 Quality of the data

It is being tried in this study to purify the acquired data of precipitation, temperature and streamflow. For this purpose, variety of method is used for visual, consistency and graphical checking of all mentioned data. During the visual checking it is being found that during the late spring, early summer and late fall when the precipitation is falling in type of rainfall the graph of rainfall is not matching with the streamflow. For example, in Figure 3-8 the rainfall graph is not matching with streamflow from month of August to December. It has two reason either of using this water in upstream before reaching to Tang-i- Saidan station or the miss measuring of streamflow data at Tang-i-Station. Due to large study area and high rate of evapotranspiration, existing of manmade canals along with main river channel more probably the water is not reaching to Tangi-saidan station.

In the process of quality checking of the data only the precipitation stations are purified using the applied methods of cumulative precipitation of one station against another station. It is because of the existence of many precipitation stations inside the catchment and near to study area which make possible to rectify the errors of close station using the information from other station. The streamflow data in only checked through visual observation but no any methods are applied to purify that. The consistency checks area applied in both streamflow and precipitation data which as result of that major errors are not found. In addition, existing of Pul-i-Surkh streamflow gauging station is not considered in this study.

Thiessen interpolation method is used for averaging the precipitation in this study but other methods are also existing such as IDW, Spline and krigging. Through GIS software it’s possible to use different method of interpolation. The Krigging method base on many studies is giving good results compare to the theimetessen hod which is not considered in this study. This is an impact to the accuracy of the model. In the annual water balance result in Figure 3-23 it was found the for every year, the amount is high compare to streamflow and evaporation. It indicates that most of water is infiltrating to the earth or using to many other palaces prior reaching to the outlet (Tang-i-Sadian station).

5.4 Uncertainty on historical trend of climate and water resources

The scope of studying the historical trend of climate change is mostly relying on the observed data of temperature, precipitation, streamflow and humidity. Beside of that the nine years’ average data (from 2009 to 2017) is used for the study which in case of climate change its too short for judging the climate and water resources condition. Studies around the word related to climate change suggests that at least 30 years of data is required for studying the climate change. but unfortunately, 30 years’ data is not available in the Afghanistan context. The result of the historical trend of climate change is verified during the field visits, which people are indicating that temperature of the study area is increased and precipitation is decreased.

Studying the climate change respect to historical trend is not only possible through water resources and climate factors but also through extensive filed survey and using the new technology. It was indicated by local people the existence of the glaciers storage that are melted after some time. Through using the new tools and modern technology. that could be possible to track the glaciers. In addition, by uing the satellite map and satellite data this could be possible to accurately determine the effect of climate change, existence of glaciers, streamflow parameters and determining the extend of grassland. Furthermore. using the remote sensing techniques identifying the land cover changes make this possible to determine the extent of climate change effect. Increasing of temperature is directly affecting to the soil moisture which leads the soil to be dried and loss its water that is not considered in this study. These are the limitations of this study that is not covered in this research.

5.5 Uncertainty in future climate projection

The two climate governing factor which is temperature and precipitation are projected using the GCM model under two popular scenarios (RCP 4.5 and RCP 8.5) up to end of 21 century. The GCM has some limitation and uncertainties which is ignored in this research. Usually, modelling uncertainties arise from fundamental choices made when building the GCM (for example, grid resolution), and from the parameterization of processes unresolved at the grid scale for example, cloud formation (Angew et al., 2011). These uncertainties include the equilibrium climate sensitivity which is the global warming associated with a doubling of atmospheric carbon dioxide, arctic amplification of temperature changes and regional precipitation responses. Rather than reducing biases stemming from an inadequate representation of basic processes (Jacobsen, Pfaltz, Yamamoto, Macmillan, & Shi, 2013). The uncertainties of model projections must be balanced with the risks of taking the wrong actions or the costs of inaction. Doing this will require that the sources and magnitudes of uncertainty are documented, and that conservationists and resource managers be willing to act despite the uncertainties. Although the alternative, of ignoring the future is not an option (Wiens, Stralberg, Jongsomjit, Howell, & Snyder, 2009).

Through existence of 39 GCMs only two scenarios are selected based on its common usage in the region. In addition of that out of four scenarios only the average and most disastrous scenarios which are RCP 4.5 and 8.5 are selected. These two scenarios are only applicable on the condition of continuation of the current situation if the world development goes rapidly. On the situation of mitigating the greenhouse gases and more strong determination by world leading countries on taking strong actions against the climate change, it is possible that anticipated scenarios effects could decrease. The current situation of Afghanistan is war and taking proper adaptations in the current political situation seems difficult. It has been clear that if the current political situation is improved and the future government paid more attention to adaptation strategies the streamflow scenarios may change.

5.6 Parameter estimation

In the HEC-HMS model, the most difficult part is estimation of parameters because this model work is based on considering the natural phenomena and doesn’t have direct method to capture the parameters. Creating methods needs a different research work which needs a separate study, considering this point the current research work is tried to find suitable ways for estimation of parameters based on carrying out researches from the different literatures. When the water is falling first its reaching to canopy storage and after filling that it reached to surface of the earth and filling the low slope and flat areas.

In the estimation of the Canopy surface, all the canopy cover is classified in three categories but this is not actually representing the realty. The Maidan-Kabul river basin is made of many plants that estimating the maximum capacity of each plant surface storage is different. To accurately estimate the canopy values, it is required remote sensing techniques to capture every single plant. In addition to that, depending on time different plants are cultivating which is not considered in this study. It’s also valuable to mention that canopy surface loss has very low impact on modeling procedure. For the surface loss method loss, the slope is the main component that through help of that its values are estimated which is the DEM 30 is used for this generating the slope. Although finer Dem resolution is not considered in this study which estimating the slope only through 30m Dem is not very accurate.

In the same manner, for generating the impervious percentage in Figure 4-16 the landuse coefficient is used which is not verified with the laboratory test. The landuse coefficient used in this study has very common usage in generating the impervious percentage but accurately estimating it requires more deep study, although in this study it’s been calibrated in the hydrological modeling section. For calculation of the time of concentration the NRCs formula is used despite the existence of many other formulas such as Kirpich and bransby because using of NRCs formula is widely used along with the SCN curve method but it’s not compared with other methods. Further it’s been calibrated during the hydrological modelling analysis part.

For estimation of the baseflow parameters the recession analysis method is used which mainly two parameters are calculated the recession contestant (K) and the ration peak. It’s been found that K parameter value is accurately estimated but regarding the ratio to peak the method is not very good because the calibrated parameters is much far. Further through many existence events during the calibration procedure only one single event in year 2010 as show in Figure 4-19 is used. Taking the average manner of all the available event may improve the initial estimation of the parameters which is not considered in this study. Also, for estimation of the temperature index parameters mainly the HEC-HMS manual is used and further calibrated. For real estimation of the relevant parameters it is always better to accurately estimate the parameters using the real laboratory test which is not in access in this research work.

5.7 Hydrological analysis’s results

The hydrological model has got good results for both lumped and distributed in the calibration and verification parts. The simulated model for low flows because the observed flow is zero mostly in summer season is not matched very well. The detail discussion regarding the results respect to hydrographs, flow duration curve, water balance and objective functions are shown in table 5-1 and table 5-2. Successul hydrologic simulation is reliabel on percipatation data that percipataion estimate based on point measurements and each point measurement can have large cath deficiencies due to wind espcially for solic precipation compare to liquid one (Peck, 1974).

Figure 5-1 Results discussion on lumped hydrological model

Lumped	**Hydrograph**						**Flow duration curve**					
	Calibration period			**Verification period**			**Calibration period**			**Verification period**		
	Time to peak	Peak	Base flow	Time to peak	Peak	Base flow	High flow	Medium flow	Low flow	High flow	Medium flow	Low flow
	Matched very well	Only in 2010 shows slight miss matching	In 2011 during summer season is not matching	Matched very well	Matched very well	Good matched	Less miss matched	Matched very well	Good matched	Matched very well	Good matched	Less miss matched
	Water Balance						**Statistical results**					
	Calibration period			**Verification period**			**Calibration period**			**Verification period**		
	The year 2011 and 2012 is showing slight high annual water balance difference compare to other years			Only the year 2015 showing slight high annual water balance difference compare to other years			NSE	PBIAS	R^2	NSE	PBIAS	R^2
							Very good	Very good	Very good	Very good	Very good	Very good

Figure 5-2 Results discussion on distributed hydrological model

	Hydrograph						**Flow duration curve**					
	Calibration period			**Verification period**			**Calibration period**			**Verification period**		
	Time to peak	Peak	Baseflow	Time to peak	Peak	Baseflow	High flow	Medium flow	Low flow	High flow	Medium flow	Low flow
Distributed	Matched very well	They year 2009 simulate peak is little lower than observed	The simulate flow during summer 2011 is not matching with observed	Matched very well	Matched very well	Matched Good	Matched Good	Matched very well	Matched Low	Matched Good	Matched Good	Matched very well
	Water balance						**Statistical results**					
	Calibration period			**Verification period**			**Calibration period**			**Verification period**		
	The year 2011 and 2012 is showing slight high annual water balance difference compare to other years			Only the year 2015 showing slight high annual water balance difference compare to other years			NSE	PBIAS	R^2	NSE	PBIAS	R^2
							Very good	Good	Very good	Very good	Very good	Very good

5.8 Future climate and water resources

The results of this study respect to temperature, precipitation and streamflow shows that future has quite different from the present. The temperature is increasing in all scenarios, especially during the winter which directly effect to the pattern of precipitation which shows that precipitation is changing to the rainfall from snow. This is also could be verified from Figure 4-39 that streamflow is responding directly to precipitation and from figure 4-38 also shows that during the months of December, January and February the temperature is raisin and it will effect to the pattern of precipitation. For the next decades under both scenarios the precipitation will be increased which simultaneously the streamflow is also increasing and it is a good news for the country respect to increase of water quantity. The un irregular precipitation is increasing and decreasing of the precipitation in winter season will seriously effect to water resources which in the future proper adaptation measures required if the climate trend is going on. In addition to that, these model requires to be update and continuously be checked regarding the time.

6 CONCLUSIONS

1- Historical analyses of water resources and climate factors indicate that peak discharge shifted earlier and the temperature trend is increasing much in winter season compare to summer season.

2- This study is revealed that HEC-HMS model with SCN loss model and temperature index could well simulate the streamflow in both lumped and distributed model.

3- The result of statistical analyses and water balance with NSE=0.86, PBIAS =8.51% and R^2 =0.89 shows that simulated values were well correlated with measured flow.

4- Two climate scenario RCP 4.5 (intermediate stabilization scenarios) and RCP 8.5 (high stabilization scenarios) successfully used for forecasting the temperature, precipitation and streamflow in Maidan-kabul watershed.

5- The precipitation under both scenarios (RCP 4.5 and 8.5) for 2020s show higher precipitation from month of February to Jun compare to base line but for 2050s and 2080s shows less, uneven and irregular precipitation.

6- Analyze of forecasted temperature, precipitation and streamflow shows that pattern of precipitation is changing form snow to rainfall under both scenarios for year 2050s and later.

7- Streamflow forecast analyses indicates flood situation under both scenarios for 2020s and drought condition for 2050s and 2080s.

8- water availability analyses indicate that compare to baseline (216 MCM) the river volume will increase up to 136% for 2020s under both scenario form (251.1-293.8 MCM) but for 2050s and 2080s it will decrease up to 20% (194.7-176.2MCM).

7 RECOMMENDATIONS

1- Parameter estimation techniques respect to base flow has to be further improved.
2- The HEC-HMS model with SCN algorithm and temperature Index method could be used for simulating streamflow for other cold catchments.
3- The thissen interpolation method is used in this study and it recommended to compare it with other interpolation techniques for overall result improvement.
4- This model can be used for water resources management, flood management, drought and environmental management in this river basin.
5- Climate change studies is playing a vital role for sustain of hydraulic structures in the current situation of country which considering it has to be pre requisite for any studies.
6- The number of meteorological and gauging stations located in this river basin is less and needs to be improved especially with evapotranspiration.
7- The blaney-criddle formula for estimation of evapotranspiration respect to result of the models shows good results but it need further verification with gauged stations.
8- This research can be further extended by using the radar precipitation data and dividing the model with smaller sub basins.
9- Afghanistan government should include the climate change studies in its budget for studying of any present and future water infrastructures.
10- Analysing the water availability of Shahtoot reservoir shows that for 2020s this reservoir has enough and more water respect to its normal volume (146MCM) bur for 2050 and 2080 this study shows its very close to its normal volume.
11- Implementing adaptations to climate change needs practical steps through structural measures, water management techniques, agriculture and irrigation improving, institutional strengthened and climate information support.

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APPENDIX A: Data Checking part

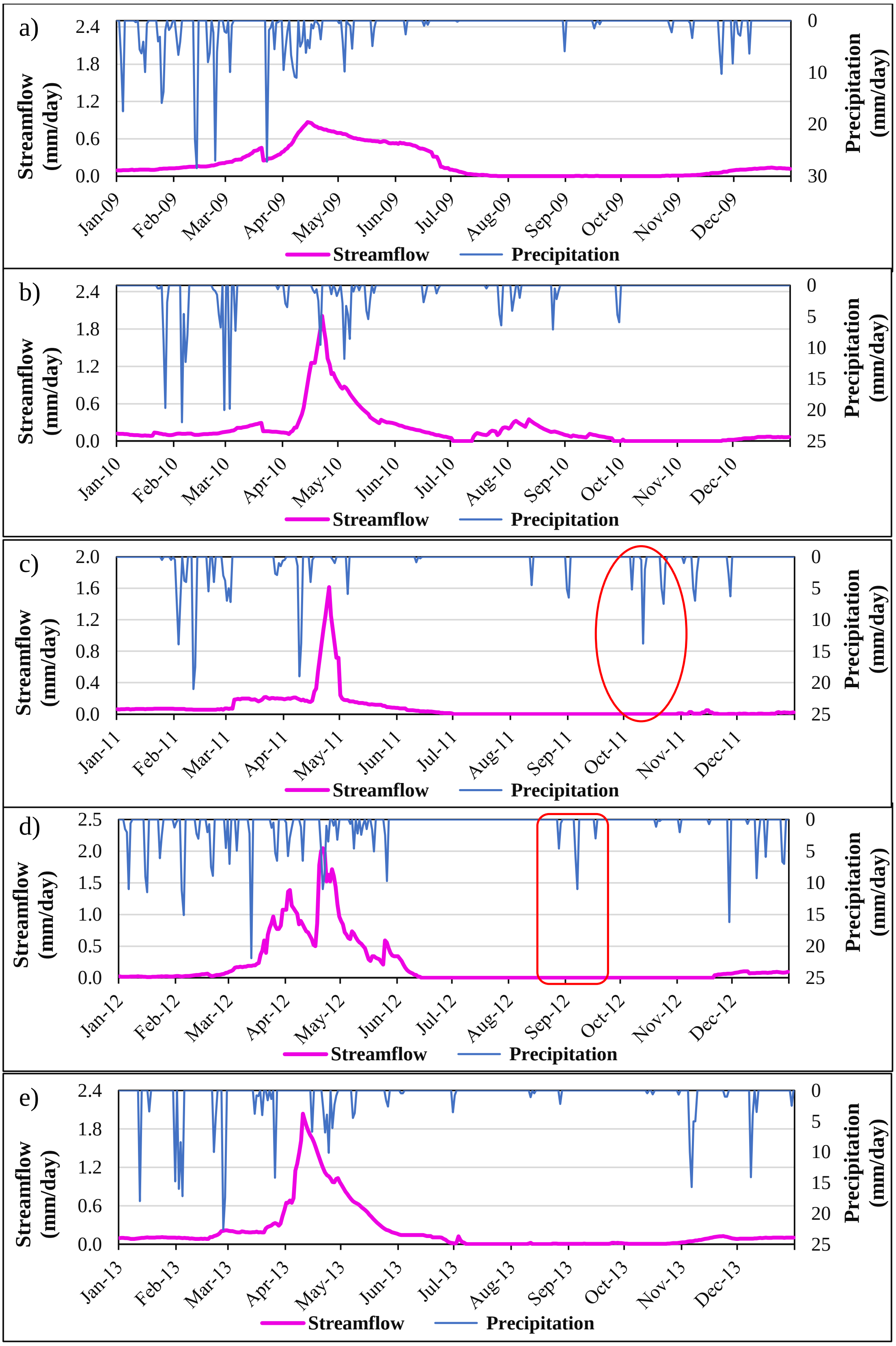


Figure A-1: Streamflow response of Tang-i-Saidan with precipitation (a, e)

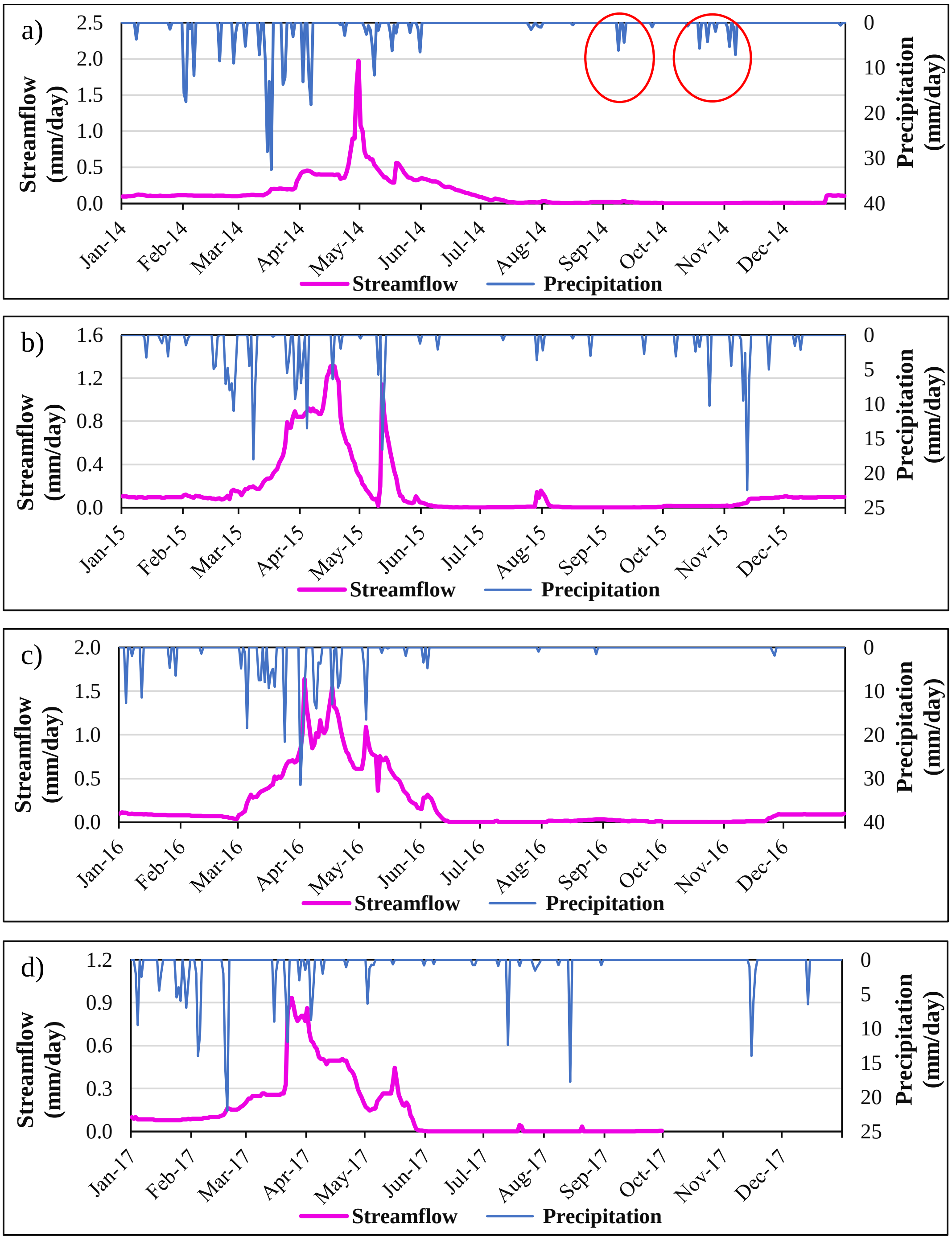


Figure A-2: Streamflow response of Tang-i-Saidan with precipitation (a, d)

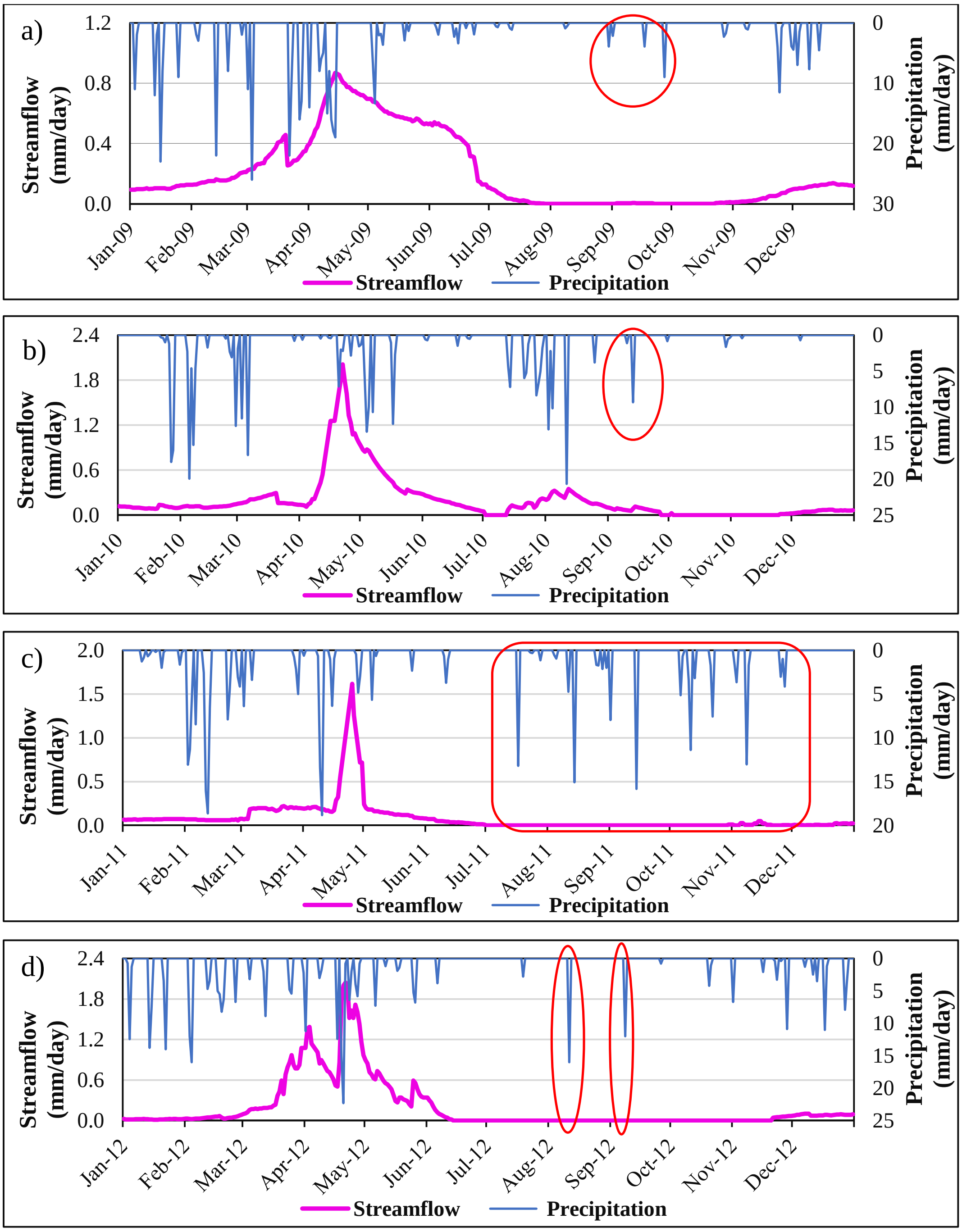


Figure A-3: Streamflow response of Pul-i-Surkh with precipitation (a, e)

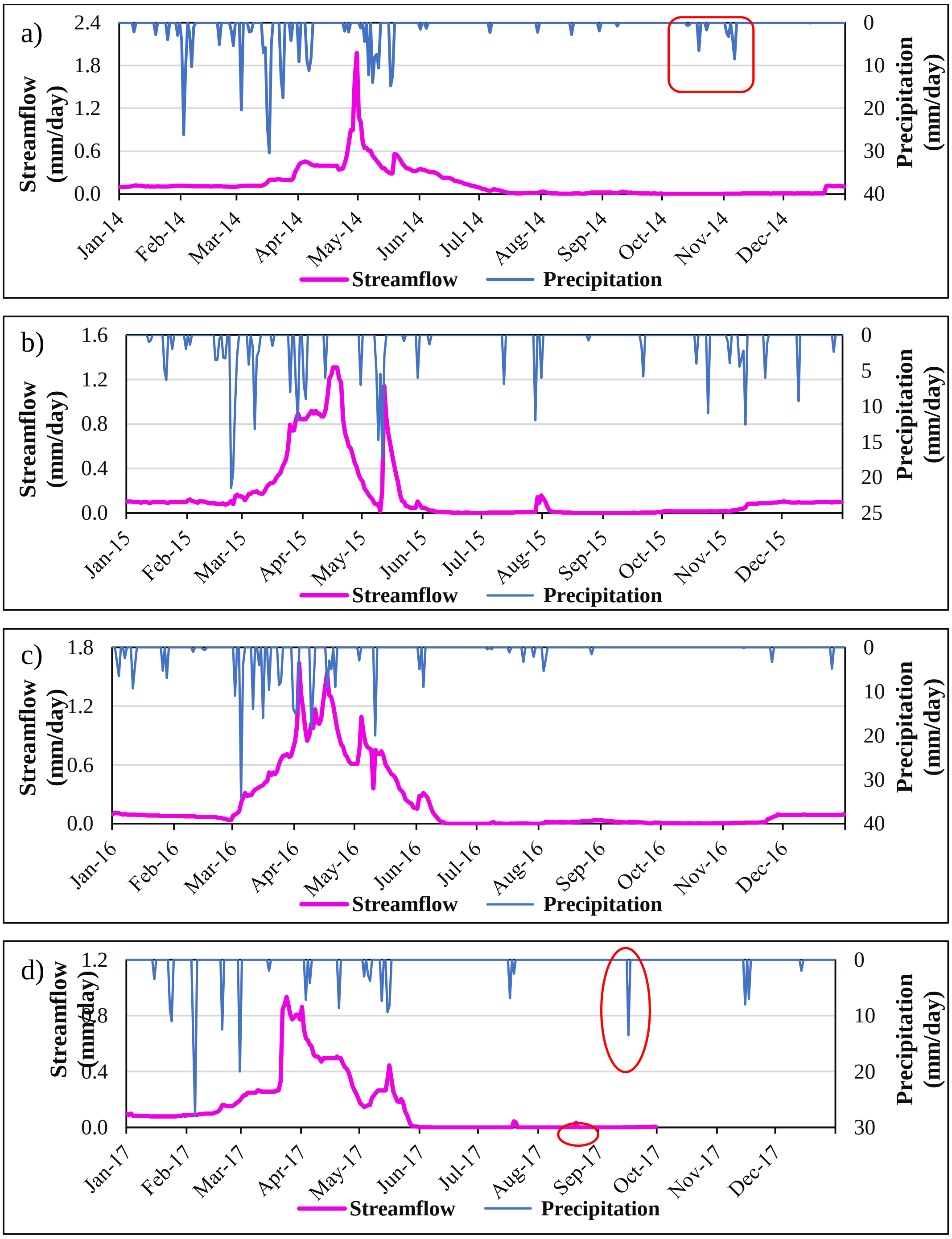


Figure A-4: Streamflow response of Pul-i-Surkh with precipitation (a, d)

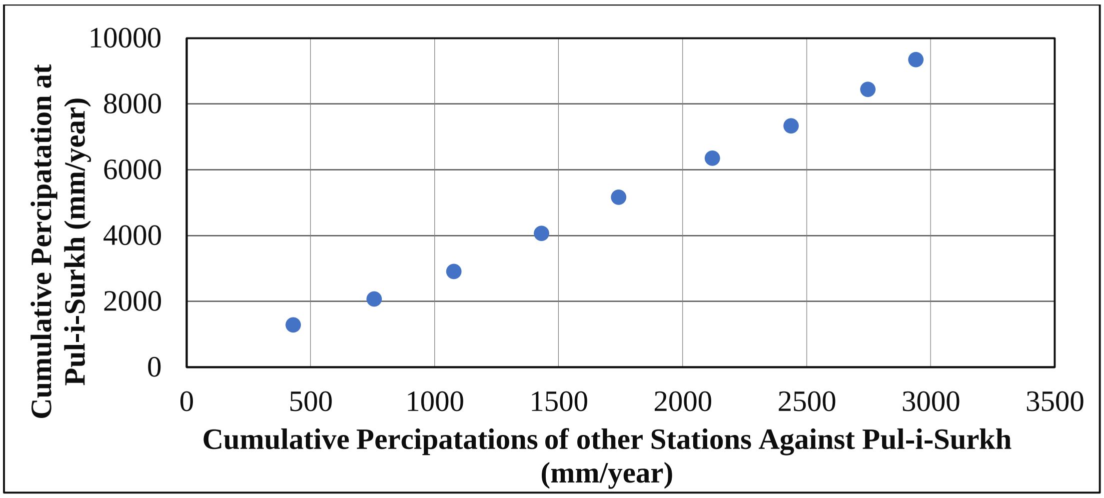


Figure A-5: Double mass curve for Pul-i-Surkh station

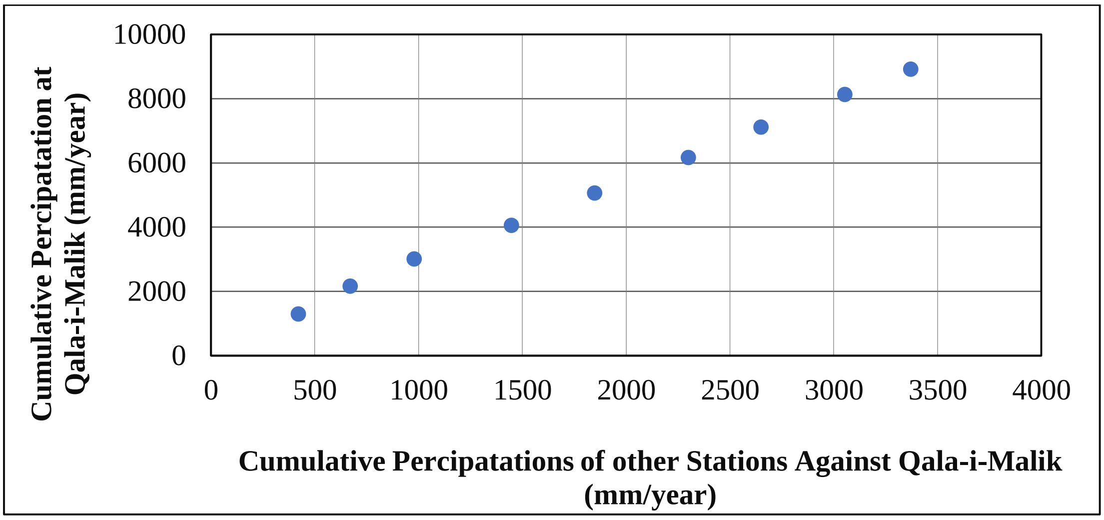


Figure A-6: Double mass curve for Qala-i-Malik station

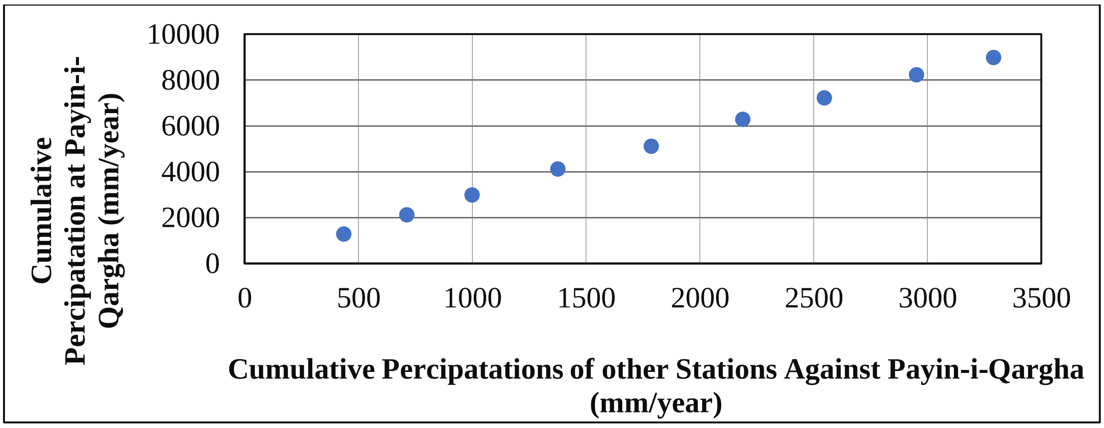


Figure A-7: Double mass curve for Payin-i-Qargha station

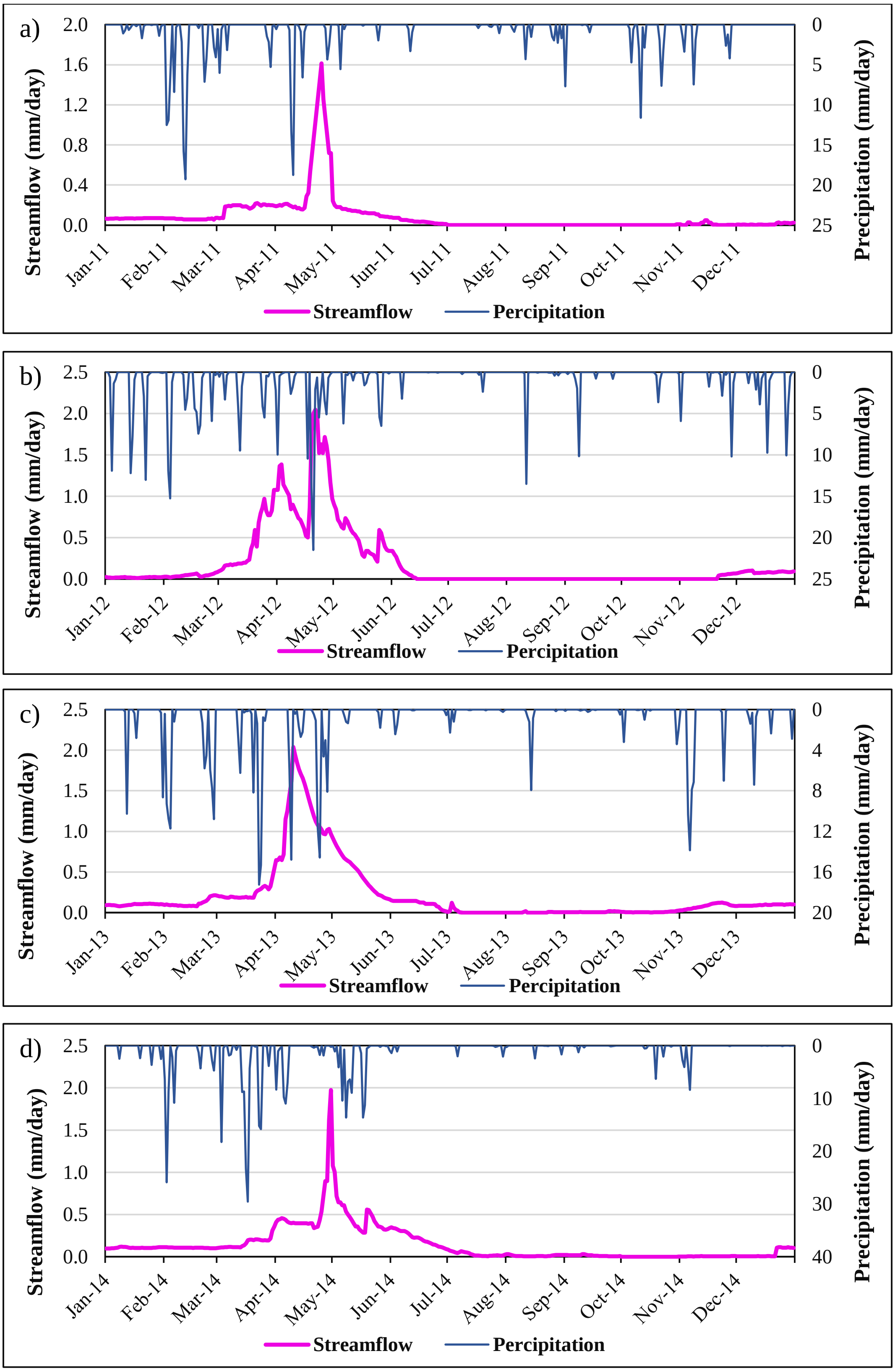


Figure A-8: Streamflow response of Tang-i-Saidan with thiessen precipitation (a, d)

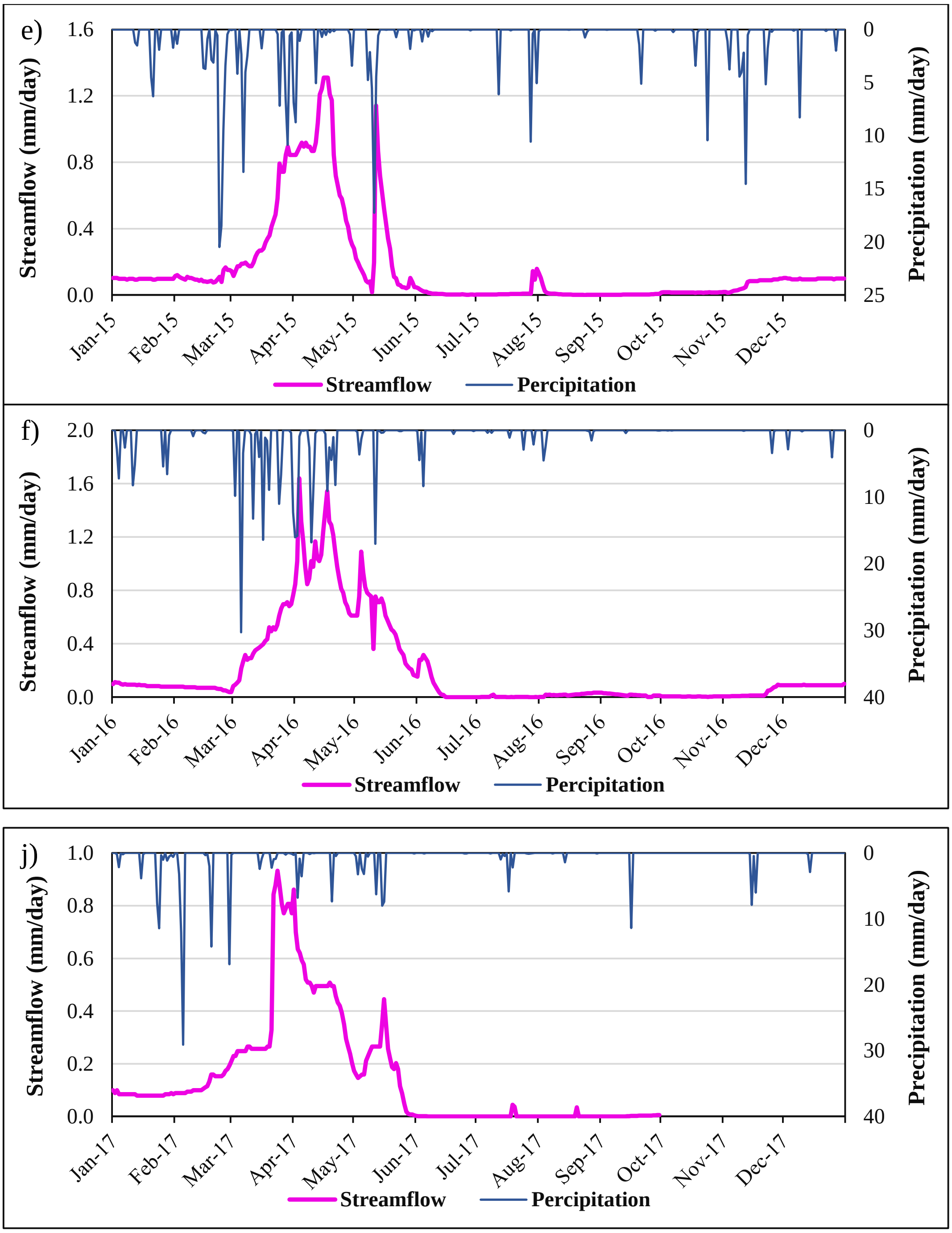


Figure A-9: Streamflow response of Tang-i-Saidan with thiessen precipitation (a, d)

APPENDIX B: Hydrological Modeling Parameters

Table B-1: Canopy, Surface storage, CN, Impervious percentage and slope values for lumped and distributed model

Model	Sub basins	Canopy Storage (mm)	Surface storage (mm)	CN (Curve Number)	Impervious Percentage %	Slope (%)
Distribute Model	0	0.11	7.44	8.92	20	25.18
	1	0.11	9.11	8.92	20	21.98
	2	0.35	15.45	8.92	20	17.22
	3	0.46	15.79	8.92	20	16.04
	4	0.31	14.90	8.92	20	16.91
Lumped Model	1	0.27	12.54	8.9224	20	19.39

Table B-2 Impervious percentage coefficient

LULC Category	Impervious surface coefficient
Commercial/Industrial/Paved	33.87
Residential & Commercial	25.97
Turf & Tree Complex	13.64
Rural Residential	12.48
Pasture & Hay & Grass	6.87
Deciduous Forest	3.48
Coniferous Forest	1.87
Exposed Soil	34.61
Pasture & Hay / Exposed Soil	11.08
Forest / Clear Cut	9.62
Deciduous Shrub Wetland	12.65
Exposed Soil / Cropland	2.92
Turf & Grass	2.40
Nursery Stock	NA
Exposed Ground & Sand	NA

Shallow Water & Mud Flats	2.91
Coniferous Forested Wetland	NA
Deciduous Forested Wetland	2.18
Non-forested Wetland	2.52
Scrub & Shrub	1.35
Mixed Forest	0.37
Deciduous Forest & Mt Laurel	0.25
Dead & Dying Hemlock	0.00
High Coastal Marsh	0.00
Deep Water	0.86
Low Coastal Marsh	NA
Shade Grown Tobacco	NA
Pasture & Hay / Cropland	NA
TOTAL ACRES	
% OF TOWN	

Source: (Prisloe, n.d.)

Table B-3: Optimizes parameters for Transform method

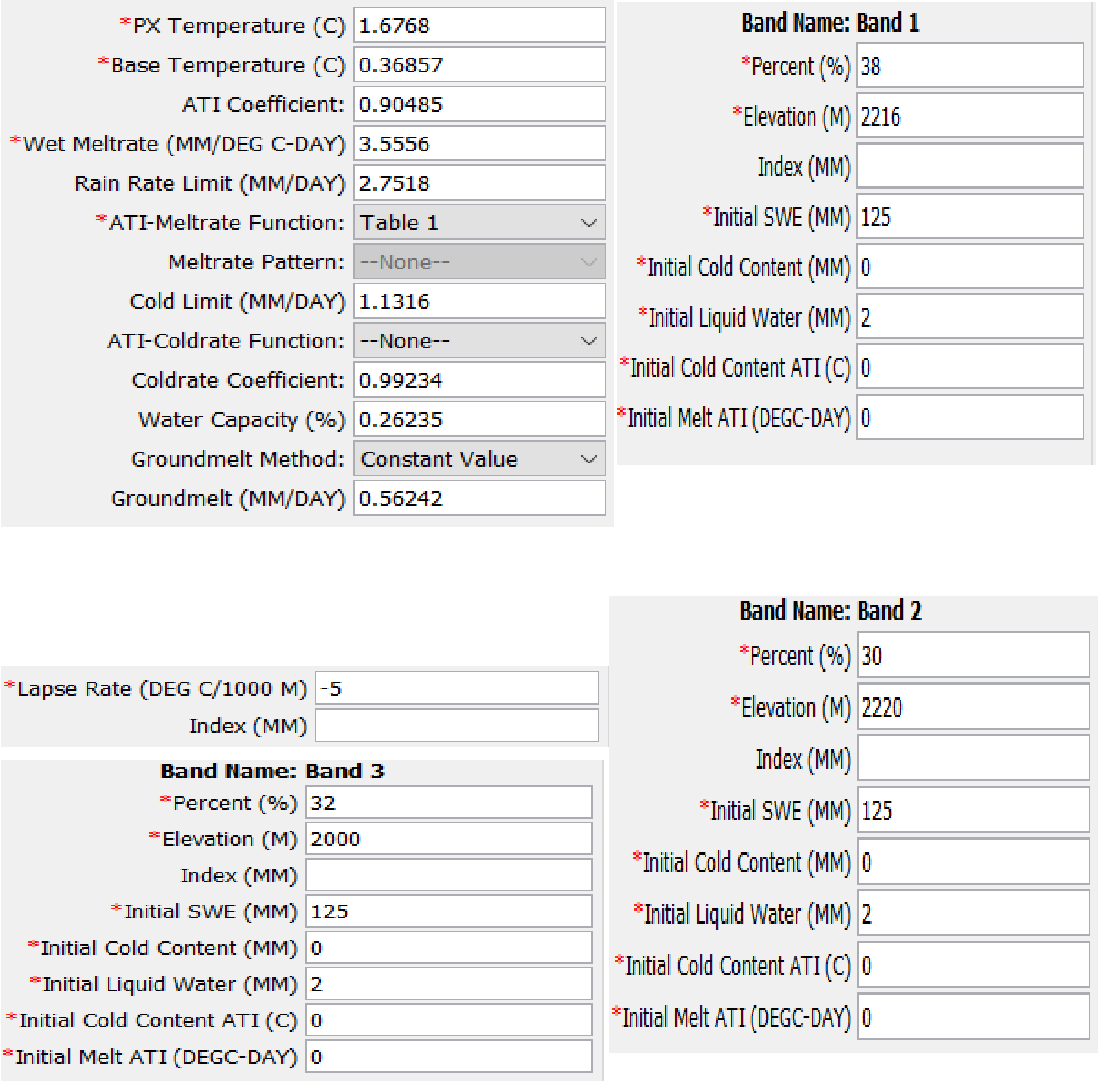
Models	Basins	Time of concentration (Hr)	Storage coefficient (Hr)
Distribute Model	0	20.833	400
	1	20.833	400
	2	20.833	400
	3	20.833	400
	4	20.833	400
Lumped model	l	20.833	400

Table B-4: Optimized parameters for Transform method

Models	Basins	Recession Constant (K)	Ratio
Distribute Model	0	0.67288	0.72178
	1	0.67288	0.72178
	2	0.67288	0.72178
	3	0.67288	0.72178
	4	0.67288	0.72178
Lumped model	l	0.67288	0.72178

Table B-5: Optimized parameters for Muskingum method

Models	Reaches	Muskingum K (HR)	Muskingum X
Distribute Model	Reach-1	19.478	0.333
	Reach-2	9.555	0.326
	Reach-3	9.959	0.080



*PX Temperature (C) 1.6768
*Base Temperature (C) 0.36857
ATI Coefficient: 0.90485
*Wet Meltrate (MM/DEG C-DAY) 3.5556
Rain Rate Limit (MM/DAY) 2.7518
*ATI-Meltrate Function: Table 1
Meltrate Pattern: --None--
Cold Limit (MM/DAY) 1.1316
ATI-Coldrate Function: --None--
Coldrate Coefficient: 0.99234
Water Capacity (%) 0.26235
Groundmelt Method: Constant Value
Groundmelt (MM/DAY) 0.56242

Band Name: Band 1
*Percent (%) 38
*Elevation (M) 2216
Index (MM)
*Initial SWE (MM) 125
*Initial Cold Content (MM) 0
*Initial Liquid Water (MM) 2
*Initial Cold Content ATI (C) 0
*Initial Melt ATI (DEGC-DAY) 0

Band Name: Band 2
*Percent (%) 30
*Elevation (M) 2220
Index (MM)
*Initial SWE (MM) 125
*Initial Cold Content (MM) 0
*Initial Liquid Water (MM) 2
*Initial Cold Content ATI (C) 0
*Initial Melt ATI (DEGC-DAY) 0

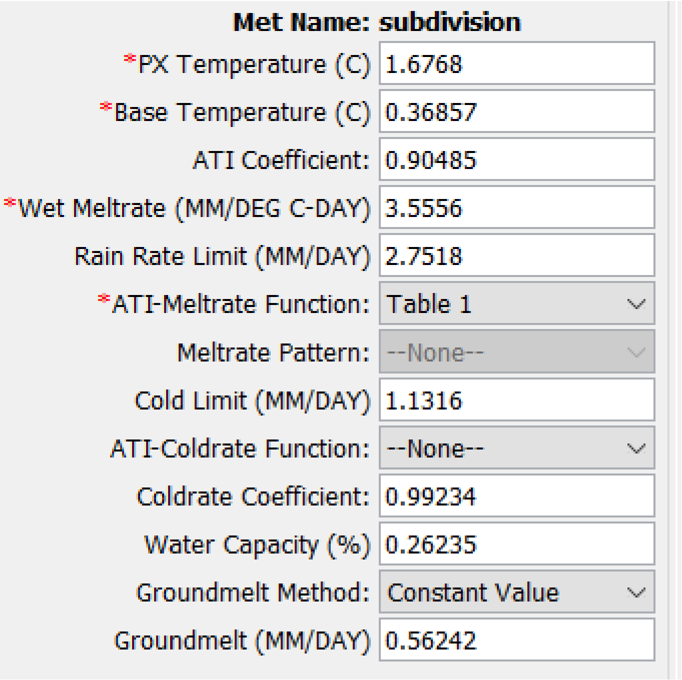
*Lapse Rate (DEG C/1000 M) -5
Index (MM)

Band Name: Band 3
*Percent (%) 32
*Elevation (M) 2000
Index (MM)
*Initial SWE (MM) 125
*Initial Cold Content (MM) 0
*Initial Liquid Water (MM) 2
*Initial Cold Content ATI (C) 0
*Initial Melt ATI (DEGC-DAY) 0

Figure B-1: Temperature Index optimized Parameters for Lumped model

Table B-5: ATI-Meltrate Function

ATI (DEG C-Day)	Meltrate (MM/DEG C-DAY)
0	0.09
150	0.2
1000	0.3
1500	0.5



Met Name: subdivision

*PX Temperature (C)	1.6768
*Base Temperature (C)	0.36857
ATI Coefficient:	0.90485
*Wet Meltrate (MM/DEG C-DAY)	3.5556
Rain Rate Limit (MM/DAY)	2.7518
*ATI-Meltrate Function:	Table 1
Meltrate Pattern:	--None--
Cold Limit (MM/DAY)	1.1316
ATI-Coldrate Function:	--None--
Coldrate Coefficient:	0.99234
Water Capacity (%)	0.26235
Groundmelt Method:	Constant Value
Groundmelt (MM/DAY)	0.56242

Figure B-2: Temperature Index optimized Parameters for Lumped mod

Appendix c: Hydrological Modeling Results

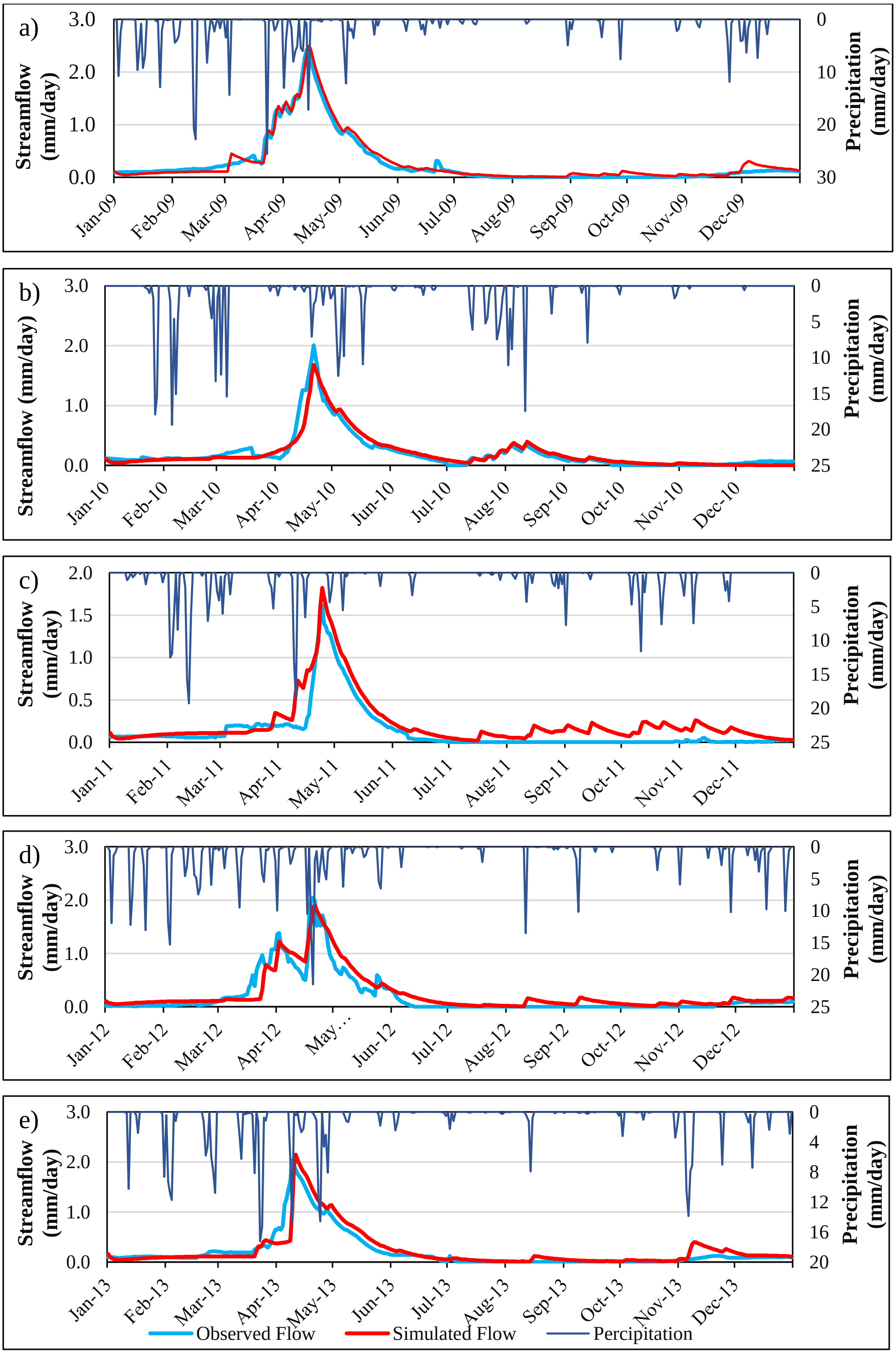


Figure 1-C: Hydrograph results for lumped model during calibration period (a, b)

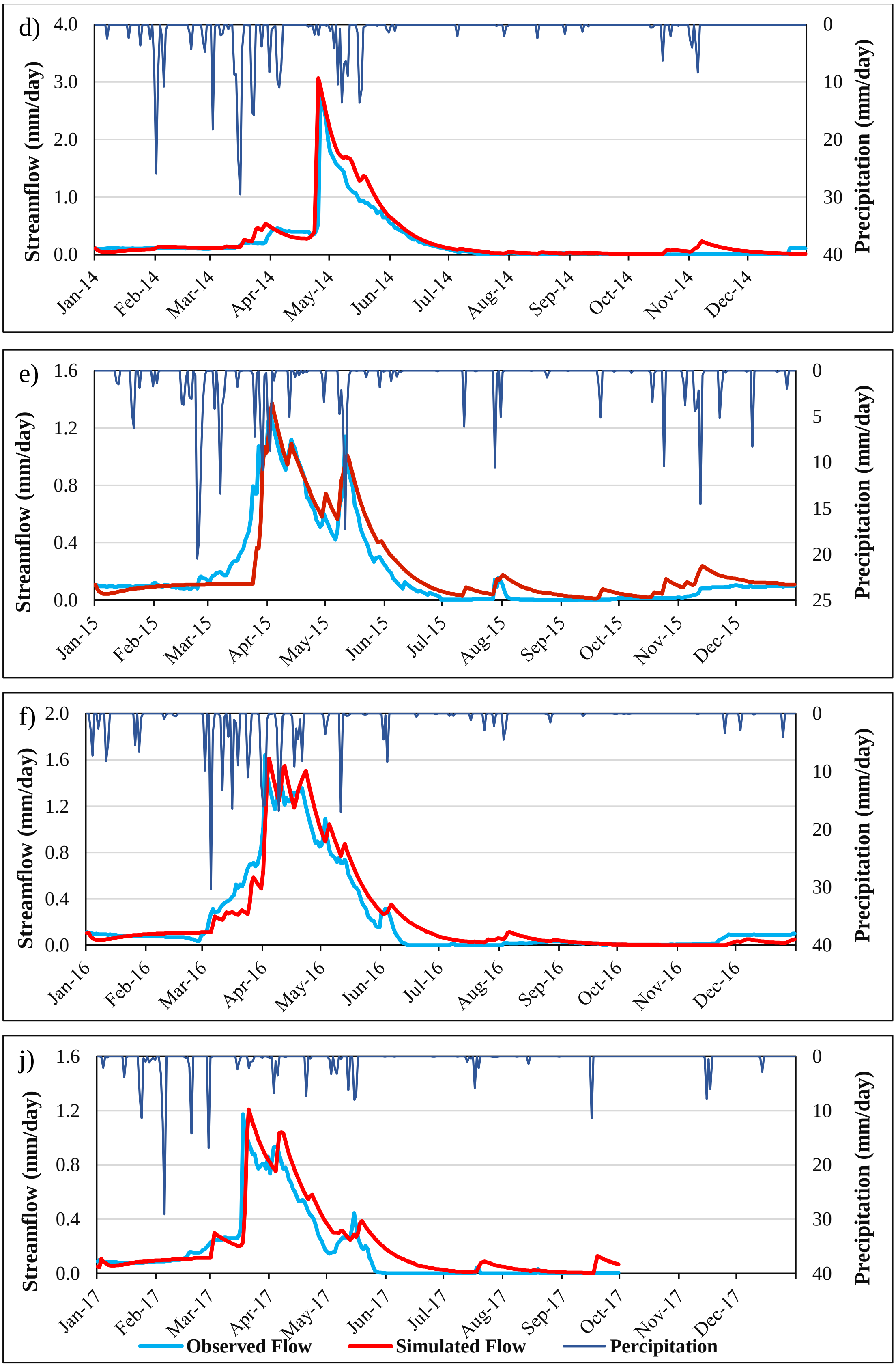


Figure 2-C: Hydrograph results for lumped model during verification period (d, j)

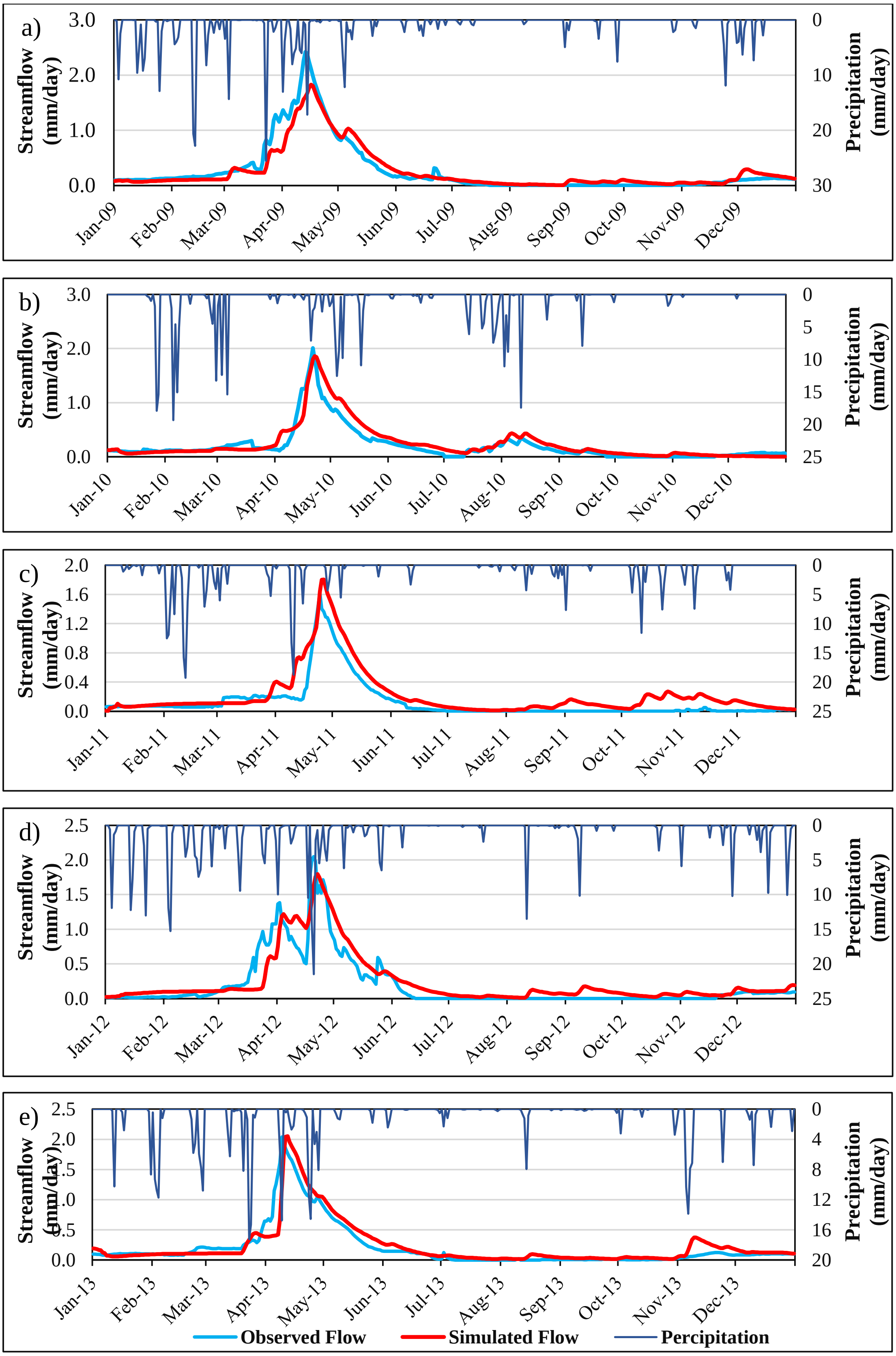


Figure 3-C: Hydrograph results for distributed model during calibration period (a, e)

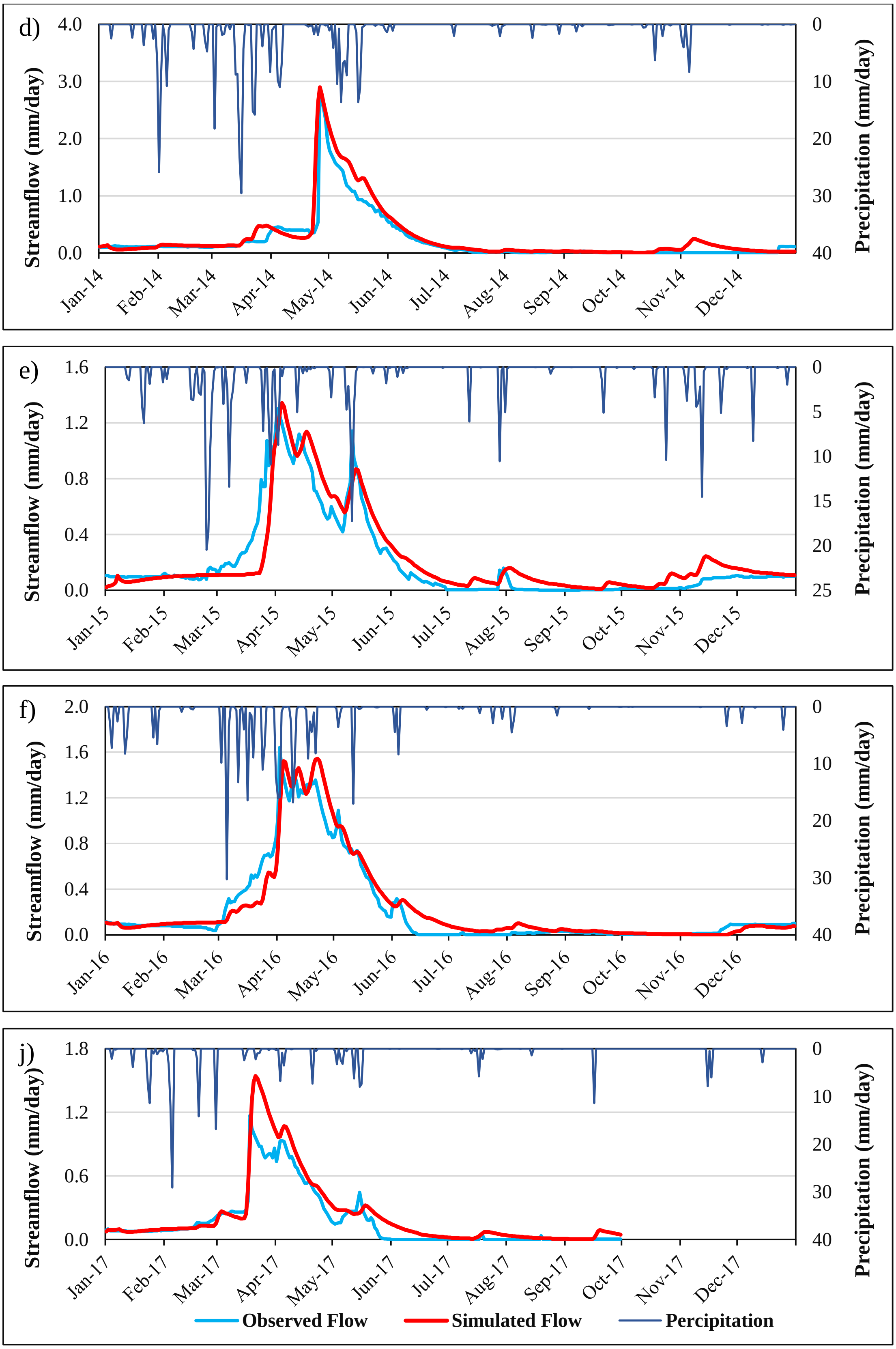


Figure 3-C: Hydrograph results for distributed model during verification period (d, j)