# Analysis of Current and Future Water Demands in Upper Indus Basin Under IPCC Climate and Socio-Economic Scenarios using a Hydro-Economic WEAP Model


By

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# CERTIFICATE

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**Analysis of current and future water demands in upper Indus basin under IPCC climate and Socio-Economic scenarios using a Hydro-Economic WEAP model**

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# DEDICATION

*Dedicated to family and friend*

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**Ali Amin**

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# LIST OF ABBREVIATIONS

| Abbreviation | Explanation |
|---|---|
| ET | Evapotranspiration |
| SWE | Snow Water Equivalent |
| WEAP | Water Evaluation and Planning |
| UIB | Upper Indus Basin |
| DEM | Digital Elevation Model |
| SRTM | Shuttle Radar Topography Mission |
| ASTER | Advanced Space borne Thermal Emission and Reflectance Radiometer |
| PMD | Pakistan Meteorological Department |
| WAPDA | Water and Power Development Authority |
| WASA | Water and Sanitation Authority |
| TRMM | Tropical Rainfall Measurement Mission |
| RCP | Representative Concentration Pathways |
| NSE | Nash-Sutcliffe Efficiency |
| HPG | High Population Growth |
| HLS | High Living Standards |
| LPG | Low Population Growth |
| MLD | Million Liters per Day |
| HKH | Hindu-Kush and Himalaya |
| WRD | Water Resource Development |

# ABSTRACT

Pakistan is facing severe water scarcity which is further exploited by the increasing population growth and effects of climate change. As climate change is the issue of century and many researchers are working on to find the effects of climate change on hydrological cycle and water scarcity in Pakistan but out those few of them focused their research towards management of water resources under climate change and other external factors. The objective of this research was to develop an integrated water governance strategy to achieve water security for a sustainable future in Upper Indus Basin (UIB) using difference climate change and socio-economic scenarios in hydro-economic WEAP (Water Evaluation and Planning) model. Five sub catchments (Gilgit, Hunza, Shigar, Shyok and Astore) in UIB and UIB were calibrated for the period of 2006-2010 and validated for the period of 2011-2014. For model performance indication, coefficient of determination and Nash Sutcliffe were used. For coefficient of determination, values ranged from 0.81-0.96 for calibration period and 0.85-0.94 for validation period. After setting up the baseline for the model unmet water demands for 2015-2050 was computed for both domestic and agriculture sectors. Scenarios were introduced to assess the effects of climate change and other external factors (Urbanization, Population growth and increase water consumption rate). Results of WEAP model indicated that the unmet water demands for the UIB will reach 134 million cubic meter (mcm) by 2050 for baseline conditions while external driven factors and climate change putting more stress on the water resources. This research further explored the water management options by taking into account the proposed dams by WAPDA (Water and Power Development Authority). These proposed dam (likely to be functional by 2025) will help achieve water security in the basin by decreasing unmet water demand by 60%. Further that, a comparative analysis for different types of future predictions (reference, moderate future-1, moderate future-2 and management scenario) was done to assess the unmet water demands in the UIB. Management scenario reveals that 60% of the water demand coverage will be achieved by 2023, which could help in developing sustainable water governance for the catchment.

*Chapter 1*

# INTRODUCTION

## 1.1 Background Information

Water is the most important and essential natural resource for the existence of life on earth. It is crucial for overall aspects of human life and activities like domestic use, irrigation purposes, industrial uses, fishing and for energy generation. Glaciers are starting to melt due to impacts of changing climate. (Gardner-Outlaw & Engelman, 1997). It is causing water shortage for agriculture and domestic sectors, which is a major global issue as it is affecting the water resources (Liu et al., 2017). The fresh water and its demands is not evenly divided across the globe (Gupta & van der Zaag, 2008). The global water resources are in stress due to exponential growth in world's economy, population and urbanization, these processes result in increased water demand for domestic, agriculture, power generation and for industries. Over the period of last thirty years global water resources were exploited to their limits, increasing the issues of safe drinking water availability and degradation of natural water resources(Cox, 1999). These issues lead the countries to the intense challenge of fulfilling the growing water demands for all sectors (domestic, agriculture and industries) and for safe, reliable water supplies. These challenge has been further intensified by the effect of climate change which results in water scarcity in many countries, causing degradation of water resources and decreasing in fresh drinking water availability (Döll, Kaspar, & Lehner, 2003); (Parish, Kodra, Steinhaeuser, & Ganguly, 2012). Many policy makers and researchers experimented with variety of water management techniques for sustainable water supply management, they came to the conclusion that in context of urbanization, population growth, economic growth and climate change supply oriented solutions will be a preferred option for managing water resources globally (Feldman, 2001); (Gupta & van der Zaag, 2008).

## 1.2 Pakistan Water Resources

Glacier melt, rainfall and snowmelt are the main sources of river runoff in Pakistan. After the Polar Regions, Upper Indus Basin (UIB) contain the largest glacier cover area in the world i.e., 22,000 $km^2$, and the snow cover area is greater in magnitude. These glaciers are the natural storage of fresh water which contribute a great deal to Indus River and its tributaries (Khattak, Babel, & Sharif, 2011).

Rivers in Pakistan are divided in to two categories western rivers (Jhelum, Chenab and Indus) and eastern rivers (Ravi, Beas and Sutlej). Kabul River on the western side and Punjnad (combination of five rivers) on the eastern side are the two main tributaries of Indus River. This division of western and eastern rivers came in to existence as a result of settlement of water dispute between Pakistan and India known as Indus Water Treaty 1960.

China contributes 181.62 $km^3$ to the Indus River annual water flow to India, which generates approximately 50.86 $km^3$, results in an accumulated 232.48 $km^3$ flow to Pakistan. Indus Water Treaty states that 170.27 $km^3$ Indus water is reserved for Pakistan and remaining 62.21 $km^3$ for India.

Indus River tributaries which are originating in India (Ravi, Beas and Sutlej) have an average annual flow of 11.1 $km^3$ before entering Pakistan. All of these rivers in Indus system are perennial (WCD, 2000). After entering Pakistan, these are aided by many smaller tributaries (Swat, Kunar, Kabul, Soan, Kurram, etc.). All these rivers and small tributaries are responsible for irrigating entire Indus Basin.

## 1.3 Indus River Basin

The Indus basin is a transboundary river basin (distributed between Pakistan, India, China, and Afghanistan) having a total area of 1.12 million $km^2$. Indus River enters from India to Pakistan and flows through the Himalayan Mountains in the north region of Pakistan to the downstream Sindh province in the southern part of Pakistan and then finally drains out into the Arabian Sea. The total area Indus Basin covers in Pakistan is 0.52 million $km^2$ (65% of the country's total area). Indus basin in Pakistan covers Khyber Pakhtunkhwa (KPK), Punjab province and some part of Sindh and Baluchistan.

As Indus River basin originates from Tibetan plateau (China) to the Arabian Sea, the climate in the basin is not uniform. It varies from semiarid, arid to moderately humid in Sindh province and Punjab provinces to the highlands of north. In the southern part of the basin precipitation ranges from 100 mm to 500 mm, and in Northern part of the basin rainfall to 2000 mm (Lutz, Immerzeel, Shrestha, & Bierkens, 2014).

The Upper Indus Basin (UIB) consists of mountainous range and these mountains limit the intrusion of the monsoon. In UIB, in winter and spring and spring season most of the rainfall is due to westerlies and monsoon brings occasional rain to Himalayan areas. Altitude has a strong impact on climatic variables. Annual precipitation in these northern valleys ranges between 100 and 200 mm. According to glaciological studies in Himalayan region, it increases to 600 mm at 4400 m with a maximum of 1500 to 2000 mm at 5500 m. In the region, winter precipitation is highly spatially correlated. From 1961 to 1999, precipitation in the UIB showed significant increases in winter, summer and annual accumulation rates. These trends will impact the future water availability (Fowler and Archer, 2005). On the lower plains, in Sindh province, the average annual rainfall received is about 90 mm. On the upper plains (Punjab Province), areas of Multan receive 150 mm and Lahore about 510 mm of average annual rainfall.

In the southern part winter season is from Dec to Feb and average monthly temperatures vary from 14 to 20°C, and in summer season (March to June) average monthly temperature vary from 42 to 44°C. In northern part of Pakistan, in summer temperature ranges from 23 to 49°C and in winter and from 2 to 23°C.

## 1.4 Hydrological Modeling in Indus Basin

Livelihood of more than 1.4 billion people depend on the water from Indus River for both drinking and agricultural purposes. Upstream snow and glacier packs are of great importance for sustainable water availability, which is likely to be affected by socioeconomic factors and climate change (Immerzeel, Van Beek, & Bierkens, 2010). So hydrological modeling for the purpose of monitoring river runoff, glacier melting, snow accumulation and socio-economic condition in the basin is important for sustainable water governance. (Immerzeel, Droogers, De Jong, & Bierkens, 2009).

Khan et al (2015) performed a study based on the availability of water in Upper Indus Basin (UIB) under different climate change scenario. They discussed the two forces responsible for climate change i.e., natural variability and human induced factors, they used four emission scenarios (A2, B2, RCP4.5 and RCP8.5) and found out that Indus River contribute 80% in hydropower generation and 44% available water per year. These results were further duplicated using emission scenarios (Khan & Pilz, 2015). Hydrological modeling in the snow and glacier pack regions is very challenging due to the scarcity of meteorological and stream flow gauge stations, Pellicciotti et al (2011) discuss the uncertainties and challenges in Hydrological Modeling of HKH Basins, they describe different procedures to perform calibration in the remote basins (Pellicciotti, Buergi, Immerzeel, Konz, & Shrestha, 2012).

Different hydrological models have been used over the period of time to model and assess the river runoff and water demands and supply conditions. Bodo Bookhagen and Douglas W. Burbank used snow runoff model to assess the rainfall runoff and snow melt changes in the Himalayan, they used calibrated remote sensing climate parameters to characterize the spatiotemporal distribution of rainfall, Evapotranspiration (ET), and snowfall to quantify their distribution in river runoff. Rainfall is calculated from Tropical Rainfall Measurement Mission (TRMM) data, snow water equivalent (SWE) from a satellite based derived snow cover, temperature and solar radiations. They concluded that snowmelt contributes 50% of the runoff in western basins, 25% in eastern basins and 20% elsewhere (Bookhagen & Burbank, 2010).

## 1.5 Rationale

Pakistan is among the most water scarce countries in the world, there is less water available for per person use, and agriculture sector is also suffering. Economy of Pakistan is largely depending on the agriculture from the single river system i.e., Indus and its tributaries. Water scarcity in Pakistan is mainly due to mismanagement of water resources as Pakistan haven't built any dams after Tarbela and Mangle. There are other projects for power generation but they are mainly dependent on runoff which is snow and glacier melt (Young & Hewitt, 1990). Hindu-Kush and Himalaya (HKH) are known as Asian water tower, source of major Asian rivers (Immerzeel et al., 2009), other than north or south pole HKH region has the biggest repository or snow-glacier (Abbaspour et al., 2007), HKH regions is main source of river runoff in the Pakistan other than rainfall (Bocchiola et al., 2011).

This study mainly focusses on the allocation and assessment of surface water demand in sub basin in the northern part of Pakistan. The leading consumers of surface water in the catchment are irrigation for agriculture land, domestic water users, and livestock. This research develops a sustainable water management plan based on the proposed Water Resource Development (WRD) projects by WAPDA Pakistan. In this study using the limited datasets for designing the hydrological process of water supply and demands under the climatic and demographic conditions of the basin.

The main problem encountered during the study include: sparsely distributed meteorological stations, lack of sufficient studies and gaps in the hydrological data.

## 1.6 Objectives

### 1.6.1 Main objective

Overall objective of the study was to design a water conservation technique for optimum water management in the catchment. The following are the specific objectives:

- To Buildup and Calibrate a hydrological model for the Upper Indus Basin using WEAP.

- To estimate the water demand in different sectors under different socio-economic and climate change scenarios.
- To assess the potential of proposed WRD (DAMS) projects on Indus River.
- Prediction of future water demands using four different water management scenarios.

## 1.7 Research Questions

In order to achieve the main objective following questions, need to be answered;

i. What is the total stream flow potential available in the catchment?

ii. What are the main water consumers in the basin, how much they consume and what is the rate of consumption?

iii. How much losses water allocation mechanism in the catchment encounters?

iv. Is there enough water available in the basin to fulfill the increasing future water demands?

*Chapter 2*

# MATERIALS AND METHODS

## 2.1 Study Area

Study was conducted on the Upper Indus Basin (UIB), which is situated in the northern region of Pakistan between latitude 33°54´05.48″E-37°05´27.96″E and longitude 72°11´26.77″N-77°41´50.36″N. It is the mountainous area of HKH (Hindu Kush, Karakorum, and Himalayan), also known as Asian towers and they are source of fresh water for the region. Upper Indus Basin (UIB) covers an area of 83003 $km^2$ (Figure 2.1).

Indus River originates from Tibetan Plateau (China) then flows through the disputed territory of Jammu and Kashmir to Pakistan (Gilgit-Baltistan). Main tributaries in the Upper Indus Basin (UIB) include Astore River, Gilgit River, Shigar River, Shyok River and Shingo River. After that Indus River flows downstream (southwards) through the Pakistan to the Arabian Sea.

Present study aimed to simulate current supply and demand condition in the Upper Indus Basin (UIB), WEAP was used to simulate runoff in the catchment from 2006-2014. For simulation period, WEAP was calibrated for 5-year period 2006-2010 and after that validated for 4-year period 2011-2014). Parameters in WEAP were tuned for each catchment separately and then applied to whole simulation period. Different socio-economic, urbanization and climate change scenarios were used to predict future runoff and water demands in the basin.

Different studies conducted in Upper Indus Basin (UIB) actually focused only on the impacts of the climate change and anthropogenic activities but this study was designed for the purposed of management option which can be applied in the basin for sustainable water governance and security.

## 2.2 Data Collection and Processing

### 2.2.1 Digital Elevation Model (DEM)

There are two types of Digital Elevation Model (DEM) which are freely available on USGS website, i.e. 90 m resolution Shuttle Radar Topography Mission (SRTM) and 30 m resolution Advanced Space borne Thermal Emission and Reflectance Radiometer (ASTER). The SRTM DEM was downloaded freely (https://earthexplorer.usgs.gov/) to delineate sub catchments in the study area despite of its low spatial resolution SRTM is found to be more reliable than ASTER DEM (Huggel, Schneider, Miranda, Granados, & Kääb, 2008).

### 2.2.2 MODIS Land Cover

Satellite images were used to create large area land use land cover images to study the natural and anthropogenic activities (Zhang & Roy, 2017). MODIS land cover data type product MCD12Q1 was projected and processed for every year for the period of 2001-2012. These land cover products are produced at 500 m spatial resolution, these classified land cover products were projected to geographical coordinates to WGS 1984 reference system. Boundaries of these datasets are -64.0° <= latitude <= 84.0° and -180° to 180° longitude. MODIS land cover product was downloaded from https://earthexplorer.usgs.gov/ (Figure 2.2).

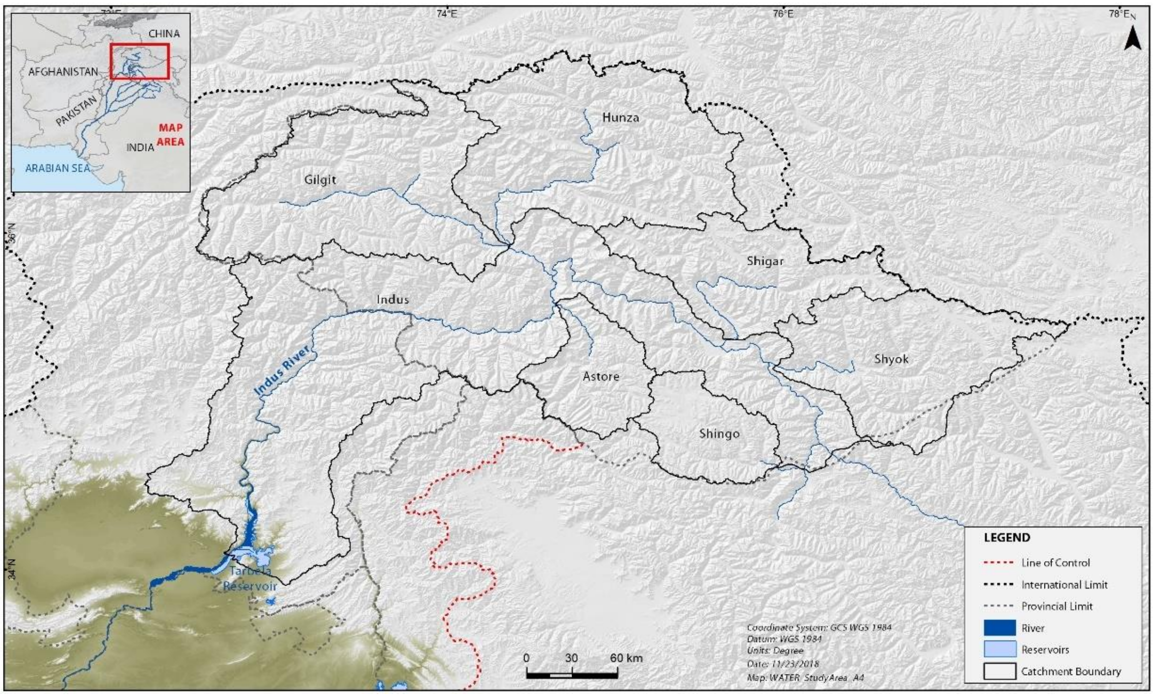


Figure 0.1. Study area map shows sub catchments in the study area.

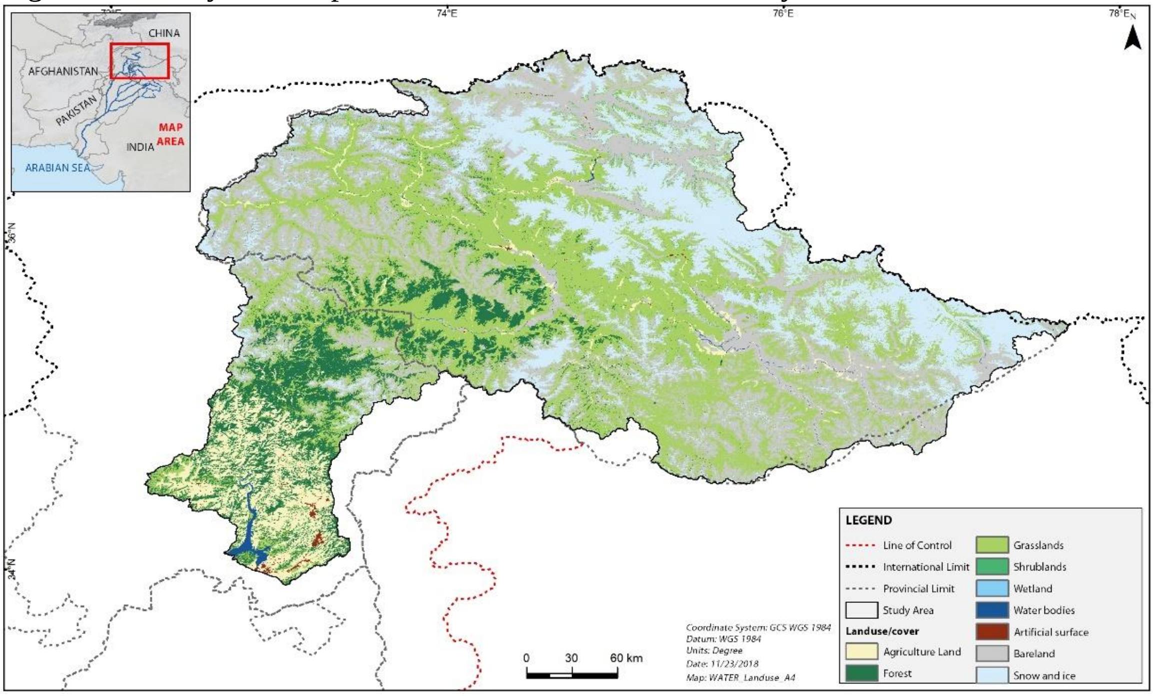


Figure 0.2. MODIS land cover data product for study area.

### 2.2.3 Climate data

Climate data was acquired from Pakistan Meteorological Department (PMD) for all the available stations in Upper Indus Basin (UIB). As shown in Figure 2.3 for large enough area there are few meteorological stations, so in order to overcome the scarcity of PMD stations in the basin TRMM data was used for the sub catchments for which there were no ground data available.

Metrological stations in Upper Indus Basin (UIB) are not well distributed, however few stations were installed in UIB for snow and hydrology project (Hewitt & Young, 1993), but their data is helpful for various research products but not reliable for long term monitoring of snow and glaciers cover in the region (Archer & Fowler, 2004). There are eight meteorological stations in the Upper Indus Basin which covers an area of 83003 $km^2$.

Monthly maximum and minimum temperature and monthly rainfall data was collected for time period of 2006-2014. Due to the scarcity of meteorological stations in UIB for two sub catchments satellite data was used.

### 2.2.4 Streamflow Data

Streamflow gauge stations installed by WAPDA are at Gilgit River, Hunza River, Shigar River, Shyok River, Astore River (Figure 2.3) and three-gauge stations on Indus River (Table 2.1).

Monthly discharge data was for the years of 2006 to 2014 for building a baseline for the research. Discharge data was used to calibrate and validate the simulated flow generated by WEAP hydrological model (Figure 2.4).

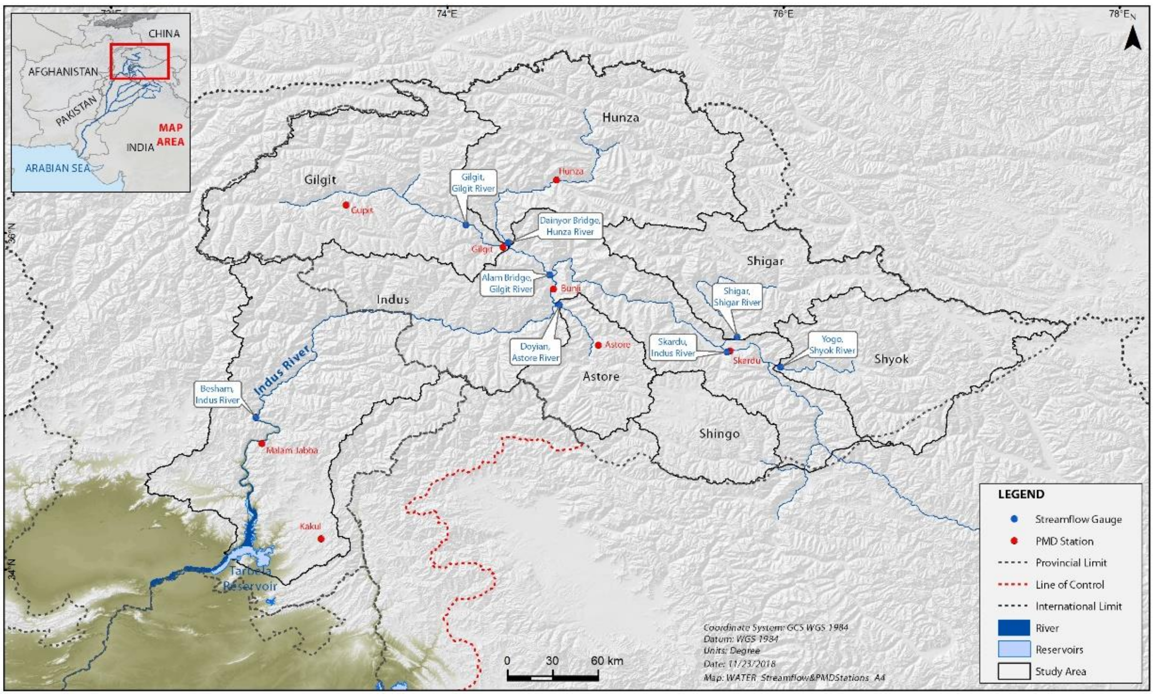


Figure 0.3. Location of streamflow gauges and PMD stations in the study area.

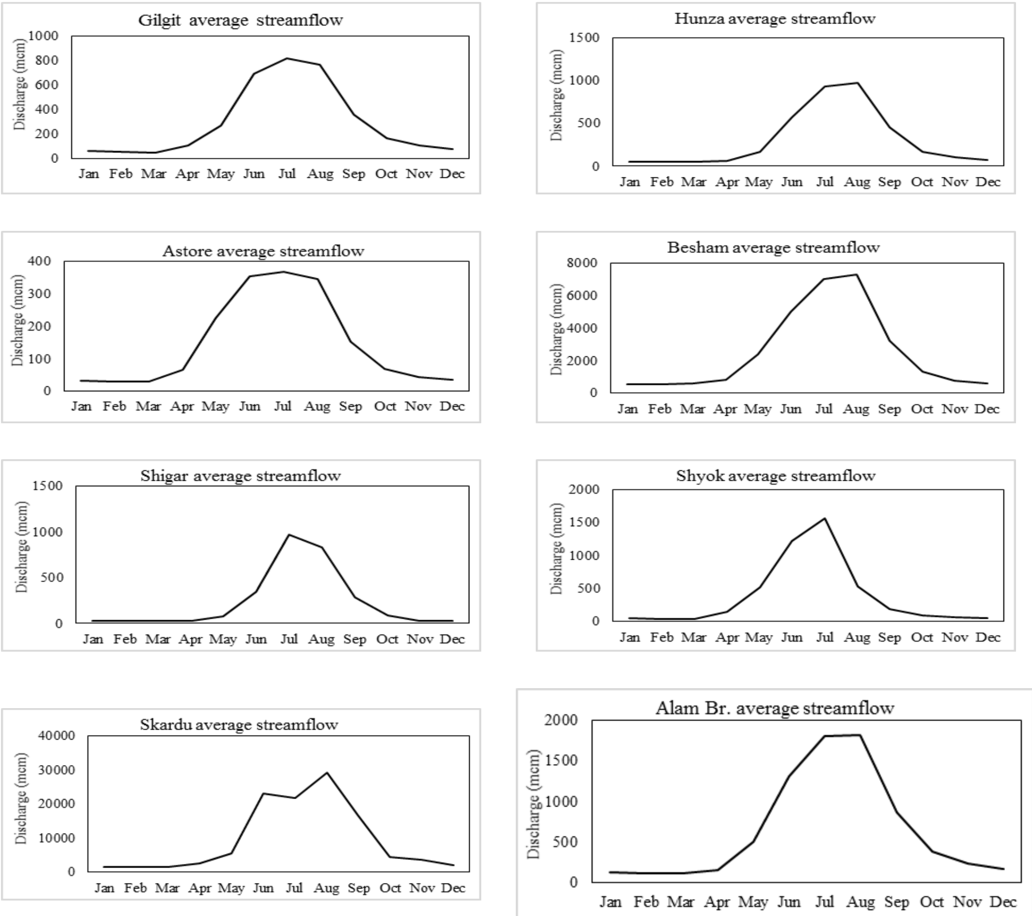


Figure 0.4. Average streamflow of streamflow gauges in Upper Indus Basin (UIB) from 2006-2014.

Table 0.1. List of streamflow gauge station in the study area.

| Sr. No. | Gauge station | Sub catchment | River | Flows in to |
|---|---|---|---|---|
| 1 | Doyian gauge station | Astore | Astore | Indus River |
| 2 | Alam Br. gauge station | Gilgit | Gilgit | Indus River |
| 3 | Shigar gauge station | Shigar | Shigar | Indus River |
| 4 | Dainyor Br. gauge station | Hunza | Hunza | Gilgit River |
| 5 | Yugo gauge station | Shyok | Shyok | Indus River |
| 6 | Gilgit gauge station | Gilgit | Gilgit | Indus River |
| 7 | Besham gauge station | Indus | Indus | - |
| 8 | Tarbela Inflow gauge station | Indus | Indus | - |
| 9 | Skardu gauge station | Indus | Indus | - |

## 2.4 Analytical Framework

Analytical framework of the research is given below;

### 2.4.1 Methodology

This application of WEAP was focused on the calibration and validation of all the sub basins in the UIB except Shingo sub basin because of non-availability of streamflow data. WEAP model was setup for baseline conditions then predicted the future based on these baseline conditions for a user specific time period, after that three different scenarios (socio-economic, urbanization and climate change) were applied to predict future under these conditions.

WEAP model was set up from 2006-2014 as a baseline period for the study for which water demands were calculated for both agriculture and domestic sectors. WEAP model used baseline conditions as a reference/business as usual, Socio-economic scenario were applied which included high population growth scenario (HPG), high living standards (HLS), low population growth (LPG), and a combination of high population growth and higher living standards. For climate change scenarios, these scenarios were developed using downloaded data from Global Climate Model datasets to calculate supply and demands condition in case to RCP4.5 and RCP8.5 by the year 2050. Figure shows the complete set of datasets used in the WEAP model and their sources (Figure 2.5).

### 2.4.2 Datasets Used

Along with above mentioned datasets following datasets also used to calibrate and validate WEAP model (Table .2.2) (Figure 2.6).

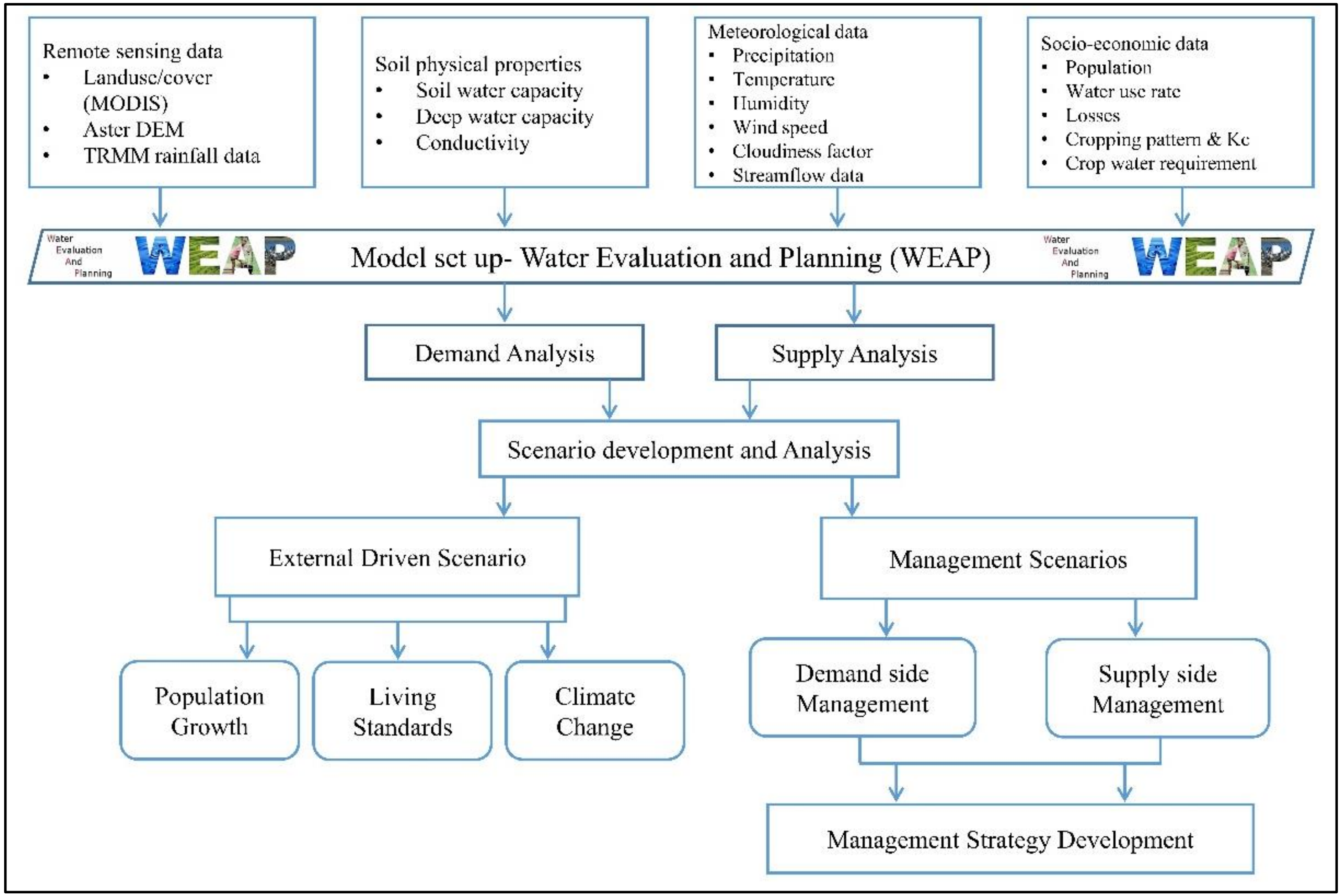


Figure 0.5. The study workflow and data inputs in the WEAP model.

Table 0.2. Data sources and their description for development of hydro-economic WEAP model.

| Datasets used | Depiction | Sources |
|---|---|---|
| Satellite data | SRTM DEM for watershed delineation, MODIS Land cover product & Precipitation from TRMM product | United States Geological Survey (https://earthexplorer.usgs.gov/) |
| Climatological datasets (2006-2014) | Cloudiness factor Precipitation, Wind speed, Humidity, Temperature | Pakistan Meteorological Department |
| Discharge data (2006-2014) | Streamflow data | Indus River System Authority & Water and Power Development Authority |
| Demographic data | District wise population data<br>Per capita water consumption<br>Crop pattern and water requirement for crops | Pakistan Bureau of Statistics and Socio-economic surveys |

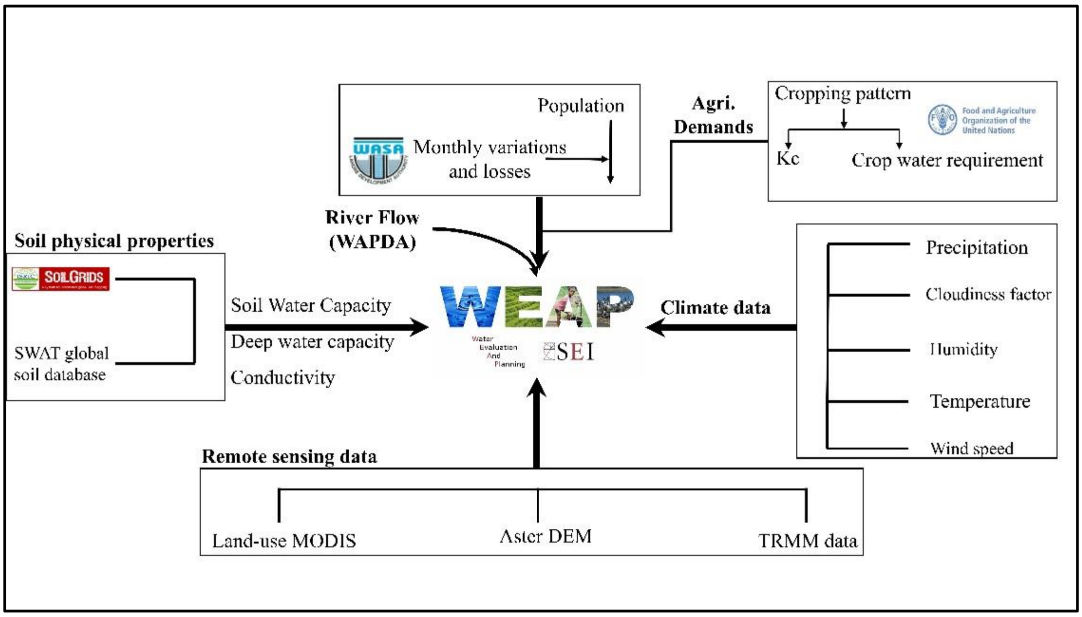


Figure 0.6. Data input in WEAP model.

## 2.5 Water Evaluation and Planning (WEAP)

WEAP is based on the mathematical model of water accounting, WEAP Integrate water demand and supply, policies, quality of water, future development in infrastructure and environmental flows for planning and evaluation purposes. It is different from other hydrological modeling and evaluation software because it simulates hydrological flows based on the water policy for the region.

Another difference between WEAP and other models is that WEAP can suggest infrastructure and management options. WEAP helps in modeling as it acts as a database, a prediction model and analyzing the policy to evaluate the water supply and demand. WEAP uses water accounting functionality to model large, complex basins, water allocation for agricultural and urban water supply system. In addition to that WEAP also helpful in water conservation, water policies, sectoral water demands, ground and surface water simulation, pollution tracing, water treatment, power generation and cost analysis of water supply systems.

### 2.5.1 WEAP Method

Water resources are earth's most valuable resource and have a long history or monitoring and mapping using computer programming. Several hydrological models were developed over the years to reach optimum efficiency, some of these models used complex mathematical functionality which makes them very difficult to use and understand. Best approach from historical point of view is to build a model which is simple, easy to use and flexible. WEAP is flexible tool which has the capability to model, plan and monitor water resources using simple mathematical equations. WEAP tools has following method considerations; Planning, Scenario development, Management options, Environmental flows and Simple design

#### 2.5.1.1 Planning

WEAP has a wide-ranging planning structure, WEAP based on the integration of several dimensions of water supply system like the gap between water supply and demand, water quality and quantity ratio and environmental restriction and economic developments.

#### 2.5.1.2 Scenario Development

WEAP uses baseline conditions to predict about the future based on the user defined scenarios, these baseline conditions are called “current accounts”. Current accounts show the real water supply condition in the area under study. After the baseline condition or current accounts are developed, scenarios are constructed based on the socio-economic condition (population growth, urbanization), climate change impacts or the infrastructure development. These scenarios then analyze the water supply and demand gap under the applied conditions.

#### 2.5.1.3 Management Options

WEAP not only help determine water demand and supply gap using different scenarios but also provide capability to manage water demands using different management options. For example, if we split the agriculture water demands to the crops being cultivated at that time span in the study area, in this way we can evaluate the water consumption rates for the crop and help manage or introduce water management practices to conserve water.

#### 2.5.1.4 Environmental Flows

While modeling in WEAP, WEAP not only assess water demands and supply introduced in the design but also consider environmental water requirements. WEAP also trace pollution effects on the environmental and provide water treatment options to reuse return flows in surface water bodies.

#### 2.5.1.5 Simple Design

WEAP is simple in design and easy to use, it has a GIS view which help user to add vector and raster layer to the view as per requirement, in addition to that WEAP have ability to load data using excel sheets, which are directly loaded in to WEAP system. It also provides user with the ability to create our own variable to refine the mathematical equations.

### 2.5.2 Catchment Methods for Runoff Simulation

WEAP uses five catchment methods to simulate runoff in a catchment; Irrigation Demands Only (Simplified Coefficient Approach), Rainfall Runoff, MABIA Method, Plant Growth Method (PGM) and Soil Moisture Method,

#### 2.5.2.1 Irrigation Demands Only

Simplest of all, this method uses $K_c$ (crop coefficient) for ET calculation. Then this method evaluates if there is any agricultural water demand which is needed to be fulfilled that ET requirement that rainfall cannot fulfill. Irrigation demands only does not simulate runoff or infiltration processes, or for tracking changes in soil moisture.

#### 2.5.2.2 Rainfall Runoff Method (Simplified Coefficient Method)

This method also based on the determination of ET for rain fed and irrigated area based on the $k_c$ like in irrigation demands only. The excesses precipitation that is not used up by the ET is simulated as runoff for the river.

#### 2.5.2.3 MABIA Method (FAO 56, Dual Kc, Daily)

Unlike others MABIA method operates on daily simulation of evaporation, transpiration, irrigation requirement, crop yield and also estimating soil water capacity and reference ET.

#### 2.5.2.4 Plant Growth Method (PGM)

Based on daily time step, plant growth method simulates water consumption, plant growth and yield. Basically, this method was design to study about all the stresses those effect plant growth like $CO_2$ concentration in atmosphere, water stress, temperature effects, water use and yield. Growth of plant and its routine is based on the approach used by several other model's line SWAT, EPIC etc. like its name this method uses parameters that related to or control plant growth. Soil moisture hydraulics are simulated using a 13-layer model that represents the top 3.5 meters of the soil profile. Outputs from the model include surface runoff, deep percolation, plant ET, water and temperature stress, biomass production and yield.

#### 2.5.2.5 Rainfall Runoff Method (Soil Moisture Method)

This is most complex catchment simulation method in WEAP, soil moisture method based on the two bucket or layers of soil and also has potential of modeling glaciers and snow melt. Top soil bucket or upper layer dealt with the simulation of

ET based on the precipitation and irrigation on agriculture and non-agriculture land. Top bucket also simulates runoff, interflow and track changes in soil moisture.

While the lower bucket simulates base flow, river routing and track changes in soil moisture. This method is complex because it requires characterization of land use/cover, and wide range of meteorological and soil data to simulate river runoff (Figure 2.7). A schematic diagram of the study area is shown in Figure 2.8.

Table 0.3. Parameters their units and description used in WEAP.

| Parameters | Units | Description |
|---|---|---|
| Area | $Km^2$ | Catchment area and percentage share of land cover classes |
| $K_c$ | -- | Crop coefficient of land cover classes and crops in agricultural demand |
| Root zone water capacity | Mm | Water holding capacity of top bucket of soil |
| Deep Water Capacity | Mm | Water holding capacity of lower bucket of soil |
| Deep Conductivity | Mm | Rate (length/time) |
| Runoff Resistance Factor | -- | Factor depend on the slope and canopy cover of the area |
| Root Zone Conductivity | Mm | Water conductivity at root zone in top bucket at full saturation |
| Preferred Flow Direction | -- | Horizontal or vertical depend on the type of land cover |
| Initial Z1 | % | Water storage in root zone at the start of simulation |
| Initial Z2 | % | Water storage in lower bucket at the start of simulation |

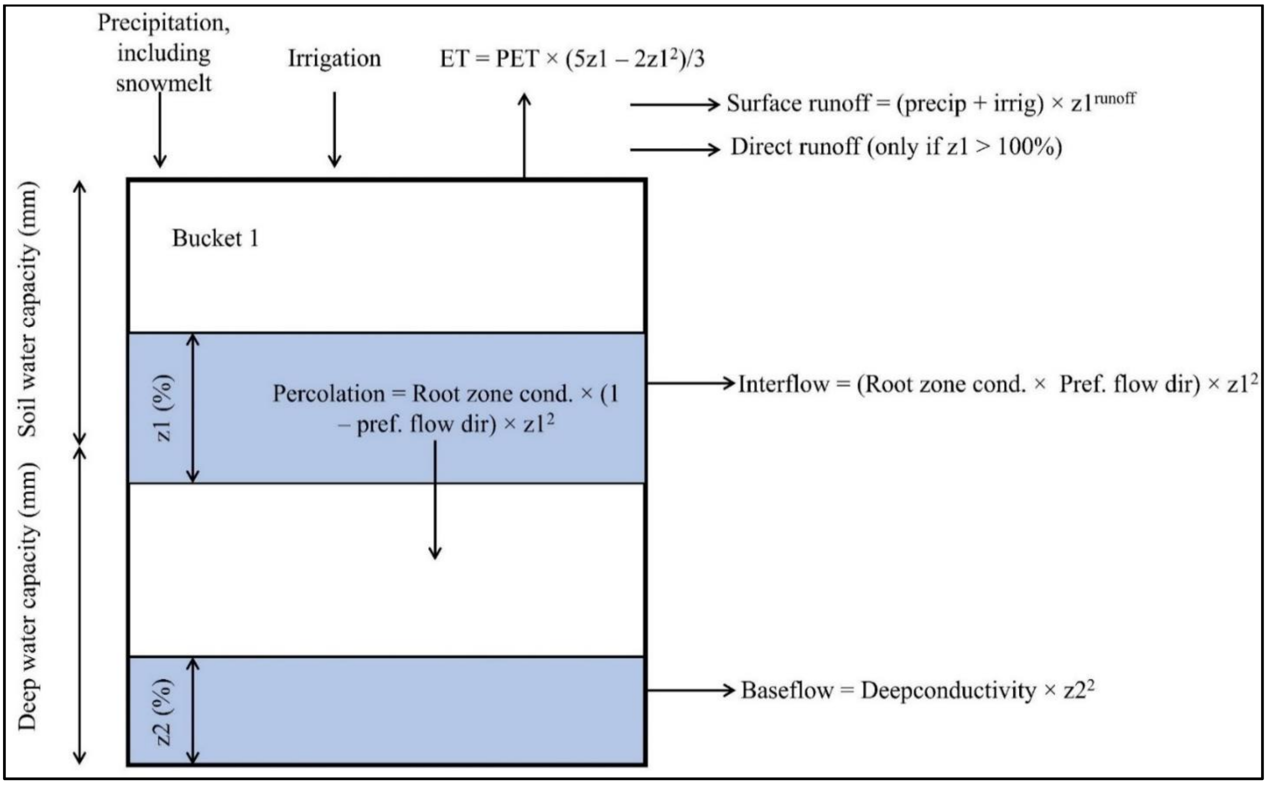


Figure 0.7. Soil moisture method (conceptual diagram and equations)

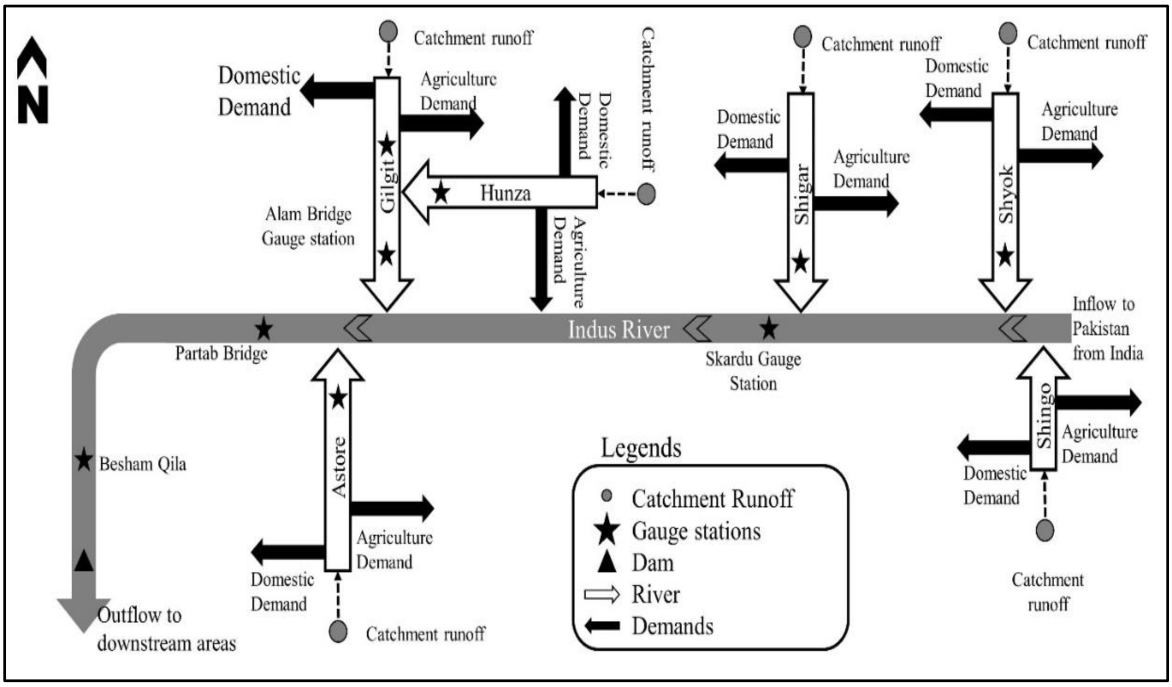


Figure 0.8. Upper Indus Basin water supply structure

### 2.5.3 WEAP model setup

Model was set up for UIB, Figure 2.9 below shows the schematic of demand and supply for WEAP model.

WEAP model set up included;

- Indus River as main river and tributaries from all the six sub catchments in the study area.
- Catchment nodes were eight which provide runoff to the rivers, a total of nine domestic demand sites and 7 agriculture demand sites and only one cattle demand site.
- Six streamflow gauge stations, one is on Astore River (Doyian), one on Hunza river (Dainyor Br.), one on Shigar river (Shigar), Gilgit river (Gilgit), Shyok river (Yogo), Indus River (Partab Br.) and Besham Qila on Indus River too.

## 2.6 Goodness of fit of model

Goodness of fit of WEAP model was evaluated using two parameters;

- Nash–Sutcliffe model efficiency coefficient
- Co-efficient of determination

### 2.6.1 Nash–Sutcliffe model efficiency coefficient

The Nash–Sutcliffe model efficiency coefficient is used to assess the predictive power of hydrological models. Nash–Sutcliffe efficiency can range from $-\infty$ to 1.

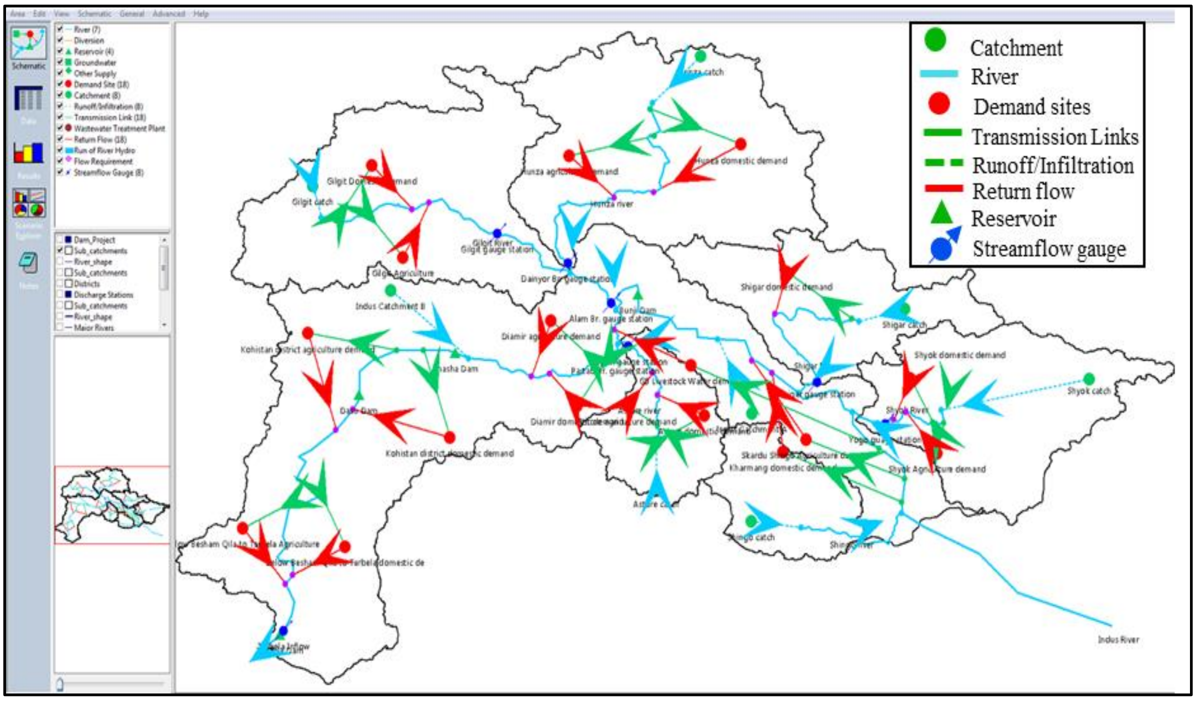


Figure 0.9. A schematic diagram showing the configuration of the WEAP model for the demand sites.

An efficiency of 1 (E = 1) corresponds to a perfect match of modeled discharge to the observed data.

$$NSE=1-\left[\frac{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs}-Y_{obs}^{mean})^2}\right] \qquad \text{Equation (1)}$$

Where $Y^{obs}$ is the *ith* observation in this case gauge station data, where $Y^{sim}$ is the *ith* observation being evaluated in this case catchment runoff generated by model, $Y^{mean}$ is the mean of gauge station data.

### 2.6.2 Co-efficient of determination

$R^2$ is a statistic that will give some information about the goodness of fit of a model. In regression, the $R^2$ coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An $R^2$ of 1 indicates that the regression line perfectly fits the data (0-1).

$$R=\frac{\sum(Y_{obs}-Y_{obs}^{mean})(Y_{sim}-Y_{sim}^{mean})}{\sqrt{\sum(Y_{obs}-Y_{obs}^{mean})^2(Y_{sim}-Y_{sim}^{mean})^2}} \qquad \text{Equation (2)}$$

Where $Y_{obs}$ is the gauge station data and $Y_{sim}$ is the discharge generated by model $Y_{obs}^{mean}$ & $Y_{sim}^{mean}$ are the mean of observed and simulated discharge data.

### 2.6.3 Scenario Development

Using WEAP model, scenarios are constructed based on "what if" question (Sieber & Purkey, 2011) and relative to the business as usual or reference scenario. For this study, scenarios were constructed based on the external driven changes in the basin which were higher living standards and population growth along with climate change scenarios to predict a clear supply demand ratio in the basin. For current water supply condition firstly, a reference scenario was constructed for the basin which will act as a baseline condition for which further scenarios were constructed.

For better understanding of external factors on future predictions for supply and demand in UIB, different socio-economic scenarios were developed in WEAP model, for example high population growth (HPG) which is set to be 6%, low population growth (LPG) of 1.35% and higher living standards in case of urbanization which cause water usage from 82.8 $m^3$ to 120 $m^3$.

In case of climate change scenario data was downloaded from Global Circulation Model (GCM) data sets (Spalding-Fecher, Joyce, & Winkler, 2017). There were four Representative Concentration Pathways (RCPs), such as RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. These scenarios were named according to their radiative forcing target level 2100. Based on the length of time period RCP 4.5 and RCP 8.5 scenarios were used. The RCP4.5 scenario describes the stabilization without exceeding pathway to 4.5 $W/m^2$ (~650 ppm $CO_2$) at stabilization after 2100 (Clarke et al., 2007). RCP 8.5 scenario corresponds to the rising radiative forcing pathway leading to 8.5 $W/m^2$ (~ 1370 ppm $CO_2$) by 2100 (Riahi, Grübler, & Nakicenovic, 2007). This scenario related to no climate policy and high emissions of greenhouse gases.

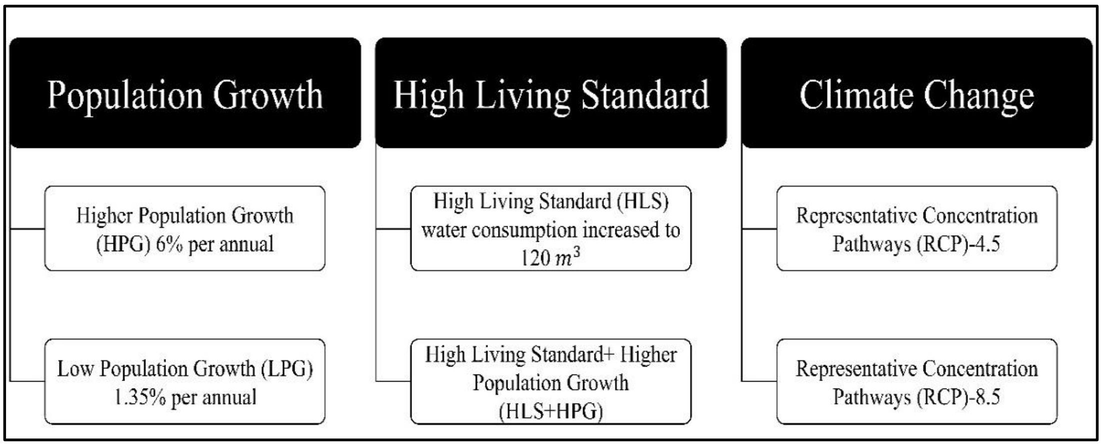


Figure 0.10. Scenarios used in WEAP model (External driven factors & Climate change)

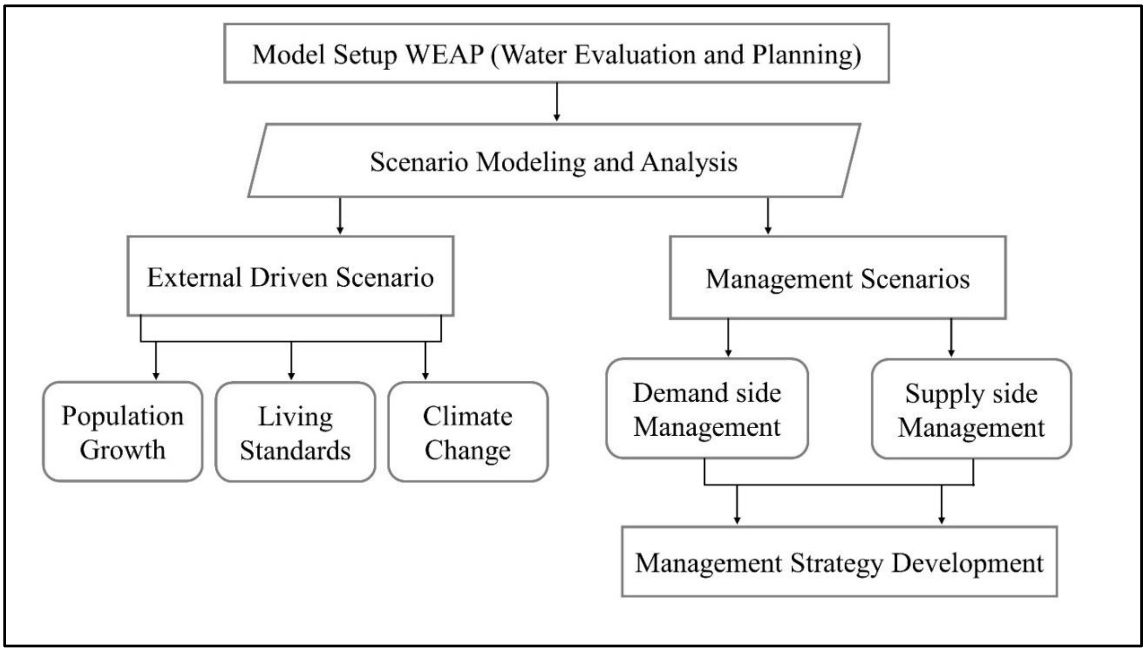


Figure 0.11. Workflow diagram or WEAP scenarios.

*Chapter 3*

# RESULTS AND DISCUSSION

## 3.1 Model Calibration and validation

Both, hydro-economic data were used for UIB to calibrate and validate WEAP model for baseline period (2006-2014). For simulation period in WEAP, crop root zone conductivity, coefficient ($k_c$) of land cover types, soil water capacity and preferred flow direction were calibrated manually based on the location of study area using hit and trial method, for some parameters WEAP provided default values were used. Coefficient of determination values were ranged between 0.82 and 0.96 with an average of 0.88, and Nash-Sutcliffe Efficiency (NSE) was varied from 0.81 to 0.94 with an average of 0.87. Range of NSE is from $-\infty$ to 1, and value of 1 (NSE = 1) shows that the simulated data closely match the discharge data (Ritter & Muñoz-Carpena, 2013). These above values show that the WEAP model predicted the hydrology of the basin accurately, which will give confidence to all the future streamflow prediction and scenario analysis. Table 1 showing the ranges and the variables used in the process of calibration.

## 3.2 Scenario 1: Reference/Business as usual

Figure 3.2 shows the baseline conditions or reference scenario simulated unmet water demands from the year 2015 to 2050. The graph below shows that the total water demand coverage in 2014 was 90% and the average monthly water supply to the basin in 2014 was 44.3 mcm. These baseline conditions and analysis for future predictions showed the supply demand conditions based on present scenario, which

Table 0.1. Ranges of parameters for calibration of WEAP model.

| **Parameters** | **Model Range** | **Optimal range (for different land covers)** |
|---|---|---|
| Soil water capacity | 0-higher (mm) | 0-1200 (mm) |
| Root zone conductivity | Default=20mm | 10-50 (mm) |
| Deep conductivity | 0.1-higher (mm/month)<br><br>default=20mm | Default=20mm |
| Runoff resistance factor | 0-1000 (default=2) | 0-100 |
| Preferred flow direction | 0-1 (default=0.15) | 0.5-1 |

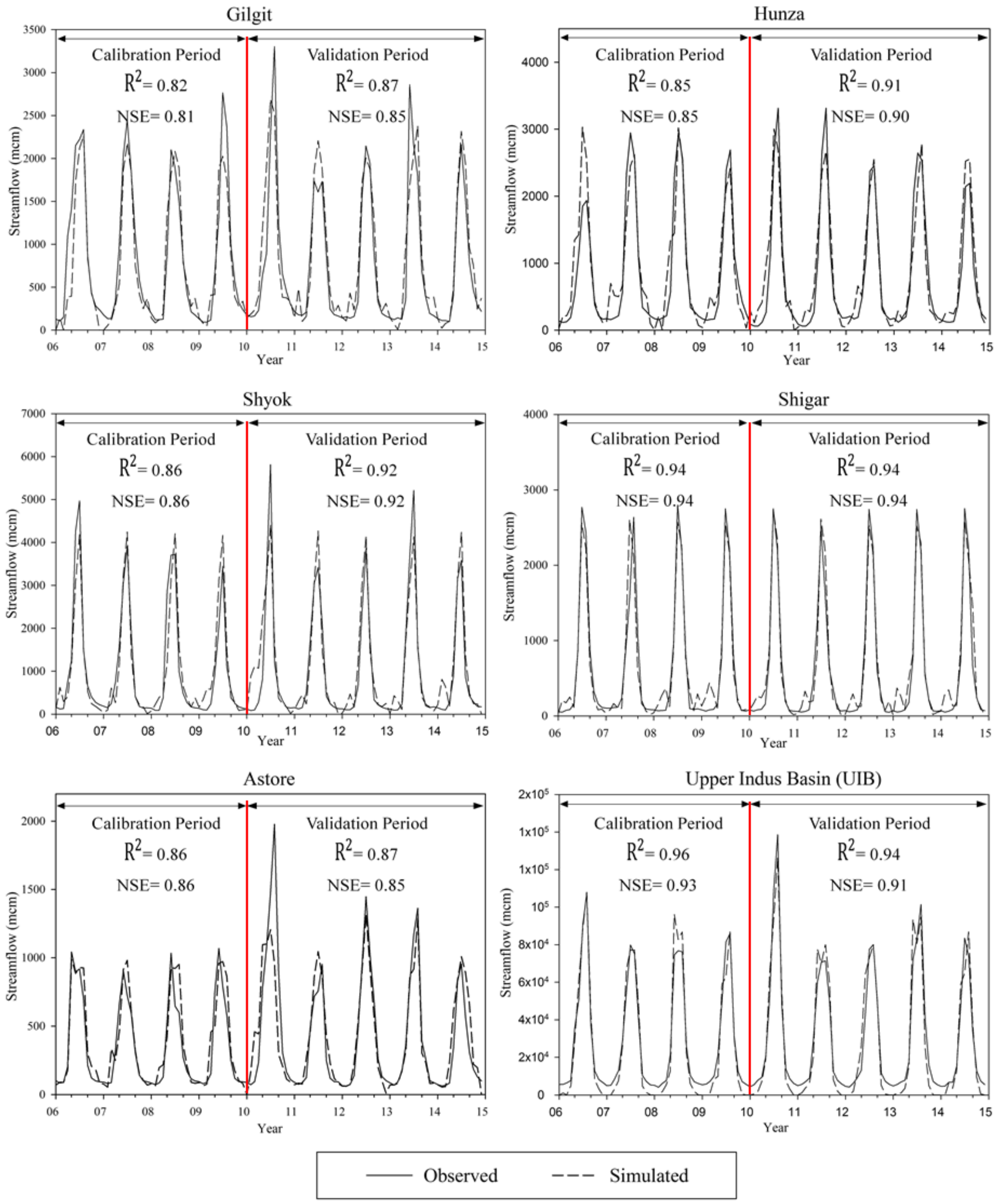


Figure 0.1. Results of calibration and validation of all sub catchments and goodness of fit of model.

indicated that water demand coverage in UIB will decrease from 90% to 75% in 2050.78.9 mcm were unmet water demands in 2014, which were projected to be 134.56 mcm by the year 2050. WEAP model calculate water demands in a basin based on the per capita water consumption rate which include other factors too like population growth factor and water demand in agriculture sector. Business as usual or reference scenario based on the supposition that the water supply system of the basin will not change, and this supposition indicate that the water coverage in the basin will decrease by 15% by 2050. The reference scenario analysis concludes that no improvement in water infrastructure and supply situation will lead the catchment to water scarcity in the future.

## 3.3 Socio-Economic and Climate Change Scenarios

Figure 3.3 below analyze the difference between unmet water demands under external driven factors like population growth (low and high), living standards, urbanization and reference scenario. First analysis of high population growth and high living standards were evaluated, results showed that these two factors have most negative effect on the supply demand condition of basin. In high population growth, the growth rate assumed to be 6% for comparison with reference scenario, the drastic increase in the population will then lead to more urbanization and could result in economic growth and higher living standards. Per capita water consumption according to Water and Sanitation Authority (WASA) was 82.9 $m^3$in current accounts or baseline conditions which is projected to increase in case of higher living standards to 120 $m^3$ by the year 2050. In case of low population growth (LPG), growth rate assumed to be 1.35% (in case of governments provide awareness to control national growth rate) (Figure 3.4).

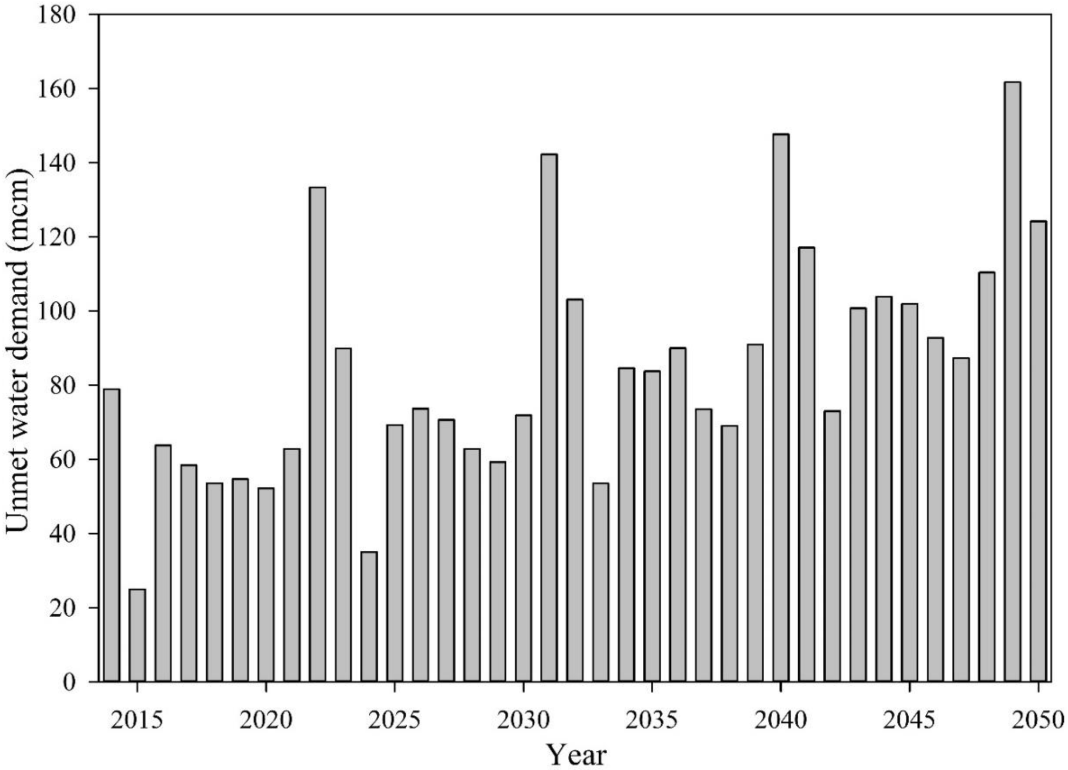

Figure 0.2. Unmet water demand for Reference/Business as usual (2014-2050) scenario in the Upper Indus Basin (UIB).

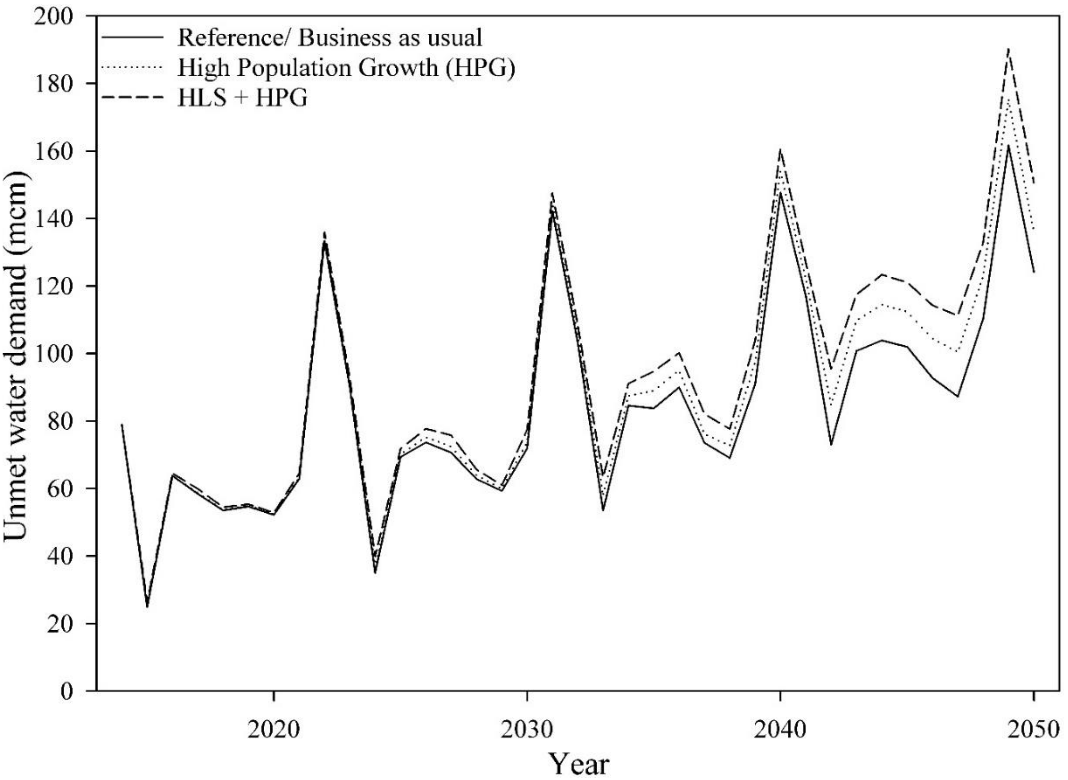

Figure 0.3. Unmet Water Demands under reference, high population growth, and high population growth + higher living standards scenarios.

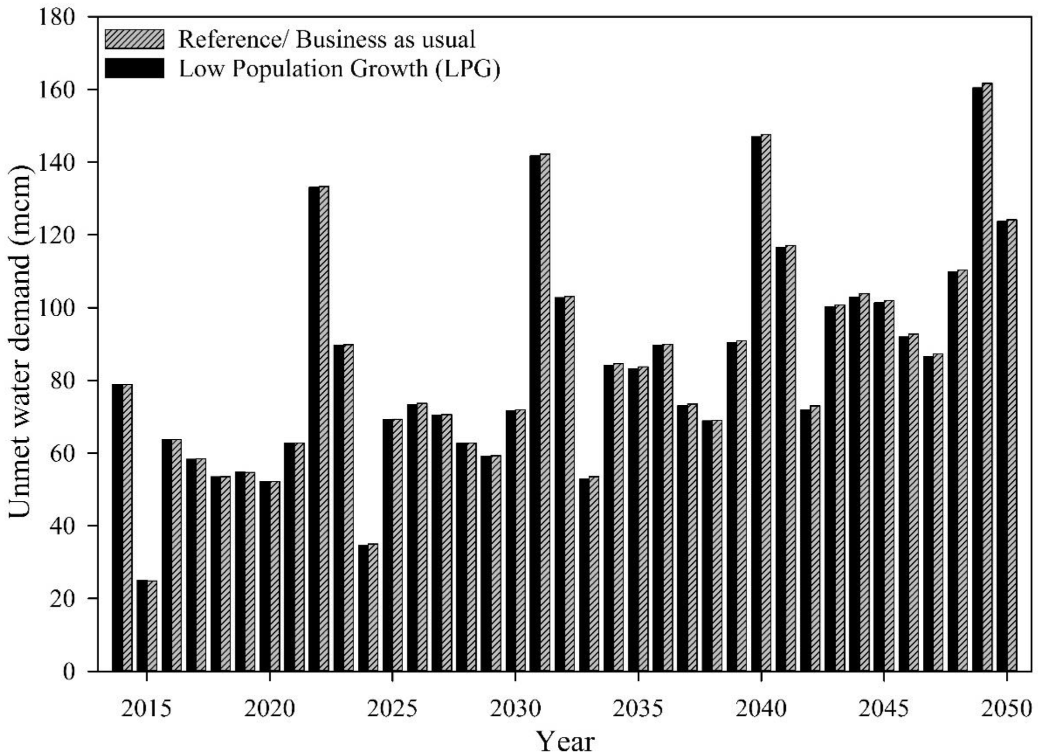

Figure 0.4. Unmet Water Demands under reference and low population growth scenario.

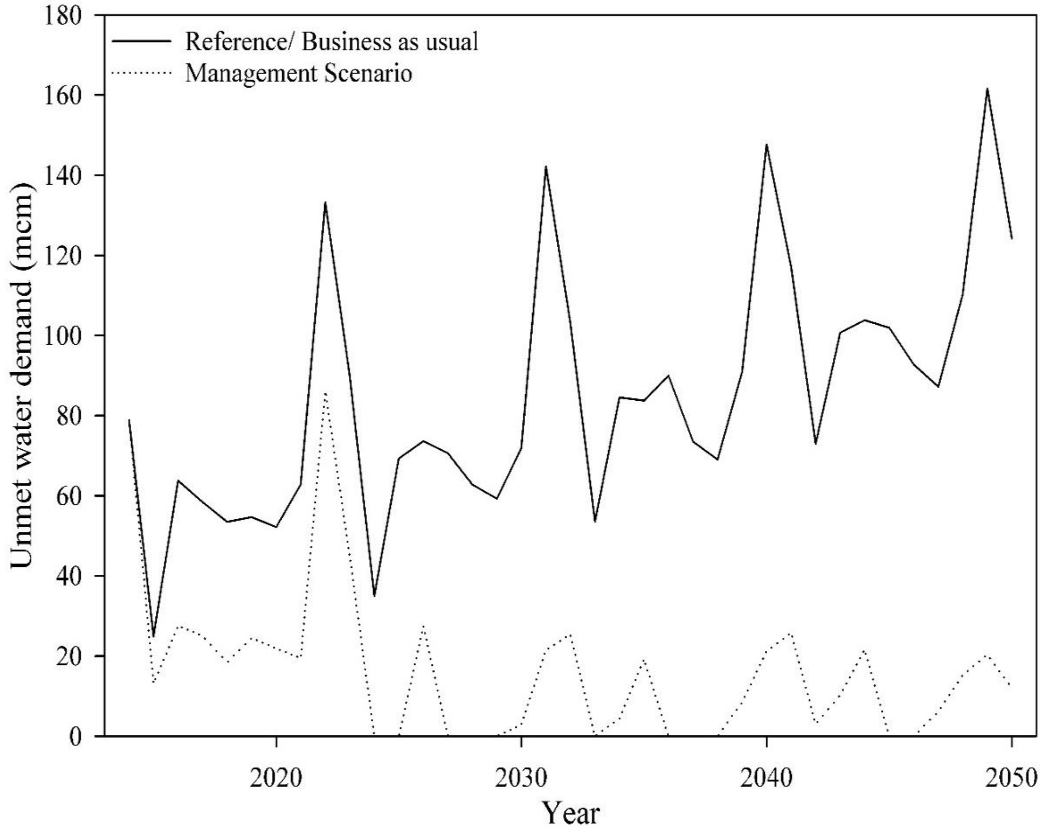

Figure 0.5. Unmet Water Demands Future under reference HPG + HLS.

A worst-case scenario was constructed by the combination of HPG and HLS along with the assumption that there was no improvement in the supply system of the catchment. This scenario was construct to analyze the worst-case scenario on the water supply system of the basin.

From all the results and analysis done in this research only in low population growth unmet water demands were similar to the reference scenario, and for all other socio-economic scenarios the unmet water demands followed an increasing trend. For example, in HPG scenario, unmet water demand expected to reach to 136 $m^3$ by the year 2050, which will be drastic for the water supply system of the UIB. Higher Living Standard scenario was developed to analyse the urbanization and economic effect on the water demand, and this scenario showed that the unmet water demand will expect to reach 163 $m^3$ by the year 2050.

## 3.4 Climate Change Scenarios

The projected climate data was downloaded from Global circulation models dataset, which is downscaled by Pakistan Meteorological Department (PMD) (Department, 2018). The RCP-4.5 stabilization scenario and RCP-8.5 for extreme conditions were used for future climate impact on water supply and demand conditions.

## 3.5 Management Scenario

Figure 3.7 shows the relative analysis of reference scenario and management scenario. In management scenario both supply and demand side management policies were applied to develop a sustainable water supply system. Supply side management included construction of proposed WRD (Water Resource Developme-

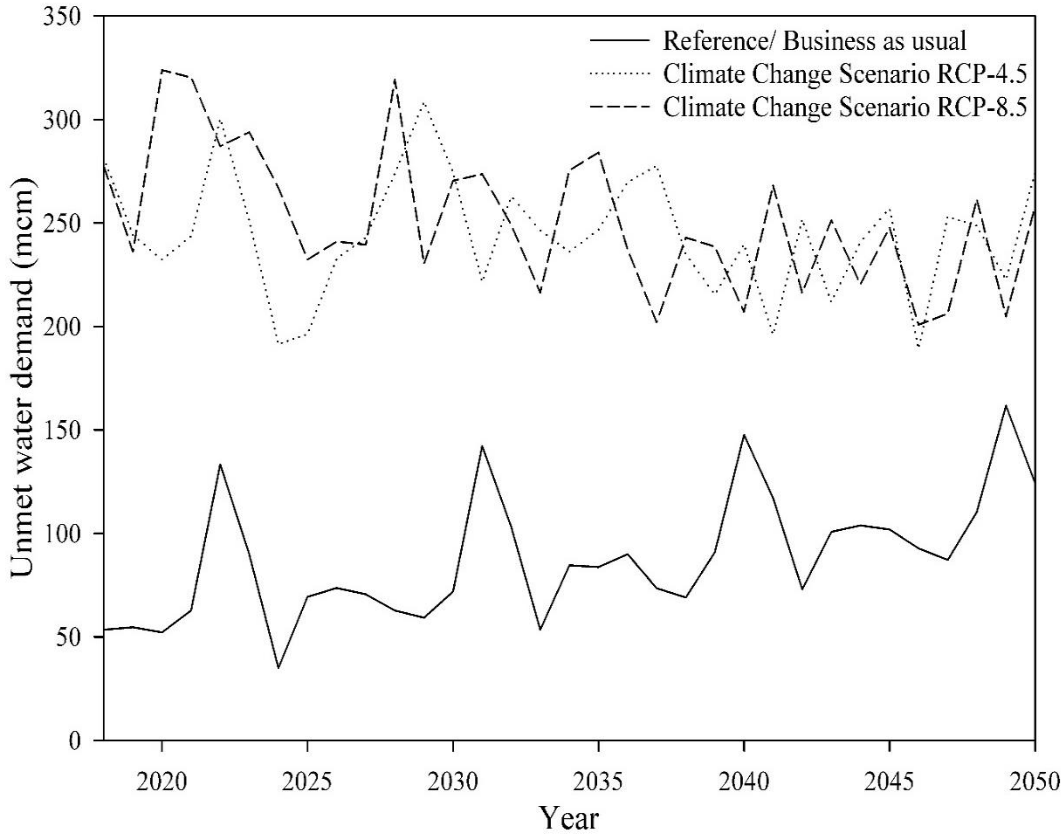


Figure 0.6. Unmet Water Demands under climate change scenarios.

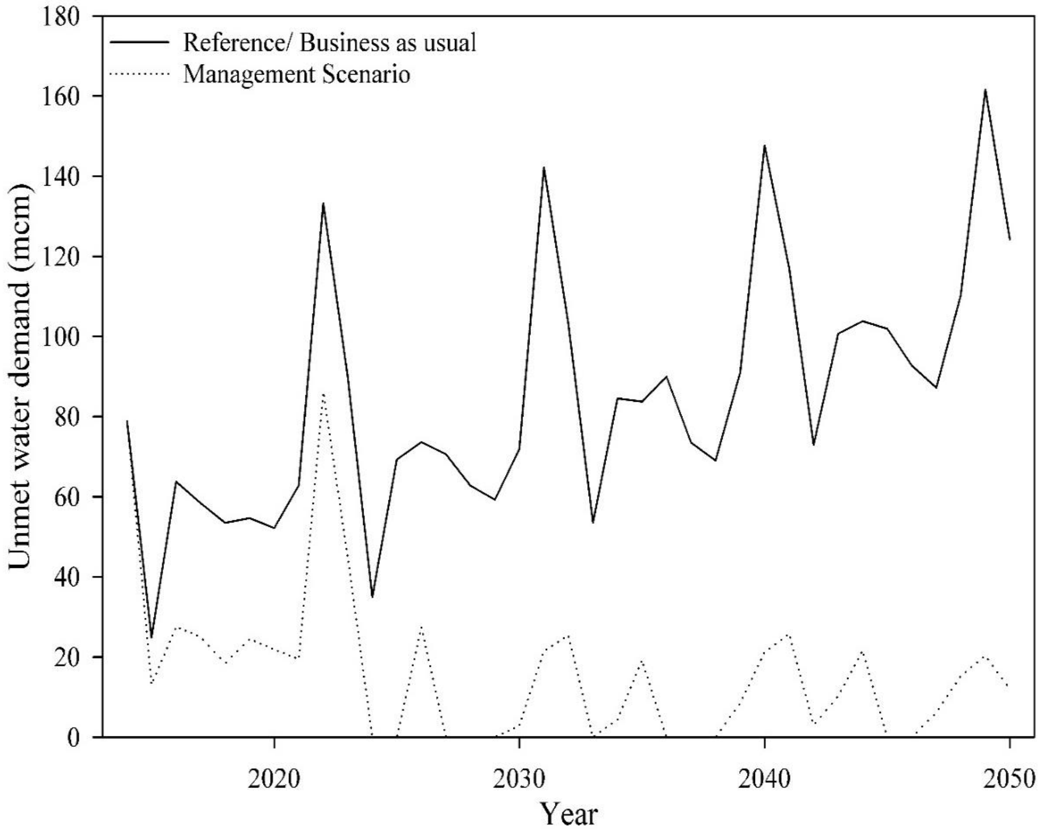


Figure 0.7. Unmet water demands under reference and water management scenarios.

-nt) projects (Bunji, Bhasha Diamir, and Dasu) on Indus River in UIB According to WAPDA these projects will be functional by 2023. For demand side management, different PCRWR (Pakistan Council of Research in Water Resources) water conservation techniques were adopted to reduce domestic and agriculture losses and decreasing per capita water consumption by using effective management policies. In supply side management, the WRD projects not only stored water sectorial uses but also help reduce energy crises in Pakistan. Figure 3.7 below showing the amount of water that can be saved using this management option.

Aim of the study was to develop management strategies to predict a sustainable future. Management strategy in the UIB was developed using different development, socio-economic and climate change scenarios. These scenarios also helped us to evaluate the impacts and effects of these scenarios on long term basis. Understanding of current water supply and demand aided in developing management strategies for the study. For potential management strategy, both supply side and demand side water management were needed.

Research showed us that under the reference scenarios the unmet demands will reach 134 mcm by the year 2050, several studies based on the similar methodologies of evaluation and planning showed similar finding like in Kathmandu Valley study performed by Chitresh Saraswat (Saraswat, Mishra, & Kumar, 2017) indicated that the unmet water demand in the valley is 388.10 MLD (million liters per day) and another study in Didessa sub-basin West Ethiopia reported that the water demand in the basin was 74 mcm (Adgolign, Rao, & Abbulu, 2016). Both studies suggested that these unmet water demands can be over come using effective water management strategies for a sustainable water secure future.

Using the current water supply conditions, both demand and supply side management was introduced as a management scenario in the model to improve water supply condition in the UIB and this scenario can help in achieving water security. Current water supply conditions indicated that 134 mcm unmet water demands in the basin, which is similar to the finding of (Khalil, Rittima, & Phankamolsil) in Mae Kong basin Thailand which were estimated to be 134 mcm. In another study conducted in Thailand in Tha Chin basin reported that the 62 mcm was unmet water demand per year in agriculture sector and 17 mcm per year in domestic sector in the basin. Both studies concluded that the proposed dams can help achieve water security in the basin in long terms. Same approach was used for this research too. After implementing the results of proposed dams (Supply side) in the study and applying necessary demand site management (Demand side management in the WEAP proposed to reduce demand site losses and with awareness reducing per capita water consumption) indicated that there is a possibility of fulfilling 80 % of the UIB unmet demand using this management scenario by 2025.

WEAP also evaluated the human induced factors (climate change, Population growth, and high living standards) and their impacts on the Basin's water supply system, the results of the study indicated that these factors are putting immense pressure on the water security of the basin. These results encourage the policy makers to implement these water management option evaluated in the study to solve water scarcity in Pakistan (Archer & Fowler, 2004). As the objective of the study suggested, the analysis performed help us construct an effective water management strategy for sustainable water governance in the basin. For better understanding of these analysis a comparative analysis of all the water management scenarios and reference scenario to identify effective water management (Figure 3.8).

For comparative analysis, in reference scenario there were no changes in the water supply system but the external driven factors were applicable on the system. Another assumption was that the proposed dams could not be constructed due to political or other reasons, the result of this scenario indicated that the average unmet water demand will reach 84 mcm by the year 2050.

For moderate future-1 following assumptions were made; water saving techniques from PCRWR handbook for domestic sectors were applied means decreasing in per capita water requirement from 82.9 $m^3$ to 70 $m^3$, and second assumption was to decrease the water losses from 30% to 20%. The results of this scenario indicated that the unmet water demand will decrease to 40 mcm by the year 2050.

Moderate future-2 scenario was based on the current accounts of WEAP, which means that there was no change applied to river flow, population, climate impacts or water losses. Results of this scenario indicated 60 mcm unmet water demand.

For management scenario which is most optimistic one based on the assumptions of PCRWR's waster conservation techniques which not only reduce per capita water demand but also decrease water losses along with the construction of proposed WRD projects which are assumed to be functional by 2023.

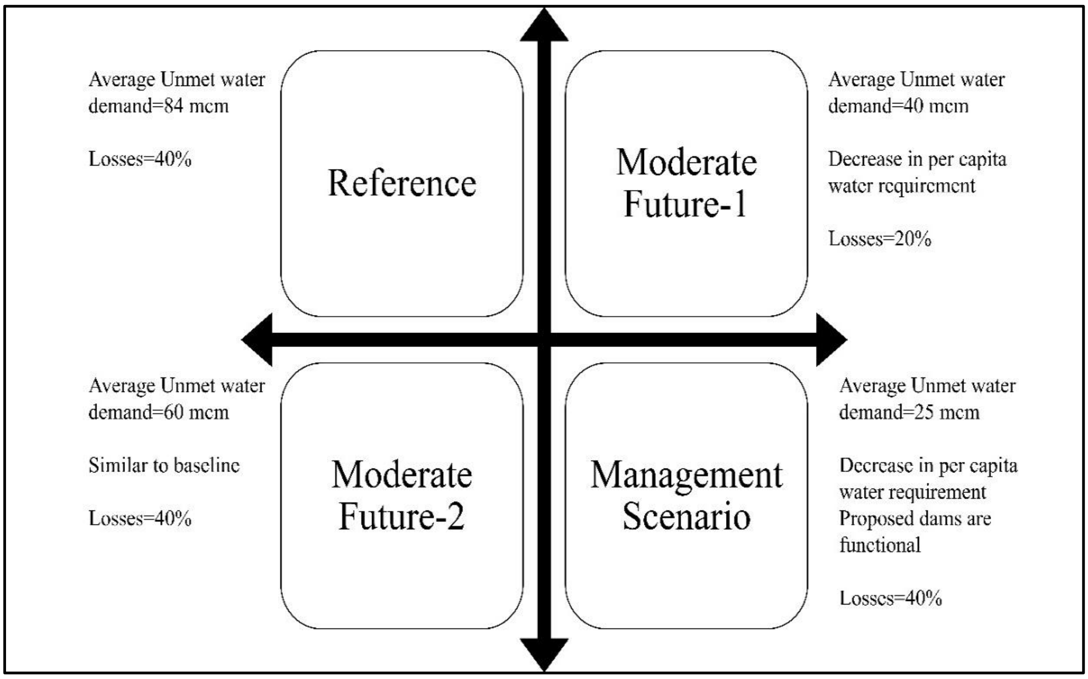


Figure 0.8. comparative analysis of different management scenarios.

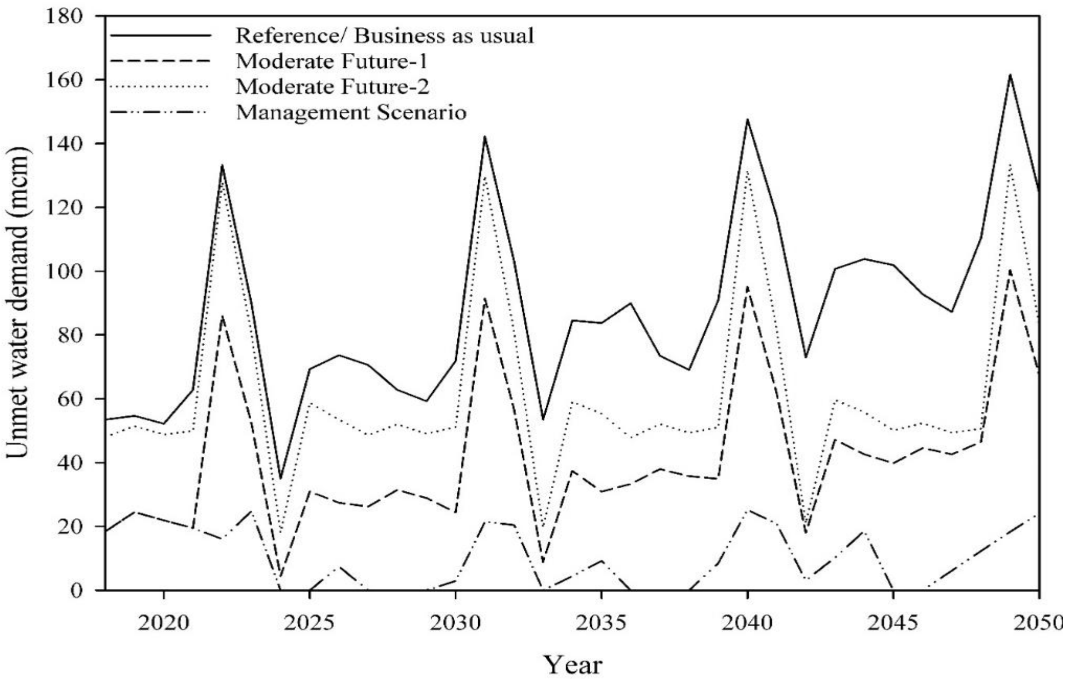


Figure 0.9. Projection of "Total Unmet Water Demand" under four different prediction scenarios (2014-2050).

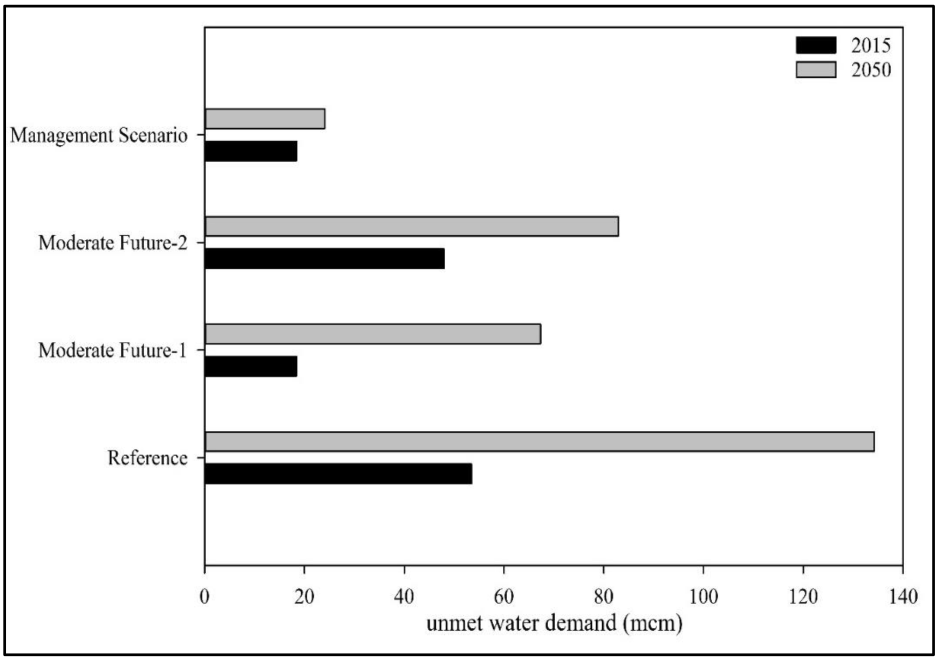

Figure 0.10. Unmet water demand for four different futures for the years of 2015 and 2050.

Results indicated that the average unmet water demand in this scenario will decrease to 25 mcm (Figure 3.9). Figure 3.10 shows that among all the scenarios in comparative analysis reference scenario a have the most negative impact on water supply system and average unmet water demands are pretty high in this case.

*Chapter 4*

# CONCLUSIONS AND RECOMMENDATIONS

## 4.1 Conclusions

Increase in unmet water demand in UIB is not only due to human induced factors but also due to the changes in seasonal distribution of precipitation during last decade in Pakistan. Changes in run off is due to the seasonal changes in rainfall but also the rapid melting of glaciers which are source of fresh water for domestic and agricultural purposes for 200 million people. The presented analysis of management strategies for future prediction should be considered for planning, developing and designing sustainable water supply system.

Pakistan is at high risk regarding water availability situation due to its dependency on the single river system in the face of the looming climate change impacts. However, Pakistan has yet to develop and implement its water policy. Apart from climate change impacts, Pakistan is facing rapid population growth, and with its steadily increasing water demand for food security, loss of storage in the existing water resource development structure due to sedimentation and inter-provincial conflicts on developing water storage reservoirs, the Government response on these issues is fragmentary (Archer, Forsythe, Fowler, & Shah, 2010). To deal with these issues integrated water management of reservoir, construction of new water infrastructure and water management for agriculture sector is required. The Water and Power Development Authority (WAPDA) and Provincial Irrigation and Drainage Authorities (PIDA) have sub-divisional control of the reservoirs, but they have a shortage of resources and technical support to make the best use of surface water available. Productivity per unit of water is 40% lower than in neighboring parts of India and 50% lower than the United States (John Briscoe, 2005).

Tarbela and Mangla dams are the only two significant reservoirs on Indus River which are under degradation due to high sediment loads. So, as this study suggests that with rapid population increase coupled with increased water requirement, and climate change, it will make the construction of new major reservoirs like Bhasha dam, Dasu dam, Bunji dam and Kalabagh dam (downstream) the need of the hour. Increasing water productivity could buy some time against increasing water demand and reducing water supply till the new reservoirs are functional.

## 4.2 Recommendations for Further Research

In this study, the socio-economic, data availability and high-altitude climatic stations data scarcity were the significant constraints. This issue has been highlighted by many in the literature (Bocchiola et al., 2011). Since we did not include the western (Kabul basin) and lower part of the Indus basin. Therefore, we would like to recommend that future studies should include the Kabul basin for water allocation for managerial point of view.

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Appendix-0.1. Stream flow data for Indus and Sub Catchments in Upper Indus Basin

| Year | Month | Headflow to Pakistan | Shyok | Shigar | Gilgit | Hunza | Astore | Alam Br. (Gilgit) | Besham |
|---|---|---|---|---|---|---|---|---|---|
| 2006 | 1 | 1619.58 | 61.35 | 20.53 | 48.12 | 51.94 | 37.51 | 115.7 | 493 |
| 2006 | 2 | 1490.54 | 48.71 | 20.41 | 45.54 | 47.65 | 34.92 | 109.1 | 517.4 |
| 2006 | 3 | 1386.51 | 48.47 | 27.69 | 56.1 | 47.24 | 33.22 | 104.4 | 490.4 |
| 2006 | 4 | 2155.64 | 286.7 | 31.84 | 421.9 | 72.88 | 78.19 | 134.3 | 753.5 |
| 2006 | 5 | 9243.9 | 468.7 | 60.07 | 528.7 | 194.3 | 389.4 | 770.2 | 3968 |
| 2006 | 6 | 17596.06 | 1642 | 336.8 | 829.7 | 435.9 | 346.9 | 921 | 4371 |
| 2006 | 7 | 22707.68 | 1855 | 1034 | 829.5 | 690.6 | 342.8 | 1450 | 7666 |
| 2006 | 8 | 32600.7 | 557.9 | 907.3 | 872.2 | 723.1 | 260.5 | 1743 | 8529 |
| 2006 | 9 | 15358.75 | 253.7 | 335.9 | 334.9 | 449.1 | 82.52 | 697.1 | 3276 |
| 2006 | 10 | 4383.68 | 150.3 | 120.8 | 159.4 | 142.7 | 44.98 | 317.8 | 1400 |
| 2006 | 11 | 3546.24 | 106 | 62.06 | 109.7 | 80.88 | 38.46 | 204.7 | 763.9 |
| 2006 | 12 | 1964.74 | 81.76 | 41.41 | 89.3 | 61.48 | 34.63 | 167.1 | 638.2 |
| 2007 | 1 | 1627.1 | 68.65 | 38.57 | 66.72 | 64.26 | 33.74 | 136.7 | 549.4 |
| 2007 | 2 | 1470.9 | 61.43 | 41.42 | 55.43 | 65.3 | 33.21 | 123 | 521.5 |
| 2007 | 3 | 1310.13 | 92.54 | 41.19 | 51.2 | 68.45 | 32.58 | 120.1 | 575.9 |
| 2007 | 4 | 3779.74 | 283.4 | 44.11 | 126.8 | 83.08 | 123.4 | 302.8 | 1222 |
| 2007 | 5 | 8197.25 | 586 | 86.87 | 363.4 | 212.6 | 244.6 | 592.7 | 3005 |
| 2007 | 6 | 19288.54 | 1182 | 339.9 | 780.9 | 900.7 | 349.4 | 1163 | 5029 |
| 2007 | 7 | 19081.58 | 1459 | 585.3 | 914.1 | 1100 | 270.5 | 1360 | 6414 |
| 2007 | 8 | 21674.28 | 698.2 | 984.9 | 685.8 | 956.4 | 221.3 | 1178 | 6019 |
| 2007 | 9 | 16433.94 | 158.4 | 404.7 | 424 | 414.8 | 119 | 735.2 | 3204 |
| 2007 | 10 | 3476.23 | 66.25 | 59.92 | 219.7 | 126.4 | 53.27 | 324.7 | 1013 |
| 2007 | 11 | 3247.85 | 55.38 | 35.39 | 135.5 | 106 | 38.5 | 233.2 | 658 |
| 2007 | 12 | 1835.78 | 54.2 | 31.04 | 102.6 | 78.26 | 34.66 | 214.8 | 554.5 |
| 2008 | 1 | 1542.96 | 51.41 | 29.99 | 73.5 | 64.26 | 31.15 | 189.1 | 518.5 |
| 2008 | 2 | 1946.96 | 36.23 | 27.91 | 50.2 | 65.3 | 29.8 | 136.7 | 489.9 |
| 2008 | 3 | 1350.52 | 32.9 | 26.57 | 45.79 | 68.45 | 31.35 | 121.3 | 534.3 |
| 2008 | 4 | 1818.05 | 147.3 | 28.19 | 49.84 | 83.08 | 49.04 | 145.1 | 622.8 |
| 2008 | 5 | 2987.03 | 1072 | 104.1 | 324.4 | 212.6 | 203.2 | 661.1 | 2353 |
| 2008 | 6 | 29569.13 | 1430 | 373.7 | 810.4 | 900.7 | 399 | 1867 | 6778 |
| 2008 | 7 | 21296.28 | 1390 | 1046 | 706.7 | 1100 | 241.4 | 2024 | 6270 |
| 2008 | 8 | 25311.42 | 367.3 | 819.4 | 558 | 956.4 | 224 | 1679 | 6528 |
| 2008 | 9 | 7292.51 | 185.6 | 318.2 | 315.3 | 414.8 | 104.2 | 804.1 | 2285 |
| 2008 | 10 | 3530.57 | 100.2 | 36.25 | 160.2 | 126.4 | 62.77 | 376.7 | 1087 |
| 2008 | 11 | 3063.55 | 65.13 | 32.77 | 82.88 | 106 | 44.34 | 198.3 | 690 |
| 2008 | 12 | 1734.76 | 54.77 | 34.79 | 66.24 | 78.26 | 36.8 | 150 | 590.6 |
| 2009 | 1 | 1446.69 | 50.44 | 29.7 | 49.42 | 63.65 | 35.14 | 122.1 | 519 |
| 2009 | 2 | 1392.62 | 42.75 | 26.13 | 39.38 | 61.9 | 32.43 | 112.2 | 525.5 |

| Year | Month | Headflow to Pakistan | Shyok | Shigar | Gilgit | Hunza | Astore | Alam Br. (Gilgit) | Besham |
|---|---|---|---|---|---|---|---|---|---|
| 2009 | 3 | 1303.55 | 34.8 | 29.9 | 35.34 | 60.19 | 33.33 | 100.8 | 553.6 |
| 2009 | 4 | 2078.24 | 92.97 | 33.11 | 46.01 | 64.01 | 59.05 | 125.8 | 779.7 |
| 2009 | 5 | 2615.72 | 349.3 | 58.18 | 244.8 | 144.3 | 278.6 | 402.6 | 2088 |
| 2009 | 6 | 16788.01 | 788.9 | 292.3 | 501.8 | 469.1 | 412.2 | 1032 | 4258 |
| 2009 | 7 | 15383.92 | 1286 | 1027 | 1032 | 896.5 | 296 | 1971 | 6516 |
| 2009 | 8 | 25561.45 | 406.3 | 824.7 | 883 | 1005 | 217.3 | 1923 | 6679 |
| 2009 | 9 | 10997.52 | 214.3 | 290.7 | 387.8 | 433.6 | 96.07 | 859.1 | 2650 |
| 2009 | 10 | 4632.37 | 93.25 | 71.86 | 212.5 | 259.7 | 44.37 | 485.6 | 1548 |
| 2009 | 11 | 3046.05 | 65.14 | 28.26 | 124.6 | 160 | 36.08 | 305.9 | 805.1 |
| 2009 | 12 | 1777.81 | 52.24 | 23.55 | 89.32 | 90.68 | 34.8 | 191 | 583.3 |
| 2010 | 1 | 1408.18 | 43.02 | 29.7 | 67.56 | 33.16 | 32.61 | 108.7 | 506.5 |
| 2010 | 2 | 1236.98 | 34.79 | 26.13 | 65.02 | 25.35 | 29.45 | 93.64 | 505.7 |
| 2010 | 3 | 1247.12 | 36.15 | 29.9 | 61.55 | 23.34 | 34.86 | 91.32 | 717.6 |
| 2010 | 4 | 2601.31 | 108.4 | 33.11 | 88.97 | 46.44 | 91.08 | 142.3 | 998 |
| 2010 | 5 | 3819.11 | 305.1 | 58.18 | 234.9 | 99.91 | 290 | 434.7 | 2052 |
| 2010 | 6 | 19174.43 | 1238 | 292.3 | 345.1 | 427.7 | 413.5 | 816.4 | 4543 |
| 2010 | 7 | 23622.16 | 2171 | 1027 | 842.2 | 991.3 | 549.6 | 2228 | 9217 |
| 2010 | 8 | 39620.32 | 450 | 824.7 | 1233 | 1238 | 738.4 | 2826 | 10933 |
| 2010 | 9 | 19557.44 | 203.4 | 290.7 | 481.8 | 481.6 | 348.6 | 1012 | 3442 |
| 2010 | 10 | 4531.58 | 116.3 | 71.86 | 243.9 | 170 | 114 | 437 | 1413 |
| 2010 | 11 | 4155.26 | 60.31 | 28.26 | 172.4 | 113.4 | 63.12 | 309.3 | 1083 |
| 2010 | 12 | 2118.63 | 53.43 | 23.55 | 113.6 | 67.96 | 40.55 | 198.9 | 791.1 |
| 2011 | 1 | 1762.87 | 56.3 | 22.03 | 81.27 | 33.16 | 32.97 | 181.1 | 633.2 |
| 2011 | 2 | 1711.03 | 50.5 | 20.6 | 74.04 | 25.35 | 30.58 | 147.8 | 568.6 |
| 2011 | 3 | 1677.52 | 56.84 | 21.56 | 64.97 | 23.34 | 32.05 | 188.3 | 748.3 |
| 2011 | 4 | 2666.11 | 192 | 31.02 | 80.79 | 46.44 | 47.24 | 185.6 | 996.7 |
| 2011 | 5 | 6319.99 | 635.5 | 160.5 | 328.4 | 99.91 | 180.9 | 634.4 | 3196 |
| 2011 | 6 | 24060.23 | 1178 | 474.9 | 669.8 | 427.7 | 276.9 | 1621 | 5281 |
| 2011 | 7 | 17411.51 | 1275 | 935.8 | 600.8 | 991.3 | 282.3 | 1664 | 5806 |
| 2011 | 8 | 21951.8 | 777.6 | 612.1 | 646.6 | 1238 | 355.8 | 1522 | 5747 |
| 2011 | 9 | 20742.78 | 160 | 243.7 | 346.8 | 481.6 | 96.07 | 986.8 | 3802 |
| 2011 | 10 | 4132.31 | 90.44 | 136.5 | 91.93 | 170 | 44.37 | 407.8 | 1266 |
| 2011 | 11 | 3627.1 | 61.14 | 36.44 | 69.93 | 113.4 | 36.08 | 275.7 | 816.2 |
| 2011 | 12 | 2046.48 | 47.81 | 24.09 | 61.93 | 67.96 | 34.8 | 183.2 | 582.8 |
| 2012 | 1 | 192.16 | 46.43 | 26.48 | 54 | 69.51 | 23.81 | 130.8 | 517.6 |
| 2012 | 2 | 168.98 | 40.83 | 22.43 | 64.59 | 86.45 | 25.65 | 163.1 | 551.2 |
| 2012 | 3 | 156.07 | 38.12 | 23.35 | 52.72 | 63.08 | 27.45 | 131.7 | 549.2 |
| 2012 | 4 | 221.93 | 66.28 | 30.35 | 61.52 | 74.27 | 52.31 | 151.3 | 605.7 |
| 2012 | 5 | 139.57 | 242.6 | 70.2 | 121.8 | 180.5 | 178 | 324.8 | 1224 |
| 2012 | 6 | 83.18 | 944.6 | 398.28 | 601.1 | 417.1 | 369 | 1169 | 3630 |
| 2012 | 7 | 511.4 | 1441 | 1024 | 801.3 | 887.1 | 540.4 | 1889 | 6580 |

| Year | Month | Headflow to Pakistan | Shyok | Shigar | Gilgit | Hunza | Astore | Alam Br. (Gilgit) | Besham |
|---|---|---|---|---|---|---|---|---|---|
| 2012 | 8 | 2171.59 | 639.4 | 840.3 | 726.1 | 917.3 | 379.5 | 1825 | 6920 |
| 2012 | 9 | 1642.31 | 128.7 | 230.93 | 350.8 | 553.1 | 264.5 | 991.5 | 3968 |
| 2012 | 10 | 316.76 | 80.74 | 97.86 | 122.9 | 135.2 | 97.11 | 288.8 | 1222 |
| 2012 | 11 | 267.17 | 61.32 | 21.8 | 75.03 | 83.46 | 50.32 | 177.2 | 798.5 |
| 2012 | 12 | 221.95 | 47.17 | 17.71 | 61.49 | 60.21 | 38 | 132.8 | 577.3 |
| 2013 | 1 | 181 | 43.91 | 25.93 | 53.81 | 65.92 | 31.79 | 137 | 572.3 |
| 2013 | 2 | 168.26 | 37.18 | 21.1 | 51.03 | 49.25 | 28.36 | 124.5 | 655.1 |
| 2013 | 3 | 142.71 | 36.37 | 21.6 | 54.16 | 59.12 | 33.95 | 124.7 | 679.3 |
| 2013 | 4 | 127.66 | 86.37 | 31 | 48.42 | 77.4 | 64.26 | 132.6 | 795.2 |
| 2013 | 5 | 149.92 | 674.7 | 65.3 | 130.7 | 216.8 | 132.9 | 384 | 1915 |
| 2013 | 6 | 983.25 | 1420 | 290.2 | 1103 | 793.7 | 313.9 | 2204 | 6674 |
| 2013 | 7 | 517.8 | 1947 | 1024 | 806.6 | 987.9 | 437.1 | 1932 | 7161 |
| 2013 | 8 | 2580.96 | 573.2 | 820.2 | 671.5 | 946.1 | 509 | 2128 | 8498 |
| 2013 | 9 | 1266.22 | 217.6 | 207.2 | 269.5 | 570.4 | 151 | 1026 | 3873 |
| 2013 | 10 | 618.66 | 71.25 | 80.3 | 146.7 | 204.7 | 97.11 | 438.6 | 1790 |
| 2013 | 11 | 264.75 | 58.54 | 25.3 | 75.59 | 103.7 | 38.56 | 204.3 | 835.6 |
| 2013 | 12 | 198.91 | 63.11 | 23 | 63.86 | 68.9 | 32.8 | 142.2 | 609.6 |
| 2014 | 1 | 174.69 | 55.02 | 25.37 | 50.79 | 55.37 | 26.86 | 108.3 | 504.6 |
| 2014 | 2 | 152.07 | 45.85 | 20.1 | 47.15 | 51.77 | 25.71 | 100.8 | 493.4 |
| 2014 | 3 | 152.15 | 36.07 | 23 | 41.99 | 44.55 | 24.9 | 87.39 | 582.4 |
| 2014 | 4 | 86.45 | 100.4 | 33 | 39.17 | 50.29 | 32.21 | 92 | 663.4 |
| 2014 | 5 | 72.31 | 332.5 | 68.3 | 147.8 | 136.2 | 126.8 | 309.6 | 1737 |
| 2014 | 6 | 380.03 | 1219 | 280.3 | 604.7 | 366.8 | 319.8 | 1046 | 4743 |
| 2014 | 7 | 1236.51 | 1337 | 1027.5 | 807.5 | 800.7 | 356.7 | 1681 | 7712 |
| 2014 | 8 | 2131.94 | 321 | 830.8 | 578.5 | 818.3 | 211.3 | 1584 | 6092 |
| 2014 | 9 | 933.39 | 163.1 | 250.1 | 306.6 | 355.4 | 118.2 | 711.9 | 2783 |
| 2014 | 10 | 405.5 | 105.5 | 90.12 | 173.9 | 163.1 | 68.56 | 364.1 | 1314 |
| 2014 | 11 | 248.56 | 68.9 | 32.73 | 113.1 | 94.84 | 49.68 | 218.6 | 744.2 |
| 2014 | 12 | 190.49 | 63.11 | 25.5 | 82.08 | 64.14 | 36.9 | 150.5 | 555.2 |

Appendix-0.2. Temperature data for sub-catchments

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2006 | 1 | -2.3 | 3.1 | -1.1 | 6.4 | -3.5 | -3.3 |
| 2006 | 2 | 4.1 | 10.5 | 4.7 | 12.4 | -2.1 | 4.3 |
| 2006 | 3 | 5.6 | 13.1 | 5.6 | 12.5 | 6.2 | 7.7 |
| 2006 | 4 | 9.1 | 16.3 | 14 | 17.7 | 13.5 | 11.4 |
| 2006 | 5 | 17.6 | 23.4 | 17.5 | 25.1 | 19.5 | 19 |
| 2006 | 6 | 17.9 | 23.4 | 19.9 | 24.8 | 21.9 | 19.6 |
| 2006 | 7 | 22.6 | 27.8 | 20.4 | 25.2 | 23.6 | 24.3 |
| 2006 | 8 | 20.1 | 25.4 | 20.9 | 23.6 | 22.3 | 23.2 |
| 2006 | 9 | 16.7 | 21.4 | 17.4 | 22 | 19.1 | 18.2 |
| 2006 | 10 | 12.4 | 17.3 | 11.2 | 18.9 | 12.9 | 12.9 |
| 2006 | 11 | 6.2 | 10.5 | 8.5 | 12.5 | 6.4 | 5.9 |
| 2006 | 12 | -0.3 | 4.3 | 1.6 | 7.6 | -0.6 | 0.6 |
| 2007 | 1 | -1.3 | 3.8 | -1.1 | 7.3 | -3.1 | -1.4 |
| 2007 | 2 | 3.7 | 9.3 | 4.7 | 8.9 | 4.4 | 4.1 |
| 2007 | 3 | 4.8 | 11.5 | 5.6 | 11.4 | 8.9 | 6.2 |
| 2007 | 4 | 13.7 | 19.9 | 14 | 20.3 | 14.6 | 15.4 |
| 2007 | 5 | 16.4 | 22.8 | 17.5 | 22.5 | 20.5 | 18.6 |
| 2007 | 6 | 19.6 | 25.6 | 19.9 | 25.7 | 23.1 | 21 |
| 2007 | 7 | 20.6 | 25.2 | 20.4 | 24.1 | 26.7 | 23.1 |
| 2007 | 8 | 20.7 | 25.6 | 20.9 | 24.8 | 24.9 | 22.9 |
| 2007 | 9 | 17.4 | 22.3 | 17.4 | 22 | 18.3 | 19 |
| 2007 | 10 | 11.3 | 15.4 | 11.2 | 18.2 | 13.7 | 10.9 |
| 2007 | 11 | 7.6 | 10.1 | 8.5 | 14.8 | 5.7 | 5.3 |
| 2007 | 12 | 1.3 | 4.8 | 1.6 | 7.9 | 0.5 | 0.5 |
| 2008 | 1 | -3.3 | 2.4 | -3.9 | 4.5 | -2.1 | -3.1 |
| 2008 | 2 | -1.8 | 5.4 | 1 | 8.9 | 2.3 | -0.2 |
| 2008 | 3 | 8 | 14.5 | 5.6 | 16 | 8.3 | 9.2 |
| 2008 | 4 | 11.1 | 17.9 | 11.5 | 16.6 | 13.1 | 13 |
| 2008 | 5 | 16.2 | 22.7 | 16.8 | 22.6 | 17.3 | 17.7 |
| 2008 | 6 | 21.8 | 27.9 | 21.7 | 25.1 | 21.6 | 24.1 |
| 2008 | 7 | 21.7 | 27.2 | 21.8 | 24.5 | 24 | 23.7 |
| 2008 | 8 | 20.8 | 26.5 | 21.7 | 23.8 | 25.3 | 22.9 |
| 2008 | 9 | 15.6 | 20.9 | 15.4 | 21.7 | 17.5 | 16.5 |
| 2008 | 10 | 12.7 | 17.3 | 11.9 | 19.2 | 13.7 | 12.1 |
| 2008 | 11 | 6.9 | 10.1 | 7.2 | 13.6 | 7.4 | 5.5 |
| 2008 | 12 | 0.1 | 5 | 1.1 | 10 | 3.3 | -0.5 |
| 2009 | 1 | -2 | 4.8 | -2.7 | 8.2 | 1.1 | -2.7 |
| 2009 | 2 | 0.1 | 7.6 | -0.6 | 8.9 | 3.3 | 0 |

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2009 | 3 | 4.5 | 12.3 | 5.6 | 12.8 | 7.3 | 6.3 |
| 2009 | 4 | 9 | 16 | 10 | 16.1 | 12.9 | 12.1 |
| 2009 | 5 | 14.4 | 21.3 | 14.7 | 22 | 14.6 | 16 |
| 2009 | 6 | 16.5 | 23.2 | 16 | 24 | 21.3 | 19.1 |
| 2009 | 7 | 20 | 26.1 | 20.1 | 25.7 | 25.4 | 22.1 |
| 2009 | 8 | 21.4 | 26.9 | 21.2 | 25.1 | 23.1 | 22.9 |
| 2009 | 9 | 16.3 | 21.6 | 14 | 22.5 | 18.9 | 17.7 |
| 2009 | 10 | 10.5 | 15.8 | 10.4 | 17.6 | 12.2 | 11.3 |
| 2009 | 11 | 5 | 9.2 | 5.1 | 12.9 | 6.4 | 4 |
| 2009 | 12 | 0.7 | 6.3 | -1.1 | 9.2 | 2.3 | 1 |
| 2010 | 1 | 1.3 | 6 | 1 | 9.6 | 1.1 | 0.2 |
| 2010 | 2 | 0.4 | 7.2 | 1.6 | 7.9 | 2.8 | 2.2 |
| 2010 | 3 | 7.4 | 14.7 | 9.3 | 16 | 10.5 | 9.2 |
| 2010 | 4 | 10.7 | 17.4 | 10.6 | 19.5 | 14.2 | 13.1 |
| 2010 | 5 | 13.2 | 19.5 | 13.4 | 21.5 | 17.7 | 15.3 |
| 2010 | 6 | 16.6 | 22.5 | 16.1 | 24.1 | 21.2 | 18.8 |
| 2010 | 7 | 19.5 | 25 | 18.4 | 24.5 | 23.5 | 21.3 |
| 2010 | 8 | 19.8 | 24.5 | 19.2 | 23.8 | 22.4 | 22 |
| 2010 | 9 | 16.2 | 21.3 | 15.2 | 21.6 | 20.5 | 18.2 |
| 2010 | 10 | 12.3 | 17 | 11.7 | 18.4 | 11.9 | 12.2 |
| 2010 | 11 | 7.6 | 11 | 7.6 | 13.9 | 7.1 | 5.7 |
| 2010 | 12 | 1.5 | 4.4 | 1 | 9.5 | 3.5 | -0.6 |
| 2011 | 1 | -1.5 | 3.8 | -2.2 | 6.9 | -2.7 | -2.1 |
| 2011 | 2 | -0.5 | 6.3 | -0.3 | 7.4 | -0.3 | 1.2 |
| 2011 | 3 | 3.8 | 12.9 | 6.4 | 12.8 | 7.5 | 6.9 |
| 2011 | 4 | 8.9 | 17.1 | 11 | 15.4 | 10.6 | 12.7 |
| 2011 | 5 | 16.3 | 23 | 16.1 | 23.5 | 14.7 | 18.3 |
| 2011 | 6 | 19.8 | 26.2 | 19.8 | 26 | 20.3 | 22.2 |
| 2011 | 7 | 19.3 | 26.2 | 19.9 | 24.1 | 22.3 | 22.6 |
| 2011 | 8 | 20.8 | 26.7 | 20.8 | 24 | 22.9 | 23 |
| 2011 | 9 | 16.2 | 21.8 | 17 | 22 | 19.5 | 18.7 |
| 2011 | 10 | 10.5 | 17 | 11.5 | 17.5 | 11.7 | 12.5 |
| 2011 | 11 | 7.4 | 11.5 | 6.9 | 13.6 | 4.8 | 6.6 |
| 2011 | 12 | 0.8 | 5.4 | 1.6 | 9.1 | -1.2 | 0.8 |
| 2012 | 1 | -2.4 | 3.4 | -1.8 | 5.6 | -3.3 | -3.1 |
| 2012 | 2 | -0.4 | 6.2 | 0.6 | 6.3 | 4.3 | 1.1 |
| 2012 | 3 | 3.4 | 11.6 | 5.3 | 11.8 | 7.7 | 5.9 |
| 2012 | 4 | 10.6 | 17.5 | 11.4 | 16.8 | 11.4 | 13.8 |
| 2012 | 5 | 13.4 | 19.4 | 12.7 | 21 | 19 | 15.8 |
| 2012 | 6 | 16.8 | 23.4 | 17.8 | 25.3 | 19.6 | 18.8 |
| 2012 | 7 | 20.8 | 27.2 | 21.5 | 26.5 | 24.3 | 23.4 |
| 2012 | 8 | 21 | 26.9 | 21.2 | 24.6 | 23.2 | 23.7 |

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2012 | 9 | 15.7 | 21.7 | 16 | 21.8 | 18.2 | 17.7 |
| 2012 | 10 | 8.8 | 15.5 | 11 | 16.7 | 12.9 | 10.8 |
| 2012 | 11 | 5.1 | 10.7 | 7.2 | 12.4 | 5.9 | 5.3 |
| 2012 | 12 | -0.5 | 5.7 | 1 | 8.2 | 0.6 | -0.4 |
| 2013 | 1 | -4.5 | 2.9 | -1.9 | 6.8 | -1.4 | -5.5 |
| 2013 | 2 | 0 | 7.7 | 2.6 | 8.2 | 4.1 | 1.5 |
| 2013 | 3 | 4.7 | 14 | 8.7 | 13.7 | 6.2 | 9.7 |
| 2013 | 4 | 10.3 | 18 | 11.8 | 16.7 | 15.4 | 13.7 |
| 2013 | 5 | 12.2 | 20.1 | 13.8 | 21.9 | 18.6 | 15.4 |
| 2013 | 6 | 18.8 | 26.6 | 20.2 | 25.6 | 21 | 21.4 |
| 2013 | 7 | 22.4 | 28.9 | 21.9 | 25.2 | 23.1 | 24.6 |
| 2013 | 8 | 21 | 26.2 | 20.6 | 23.9 | 22.9 | 23.2 |
| 2013 | 9 | 16.1 | 22.1 | 18.9 | 22.1 | 19 | 18.9 |
| 2013 | 10 | 12.4 | 18.1 | 14.8 | 19.1 | 10.9 | 14 |
| 2013 | 11 | 4.6 | 9.3 | 5.9 | 12 | 5.3 | 4.7 |
| 2013 | 12 | 1.6 | 5.6 | 1.9 | 9.2 | 0.5 | 0.3 |
| 2014 | 1 | -2.9 | 3.5 | -1.3 | 7.1 | -3.1 | -2.9 |
| 2014 | 2 | -0.9 | 7.4 | 2.1 | 7.9 | -0.2 | 1.9 |
| 2014 | 3 | 3.3 | 12 | 6.2 | 10.7 | 9.2 | 7.5 |
| 2014 | 4 | 8.8 | 16.7 | 10.6 | 16.1 | 13 | 11.8 |
| 2014 | 5 | 14.5 | 21.4 | 15.4 | 20.4 | 17.7 | 17.1 |
| 2014 | 6 | 18.4 | 24.6 | 19.3 | 25.5 | 24.1 | 20.1 |
| 2014 | 7 | 21.5 | 27 | 22.7 | 25.3 | 23.7 | 23.8 |
| 2014 | 8 | 20.1 | 25.5 | 20.4 | 24.6 | 22.9 | 22.4 |
| 2014 | 9 | 16 | 21.3 | 17.7 | 22 | 16.5 | 16.8 |
| 2014 | 10 | 11.3 | 16.8 | 11.8 | 17.9 | 12.1 | 12.2 |
| 2014 | 11 | 5.8 | 9.6 | 6.4 | 12.9 | 5.5 | 5.3 |
| 2014 | 12 | 1.5 | 4.7 | 1.6 | 9.5 | -0.5 | 0.7 |

Appendix-0.3. Precipitation data for sub-catchments

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2006 | 1 | 118.4 | 25.4 | 20.24 | 125.5 | 13.4 | 63.1 |
| 2006 | 2 | 16.6 | 16 | 8.43 | 78.5 | 18.3 | 19.23 |
| 2006 | 3 | 10 | 12.1 | 10 | 61.5 | 11.7 | 16.7 |
| 2006 | 4 | 36.6 | 23 | 18.24 | 74.7 | 23.12 | 32.76 |
| 2006 | 5 | 0.2 | 15.5 | 39.4 | 61.7 | 2.1 | 2.1 |
| 2006 | 6 | 18 | 11.1 | 11.1 | 68.1 | 4.5 | 4.5 |
| 2006 | 7 | 10 | 8.1 | 70.1 | 329.7 | 8.2 | 8.2 |
| 2006 | 8 | 21.3 | 39 | 21 | 191.5 | 14.6 | 14.6 |
| 2006 | 9 | 13.6 | 11.9 | 17.3 | 62 | 17.7 | 17.7 |
| 2006 | 10 | 13.1 | 14.7 | 11.2 | 37 | 2.6 | 2.6 |
| 2006 | 11 | 20.3 | 14 | 2.5 | 84.6 | 1 | 1 |
| 2006 | 12 | 30.31 | 15.8 | 23.4 | 171.9 | 19.4 | 19.4 |
| 2007 | 1 | 28.23 | 26 | 34.53 | 2.1 | 0 | 0 |
| 2007 | 2 | 21.67 | 14.3 | -9999 | 85.8 | 4.8 | 4.8 |
| 2007 | 3 | 62.2 | 11.9 | -9999 | 179.2 | 11.5 | 55.6 |
| 2007 | 4 | 53.3 | 15.2 | -9999 | 41.1 | 3 | 17.43 |
| 2007 | 5 | 19.1 | 12 | -9999 | 65.6 | 0 | 0 |
| 2007 | 6 | 25.6 | 18.8 | -9999 | 135.1 | 21.4 | 21.4 |
| 2007 | 7 | 23 | 12.5 | -9999 | 294.6 | 12.1 | 12.1 |
| 2007 | 8 | 31.5 | 6.3 | -9999 | 180.4 | 4.7 | 4.7 |
| 2007 | 9 | 17.1 | 6.3 | -9999 | 155.2 | 4.4 | 4.4 |
| 2007 | 10 | 0.6 | 14.7 | -9999 | 0 | 0 | 0 |
| 2007 | 11 | 20.3 | 14 | -9999 | 19.3 | 0 | 0 |
| 2007 | 12 | 18.7 | 15.8 | -9999 | 35.7 | 0 | 0 |
| 2008 | 1 | 21 | 2.9 | 20.45 | 200 | 21.12 | 34.7 |
| 2008 | 2 | 29.5 | 4.7 | 11.3 | 67.8 | 21.4 | 21.4 |
| 2008 | 3 | 16.8 | 11.9 | 8.4 | 20.3 | 7.4 | 7.4 |
| 2008 | 4 | 47.1 | 8.3 | 13.45 | 131 | 39.8 | 39.8 |
| 2008 | 5 | 10.9 | 75.8 | 79.4 | 45.1 | 3.9 | 3.9 |
| 2008 | 6 | 30.7 | 15.6 | 11.1 | 248.7 | 13.4 | 13.4 |
| 2008 | 7 | 18.8 | 3.5 | 70.1 | 269.1 | 7.3 | 7.3 |
| 2008 | 8 | 28.3 | 10.9 | 21 | 161.6 | 24.8 | 24.8 |
| 2008 | 9 | 26.8 | 8.3 | 17.3 | 39.5 | 31.1 | 31.1 |
| 2008 | 10 | 13.3 | 12.9 | 11.2 | 36.1 | 16.1 | 16.1 |
| 2008 | 11 | 5.8 | 6.3 | 4.6 | 77 | 0 | 0 |
| 2008 | 12 | 57.3 | 8.4 | 20.3 | 111.5 | 89.5 | 89.5 |
| 2009 | 1 | 45.2 | 32.2 | 38.23 | 74.2 | 23.12 | 23.21 |
| 2009 | 2 | 18.3 | 4.7 | 12.6 | 99.5 | 12.8 | 17.89 |
| 2009 | 3 | 58.7 | 6.1 | 7 | 85.6 | 18.3 | 18.23 |
| 2009 | 4 | 101.5 | 25 | 21 | 207.8 | 28.9 | 51.2 |

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2009 | 5 | 26.9 | 3.1 | 22.2 | 34.5 | 0.8 | 0.8 |
| 2009 | 6 | 38 | 21.6 | 19.4 | 78.9 | 5.1 | 5.1 |
| 2009 | 7 | 22.1 | 2.5 | 4.1 | 152.5 | 6.9 | 6.9 |
| 2009 | 8 | 9.2 | 1.4 | 12.8 | 177.8 | 16.3 | 16.3 |
| 2009 | 9 | 9.4 | 16.8 | 10.3 | 48.8 | 1.8 | 1.8 |
| 2009 | 10 | 4.8 | 1.2 | 6.4 | 23.8 | 4.5 | 4.5 |
| 2009 | 11 | 7.9 | 6.2 | 3.2 | 34.7 | 9.1 | 9.1 |
| 2009 | 12 | 35.9 | 6.5 | 24.5 | 8.2 | 16.1 | 16.1 |
| 2010 | 1 | 32.3 | 6 | 33.45 | 20.2 | 11.1 | 11.1 |
| 2010 | 2 | 63.8 | 13.3 | 2.4 | 214.4 | 21.32 | 124.3 |
| 2010 | 3 | 28.2 | 20.7 | 11.4 | 53.5 | 18.7 | 76.4 |
| 2010 | 4 | 103.1 | 24.6 | 24.7 | 49.6 | 21.32 | 104.4 |
| 2010 | 5 | 137.6 | 60.7 | 52.2 | 85.6 | 35.56 | 115.3 |
| 2010 | 6 | 70.8 | 23.2 | 12.1 | 59.1 | 5.1 | 5.1 |
| 2010 | 7 | 79.3 | 52.9 | 68.1 | 389.2 | 24.8 | 24.8 |
| 2010 | 8 | 26.2 | 60.1 | 29.8 | 140.5 | 29.6 | 29.6 |
| 2010 | 9 | 11.2 | 10.4 | 22 | 120 | 0.6 | 0.6 |
| 2010 | 10 | 14.3 | 1 | 6 | 15.9 | 2 | 2 |
| 2010 | 11 | 32 | 14 | 18.5 | 2 | 0 | 0 |
| 2010 | 12 | 28 | 10 | 0.5 | 24.4 | 1.8 | 1.8 |
| 2011 | 1 | 34.6 | 7 | 40.35 | 23.9 | 6.1 | 34 |
| 2011 | 2 | 37.5 | 35.5 | 2.8 | 218.3 | 18.23 | 27.23 |
| 2011 | 3 | 25.4 | 10.6 | 2.8 | 138.2 | 27.34 | 19.56 |
| 2011 | 4 | 41.1 | 5.8 | 14.6 | 120.7 | 14 | 14 |
| 2011 | 5 | 19.9 | 16.6 | 22.6 | 20.8 | 14.9 | 14.9 |
| 2011 | 6 | 15.8 | 19.8 | 13.6 | 82 | 6 | 6 |
| 2011 | 7 | 40.1 | 14.5 | 20.2 | 189.2 | 8.3 | 8.3 |
| 2011 | 8 | 7 | 11.1 | 30.8 | 266.3 | 15.6 | 15.6 |
| 2011 | 9 | 44.3 | 32.7 | 65.4 | 88 | 19.5 | 19.5 |
| 2011 | 10 | 18.9 | 4.9 | 18.6 | 63.3 | 1 | 1 |
| 2011 | 11 | 12.6 | 0.2 | 4.6 | 16.4 | 11.4 | 11.4 |
| 2011 | 12 | 39 | 2.3 | 17.6 | 9 | 0.7 | 0.7 |
| 2012 | 1 | 31.3 | 8 | 28.98 | 26 | 6.9 | 6.9 |
| 2012 | 2 | 36.4 | 6 | 5.6 | 77.3 | 26.34 | 26.45 |
| 2012 | 3 | 32.1 | 36.9 | 4 | 107.2 | 18.8 | 28.9 |
| 2012 | 4 | 34.2 | 11.3 | 43 | 214.3 | 5.6 | 5.6 |
| 2012 | 5 | 37.2 | 18.4 | 17.6 | 42.8 | 4 | 4 |
| 2012 | 6 | 29.2 | 9.3 | 10 | 45.7 | 4.4 | 4.4 |
| 2012 | 7 | 70.2 | 1.1 | 4 | 146.4 | 1 | 1 |
| 2012 | 8 | 18.2 | 11.3 | 20.8 | 299.8 | 10.1 | 10.1 |
| 2012 | 9 | 78.2 | 49 | 40.1 | 173 | 30.8 | 30.8 |
| 2012 | 10 | 10.5 | 0.2 | 3.6 | 33 | 0 | 0 |

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2012 | 11 | 7 | 2.2 | 0.6 | 5.3 | 0.4 | 0.4 |
| 2012 | 12 | 36.2 | 5.1 | 19.89 | 74 | 57.2 | 57.2 |
| 2013 | 1 | 39.1 | 3.1 | 36.45 | 7.6 | 23.4 | 21.32 |
| 2013 | 2 | 52.4 | 3.6 | 5.6 | 180.2 | 25.24 | 18.7 |
| 2013 | 3 | 6.2 | 3.2 | 0.6 | 105.1 | 0 | 0 |
| 2013 | 4 | 33.6 | 5.6 | 13.8 | 110.3 | 0 | 0 |
| 2013 | 5 | 89.3 | 50 | 31.1 | 91.2 | 56.2 | 56.2 |
| 2013 | 6 | 15.7 | 7.1 | 5 | 165.3 | 0.8 | 0.8 |
| 2013 | 7 | 49.1 | 3.4 | 9.4 | 231.7 | 0.2 | 0.2 |
| 2013 | 8 | 37.6 | 47.6 | 39.6 | 444.9 | 27.1 | 27.1 |
| 2013 | 9 | 13.9 | 14.4 | 18.4 | 179.9 | 3.6 | 3.6 |
| 2013 | 10 | 7.7 | 1.5 | 1.8 | 21.5 | 0.7 | 0.7 |
| 2013 | 11 | 2.6 | 14 | 2 | 12.1 | 1 | 17.8 |
| 2013 | 12 | 5.9 | 10 | 21.7 | 0.1 | 9.4 | 12.34 |
| 2014 | 1 | 41.9 | 1.8 | 41.23 | 21.6 | 32.12 | 103.5 |
| 2014 | 2 | 27 | 0.4 | 6.1 | 85.4 | 30.3 | 40.9 |
| 2014 | 3 | 23.9 | 8.7 | 5.2 | 316.1 | 20.9 | 20.9 |
| 2014 | 4 | 31.6 | 1.4 | 12.2 | 76.5 | 7.4 | 7.4 |
| 2014 | 5 | 58.1 | 8.9 | 10.6 | 152.4 | 6.1 | 6.1 |
| 2014 | 6 | 8.5 | 4.5 | 17.8 | 88 | 9.3 | 9.3 |
| 2014 | 7 | 31.4 | 21.1 | 33 | 189.7 | 10 | 10 |
| 2014 | 8 | 16.5 | 17 | 23.8 | 165.8 | 3 | 3 |
| 2014 | 9 | 100.4 | 22.4 | 41.3 | 213.2 | 127.2 | 11.56 |
| 2014 | 10 | 16.4 | 30.6 | 23.6 | 49.2 | 1.8 | 1.8 |
| 2014 | 11 | 31.4 | 3.8 | 0.8 | 19 | 7 | 7 |
| 2014 | 12 | 2.6 | 10 | 19.6 | 0 | 0 | 0 |

Appendix-0.4. Humidity data for sub-catchments

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2006 | 1 | 72 | 88 | 77 | 78 | 87 | 90 |
| 2006 | 2 | 77 | 76 | 71 | 72 | 86 | 85 |
| 2006 | 3 | 62 | 63 | 70 | 65 | 54 | 60 |
| 2006 | 4 | 56 | 65 | 46 | 58 | 43 | 44 |
| 2006 | 5 | 50 | 54 | 52 | 49 | 35 | 37 |
| 2006 | 6 | 60 | 59 | 51 | 53 | 37 | 40 |
| 2006 | 7 | 58 | 63 | 65 | 62 | 50 | 42 |
| 2006 | 8 | 69 | 80 | 68 | 76 | 51 | 61 |
| 2006 | 9 | 54 | 78 | 62 | 64 | 49 | 55 |
| 2006 | 10 | 60 | 80 | 65 | 63 | 48 | 53 |
| 2006 | 11 | 60 | 85 | 55 | 69 | 65 | 72 |
| 2006 | 12 | 75 | 84 | 72 | 76 | 86 | 84 |
| 2007 | 1 | 54 | 78 | 77 | 69 | 85 | 80 |
| 2007 | 2 | 64 | 70 | 71 | 70 | 73 | 80 |
| 2007 | 3 | 68 | 63 | 70 | 67 | 63 | 64 |
| 2007 | 4 | 51 | 56 | 46 | 56 | 49 | 36 |
| 2007 | 5 | 54 | 63 | 52 | 53 | 38 | 38 |
| 2007 | 6 | 59 | 63 | 51 | 55 | 46 | 40 |
| 2007 | 7 | 63 | 71 | 65 | 68 | 50 | 46 |
| 2007 | 8 | 65 | 73 | 68 | 68 | 51 | 50 |
| 2007 | 9 | 63 | 75 | 62 | 67 | 61 | 58 |
| 2007 | 10 | 46 | 76 | 65 | 52 | 68 | 47 |
| 2007 | 11 | 42 | 82 | 55 | 51 | 79 | 65 |
| 2007 | 12 | 54 | 81 | 72 | 70 | 88 | 79 |
| 2008 | 1 | 58 | 84 | 75 | 72 | 81 | 84 |
| 2008 | 2 | 66 | 68 | 73 | 71 | 79 | 81 |
| 2008 | 3 | 62 | 65 | 55 | 58 | 62 | 45 |
| 2008 | 4 | 56 | 61 | 64 | 68 | 58 | 43 |
| 2008 | 5 | 52 | 65 | 62 | 53 | 50 | 41 |
| 2008 | 6 | 53 | 60 | 63 | 57 | 47 | 38 |
| 2008 | 7 | 59 | 70 | 62 | 65 | 48 | 46 |
| 2008 | 8 | 67 | 72 | 65 | 69 | 55 | 53 |
| 2008 | 9 | 67 | 79 | 38 | 63 | 64 | 55 |
| 2008 | 10 | 58 | 76 | 57 | 59 | 66 | 57 |
| 2008 | 11 | 48 | 82 | 56 | 54 | 67 | 63 |
| 2008 | 12 | 67 | 82 | 72 | 66 | 76 | 86 |
| 2009 | 1 | 73 | 81 | 77 | 76 | 80 | 82 |
| 2009 | 2 | 78 | 64 | 75 | 74 | 80 | 82 |
| 2009 | 3 | 73 | 59 | 70 | 67 | 75 | 70 |
| 2009 | 4 | 65 | 69 | 61 | 67 | 60 | 55 |

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2009 | 5 | 53 | 60 | 55 | 52 | 56 | 47 |
| 2009 | 6 | 58 | 64 | 57 | 53 | 50 | 43 |
| 2009 | 7 | 60 | 62 | 64 | 56 | 49 | 43 |
| 2009 | 8 | 58 | 67 | 62 | 63 | 61 | 48 |
| 2009 | 9 | 63 | 75 | 78 | 61 | 72 | 49 |
| 2009 | 10 | 62 | 80 | 72 | 61 | 72 | 56 |
| 2009 | 11 | 56 | 84 | 65 | 62 | 67 | 76 |
| 2009 | 12 | 62 | 77 | 74 | 68 | 81 | 84 |
| 2010 | 1 | 62 | 81 | 78 | 68 | 90 | 74 |
| 2010 | 2 | 71 | 77 | 77 | 75 | 79 | 82 |
| 2010 | 3 | 65 | 66 | 69 | 62 | 60 | 65 |
| 2010 | 4 | 68 | 71 | 67 | 65 | 62 | 61 |
| 2010 | 5 | 70 | 77 | 76 | 62 | 49 | 60 |
| 2010 | 6 | 66 | 70 | 69 | 56 | 52 | 49 |
| 2010 | 7 | 65 | 70 | 71 | 61 | 53 | 55 |
| 2010 | 8 | 77 | 83 | 77 | 77 | 61 | 70 |
| 2010 | 9 | 67 | 78 | 72 | 70 | 55 | 56 |
| 2010 | 10 | 54 | 78 | 58 | 62 | 73 | 55 |
| 2010 | 11 | 45 | 81 | 56 | 59 | 72 | 65 |
| 2010 | 12 | 42 | 86 | 74 | 61 | 72 | 77 |
| 2011 | 1 | 65 | 87 | 81 | 68 | 88 | 83 |
| 2011 | 2 | 79 | 80 | 78 | 76 | 88 | 85 |
| 2011 | 3 | 67 | 66 | 61 | 64 | 69 | 67 |
| 2011 | 4 | 56 | 58 | 52 | 61 | 48 | 49 |
| 2011 | 5 | 51 | 57 | 63 | 50 | 50 | 43 |
| 2011 | 6 | 51 | 58 | 56 | 50 | 44 | 38 |
| 2011 | 7 | 62 | 69 | 67 | 62 | 51 | 54 |
| 2011 | 8 | 60 | 70 | 66 | 64 | 42 | 54 |
| 2011 | 9 | 72 | 79 | 78 | 74 | 47 | 63 |
| 2011 | 10 | 57 | 82 | 68 | 65 | 51 | 63 |
| 2011 | 11 | 55 | 80 | 59 | 67 | 73 | 75 |
| 2011 | 12 | 56 | 80 | 69 | 67 | 82 | 77 |
| 2012 | 1 | 60 | 77 | 78 | 76 | 90 | 76 |
| 2012 | 2 | 68 | 72 | 75 | 74 | 85 | 86 |
| 2012 | 3 | 66 | 58 | 61 | 66 | 60 | 71 |
| 2012 | 4 | 59 | 68 | 61 | 69 | 44 | 48 |
| 2012 | 5 | 55 | 72 | 69 | 58 | 37 | 46 |
| 2012 | 6 | 58 | 66 | 60 | 54 | 40 | 47 |
| 2012 | 7 | 56 | 60 | 61 | 53 | 42 | 47 |
| 2012 | 8 | 64 | 67 | 69 | 66 | 61 | 55 |
| 2012 | 9 | 71 | 76 | 74 | 75 | 55 | 65 |
| 2012 | 10 | 65 | 78 | 58 | 67 | 53 | 61 |

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2012 | 11 | 63 | 81 | 50 | 63 | 72 | 73 |
| 2012 | 12 | 63 | 75 | 72 | 68 | 84 | 82 |
| 2013 | 1 | 46 | 79 | 71 | 76 | 80 | 76 |
| 2013 | 2 | 68 | 79 | 73 | 72 | 80 | 80 |
| 2013 | 3 | 54 | 63 | 52 | 67 | 64 | 54 |
| 2013 | 4 | 57 | 58 | 60 | 67 | 36 | 46 |
| 2013 | 5 | 61 | 60 | 65 | 59 | 38 | 49 |
| 2013 | 6 | 55 | 57 | 52 | 55 | 40 | 40 |
| 2013 | 7 | 56 | 60 | 53 | 56 | 46 | 45 |
| 2013 | 8 | 67 | 81 | 66 | 69 | 50 | 60 |
| 2013 | 9 | 61 | 82 | 62 | 66 | 58 | 55 |
| 2013 | 10 | 61 | 78 | 57 | 60 | 47 | 57 |
| 2013 | 11 | 60 | 82 | 67 | 64 | 65 | 72 |
| 2013 | 12 | 63 | 81 | 67 | 67 | 79 | 82 |
| 2014 | 1 | 60 | 86 | 73 | 73 | 84 | 80 |
| 2014 | 2 | 64 | 70 | 61 | 70 | 81 | 77 |
| 2014 | 3 | 69 | 65 | 63 | 73 | 45 | 63 |
| 2014 | 4 | 56 | 63 | 56 | 65 | 43 | 47 |
| 2014 | 5 | 52 | 59 | 54 | 55 | 41 | 47 |
| 2014 | 6 | 53 | 61 | 54 | 50 | 38 | 47 |
| 2014 | 7 | 58 | 73 | 62 | 58 | 46 | 47 |
| 2014 | 8 | 59 | 69 | 62 | 62 | 53 | 48 |
| 2014 | 9 | 70 | 76 | 68 | 68 | 55 | 67 |
| 2014 | 10 | 69 | 78 | 67 | 66 | 57 | 66 |
| 2014 | 11 | 62 | 84 | 56 | 64 | 63 | 75 |
| 2014 | 12 | 60 | 82 | 62 | 63 | 86 | 76 |
| | | | | | | | |
| | | | | | | | |

Appendix-0.5. Wind Speed data for sub-catchments

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2006 | 1 | 0.3084 | 0.05144 | 0.2572 | 0.1714667 | 0.05144 | 0.20576 |
| 2006 | 2 | 0.7196 | 0 | 0.61728 | 0.2400533 | 0.10288 | 0.10288 |
| 2006 | 3 | 1.1308 | 0.15432 | 0.66872 | 0.4458133 | 1.59464 | 0.2572 |
| 2006 | 4 | 0.8738 | 0.15432 | 0.46296 | 0.3943733 | 0.7716 | 0.41152 |
| 2006 | 5 | 0.771 | 0.30864 | 0.36008 | 0.2400533 | 1.5432 | 0.7716 |
| 2006 | 6 | 0.771 | 0.30864 | 0.2572 | 0.4801067 | 0.5144 | 0.97736 |
| 2006 | 7 | 0.5654 | 0.41152 | 0.15432 | 0.3772267 | 0.7716 | 0.97736 |
| 2006 | 8 | 0.3084 | 0.20576 | 0.05144 | 0.1200267 | 0.56584 | 0.36008 |
| 2006 | 9 | 0.6168 | 0 | 0.10288 | 0.2229067 | 0.30864 | 0.15432 |
| 2006 | 10 | 0.3598 | 0.05144 | 0.15432 | 0.1200267 | 0.56584 | 0.36008 |
| 2006 | 11 | 0.8224 | 0 | 0.05144 | 0.3429333 | 0.30864 | 0.05144 |
| 2006 | 12 | 0.7196 | 0 | 0.30864 | 0.0171467 | 0.30864 | 0.20576 |
| 2007 | 1 | 0.6168 | 0 | -9999 | 0.10288 | 0.56584 | 0 |
| 2007 | 2 | 1.0794 | 0.15432 | -9999 | 0.15432 | 0.30864 | 0.05144 |
| 2007 | 3 | 1.1822 | 0.10288 | -9999 | 0.2743467 | 0.41152 | 0 |
| 2007 | 4 | 1.028 | 0.30864 | -9999 | 0.30864 | 0.5144 | 0.66872 |
| 2007 | 5 | 0.5654 | 0.41152 | -9999 | 0.3257867 | 0.61728 | 0.41152 |
| 2007 | 6 | 0.6682 | 0.05144 | -9999 | 0.1714667 | 0.36008 | 0.15432 |
| 2007 | 7 | 0.4626 | 0.10288 | -9999 | 0.5486933 | 0.82304 | 0.2572 |
| 2007 | 8 | 0.5654 | 0.10288 | -9999 | 0.2400533 | 0.2572 | 0.05144 |
| 2007 | 9 | 0.4626 | 0.10288 | -9999 | 0.1886133 | 0.46296 | 0.15432 |
| 2007 | 10 | 0.1542 | 0.05144 | -9999 | 0.1371733 | 0.36008 | 0 |
| 2007 | 11 | 0.4626 | 0 | -9999 | 0.2400533 | 0.30864 | 0 |
| 2007 | 12 | 0.7196 | 0 | -9999 | 0.1714667 | 0.36008 | 0.10288 |
| 2008 | 1 | 0.7196 | 0.15432 | 1.8004 | 0.2914933 | 0.46296 | 0 |
| 2008 | 2 | 0.771 | 0.2572 | 0.82304 | 0.3429333 | 0.30864 | 0 |
| 2008 | 3 | 1.2336 | 0.2572 | 0.46296 | 0.4286667 | 0.41152 | 0.05144 |
| 2008 | 4 | 0.9766 | 0.2572 | 0.61728 | 0.3943733 | 0.46296 | 0.46296 |
| 2008 | 5 | 0.9252 | 0 | 0.66872 | 0.36008 | 0.41152 | 0.2572 |
| 2008 | 6 | 0.7196 | 0.30864 | 0.05144 | 0.3429333 | 0.61728 | 0.15432 |
| 2008 | 7 | 0.771 | 0.2572 | 0.05144 | 0.20576 | 0.82304 | 0.2572 |
| 2008 | 8 | 0.6168 | 0.10288 | 0.56584 | 0.3429333 | 0.5144 | 0.20576 |
| 2008 | 9 | 0.4626 | 0.05144 | 0.05144 | 0.20576 | 0.56584 | 0.10288 |
| 2008 | 10 | 0.514 | 0.15432 | 0.10288 | 0.1714667 | 0.2572 | 0.10288 |
| 2008 | 11 | 0.9252 | 0 | 0.10288 | 0.1200267 | 0.05144 | 0 |
| 2008 | 12 | 0.7196 | 0.20576 | 0.15432 | 0.2743467 | 0.56584 | 0 |
| 2009 | 1 | 0.5654 | 0.36008 | 0 | 0.2743467 | 0.7716 | 0.10288 |
| 2009 | 2 | 1.0794 | 1.08024 | 0.20576 | 0.4972533 | 0.36008 | 0.15432 |
| 2009 | 3 | 1.0794 | 0.72016 | 0.20576 | 0.3257867 | 0.82304 | 0.2572 |
| 2009 | 4 | 1.6448 | 0.30864 | 0.36008 | 0.3772267 | 0.72016 | 0.5144 |

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2009 | 5 | 1.285 | 0.2572 | 0.10288 | 0.2743467 | 1.08024 | 0.41152 |
| 2009 | 6 | 0.9252 | 0 | 0.2572 | 0.2914933 | 0.7716 | 0.46296 |
| 2009 | 7 | 0.6168 | 0.15432 | 0.10288 | 0.4286667 | 1.18312 | 0.2572 |
| 2009 | 8 | 0.771 | 0.61728 | 0.15432 | 0.41152 | 0.46296 | 0.2572 |
| 2009 | 9 | 0.6682 | 0.10288 | 0 | 0.2229067 | 0.36008 | 0.05144 |
| 2009 | 10 | 0.3598 | 0.05144 | 0 | 0.2743467 | 0.41152 | 0.10288 |
| 2009 | 11 | 1.1308 | 0 | 0.20576 | 0.2914933 | 0.41152 | 0.72016 |
| 2009 | 12 | 0.7196 | 0.2572 | 0.56584 | 0.2743467 | 0.15432 | 0.15432 |
| 2010 | 1 | 0.771 | 0.10288 | 0 | 0.2914933 | 0.36008 | 0 |
| 2010 | 2 | 1.0794 | 0.15432 | 0.56584 | 0.3257867 | 0.36008 | 0.20576 |
| 2010 | 3 | 0.6682 | 0.2572 | 0 | 0.3772267 | 0.36008 | 0.05144 |
| 2010 | 4 | 0.5654 | 0.30864 | 0.10288 | 0.2743467 | 0.72016 | 0.10288 |
| 2010 | 5 | 0.7196 | 0.20576 | 0.20576 | 0.2743467 | 0.5144 | 0.10288 |
| 2010 | 6 | 0.5654 | 0 | 0.15432 | 0.2229067 | 1.08024 | 0.10288 |
| 2010 | 7 | 0.514 | 0.05144 | 0.05144 | 0.2400533 | 0.56584 | 0.2572 |
| 2010 | 8 | 0.1542 | 0.05144 | 0 | 0.3943733 | 0.30864 | 0.05144 |
| 2010 | 9 | 0.257 | 0.2572 | 0.10288 | 0.2743467 | 0.10288 | 0.10288 |
| 2010 | 10 | 0.3084 | 0 | 0.05144 | 0.30864 | 0 | 0 |
| 2010 | 11 | 0.3598 | 0 | 0.05144 | 0.1371733 | 0 | 0 |
| 2010 | 12 | 0.4626 | 0 | 0.10288 | 0.1886133 | 0.10288 | 0 |
| 2011 | 1 | 0.3084 | 0 | 0.41152 | 0.1200267 | 0 | 0 |
| 2011 | 2 | 0.771 | 0 | 0.46296 | 0.3429333 | 0.10288 | 0 |
| 2011 | 3 | 1.1308 | 0.10288 | 0.41152 | 0.3257867 | 0.36008 | 0.05144 |
| 2011 | 4 | 1.1822 | 0.05144 | 0.30864 | 0.3257867 | 1.0288 | 0 |
| 2011 | 5 | 0.7196 | 0.41152 | 0.05144 | 0.56584 | 0.56584 | 0.15432 |
| 2011 | 6 | 0.0514 | 0.20576 | 0 | 0.2572 | 1.23456 | 0.30864 |
| 2011 | 7 | 0.1542 | 0.5144 | 0.20576 | 0.3943733 | 0.72016 | 0.10288 |
| 2011 | 8 | 0.3084 | 0.2572 | 0.15432 | 0.36008 | 0.97736 | 0.05144 |
| 2011 | 9 | 0.257 | 0.05144 | 0 | 0.20576 | 0.41152 | 0 |
| 2011 | 10 | 0.4112 | 0.05144 | 0 | 0.2229067 | 0.10288 | 0 |
| 2011 | 11 | 0.9252 | 0.10288 | 0.2572 | 0.1886133 | 0.10288 | 0 |
| 2011 | 12 | 0.514 | 0 | 0.20576 | 0.2572 | 0.05144 | 0.05144 |
| 2012 | 1 | 0.771 | 0.2572 | 0.05144 | 0.3428533 | 0.20576 | 0 |
| 2012 | 2 | 0.4112 | 0.30864 | 0.5144 | 0.36 | 0.10288 | 0 |
| 2012 | 3 | 0.8738 | 0.46296 | 0.15432 | 0.6000667 | 0.2572 | 0 |
| 2012 | 4 | 0.3084 | 0.36008 | 0.05144 | 0.2400133 | 0.41152 | 0.15432 |
| 2012 | 5 | 0.771 | 0.41152 | 0.2572 | 0.3257067 | 0.7716 | 0.46296 |
| 2012 | 6 | 0.257 | 0.2572 | 0 | 0.3599333 | 0.97736 | 0.05144 |
| 2012 | 7 | 0.0514 | 0.30864 | 0 | 0.51412 | 0.97736 | 0.20576 |
| 2012 | 8 | 0.1028 | 0.2572 | 0 | 0.25704 | 0.36008 | 0.30864 |
| 2012 | 9 | 0.0514 | 0.15432 | 0.05144 | 0.2056667 | 0.15432 | 0.05144 |
| 2012 | 10 | 0.257 | 0 | 0.30864 | 0.1371467 | 0.36008 | 0 |

| Year | Month | Astore | Gilgit | Hunza | Indus | Shigar | Shyok |
|---|---|---|---|---|---|---|---|
| 2012 | 11 | 0.6168 | 0 | 0.15432 | 0.3428133 | 0.05144 | 0 |
| 2012 | 12 | 0.514 | 0.2572 | 0.5144 | 0.2399733 | 0.20576 | 0 |
| 2013 | 1 | 0.3084 | 0.05144 | 0.15432 | 0.4970267 | 0 | 0 |
| 2013 | 2 | 0.6682 | 0 | 0.30864 | 0.5312933 | 0.05144 | 0 |
| 2013 | 3 | 1.1822 | 0.30864 | 0.56584 | 0.7884267 | 0 | 0.05144 |
| 2013 | 4 | 0.6682 | 0.2572 | 0.36008 | 0.6514267 | 0.66872 | 0.05144 |
| 2013 | 5 | 0.771 | 0.15432 | 0 | 0.63428 | 0.41152 | 0.05144 |
| 2013 | 6 | 0.6682 | 0.36008 | 0.15432 | 0.5999733 | 0.15432 | 0.41152 |
| 2013 | 7 | 0.514 | 0.61728 | 0 | 0.5142667 | 0.2572 | 0.41152 |
| 2013 | 8 | 0.257 | 0 | 0 | 0.3428 | 0.05144 | 0.15432 |
| 2013 | 9 | 0.2056 | 0 | 0 | 0.3942533 | 0.15432 | 0 |
| 2013 | 10 | 0.1542 | 0.15432 | 0 | 0.4628933 | 0 | 0 |
| 2013 | 11 | 0.4626 | 0 | 0 | 0.4628267 | 0 | 0 |
| 2013 | 12 | 0.514 | 0.10288 | 0.15432 | 0.56568 | 0.10288 | 0 |
| 2014 | 1 | 0.3598 | 0 | 0 | 0.5484933 | 0 | 0 |
| 2014 | 2 | 0.8224 | 0.30864 | 0.30864 | 0.58288 | 0 | 0 |
| 2014 | 3 | 0.9766 | 0.46296 | 0.30864 | 0.6170667 | 0.05144 | 0.05144 |
| 2014 | 4 | 1.2336 | 0.15432 | 0.05144 | 0.83996 | 0.46296 | 0.05144 |
| 2014 | 5 | 0.9766 | 0.41152 | 0 | 0.7199467 | 0.2572 | 0.15432 |
| 2014 | 6 | 0.6682 | 0.2572 | 0 | 0.9939867 | 0.15432 | 0.05144 |
| 2014 | 7 | 0.6168 | 0.66872 | 0 | 0.5998933 | 0.2572 | 0.30864 |
| 2014 | 8 | 0.257 | 0.7716 | 0 | 0.63416 | 0.20576 | 0.2572 |
| 2014 | 9 | 0.1542 | 0.05144 | 0 | 0.3943067 | 0.10288 | 0 |
| 2014 | 10 | 0.257 | 0 | 0.10288 | 0.36004 | 0.10288 | 0 |
| 2014 | 11 | 0.4626 | 0 | 0.10288 | 0.4800133 | 0 | 0 |
| 2014 | 12 | 0.514 | 0.10288 | 0.15432 | 0.4286 | 0 | 0 |