Norwegian University of
Science and Technology

Water Resource Management for Integrated Use of Rivers and Reservoirs in Rural Areas of Developing Countries: Guder River Basin

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Hydropower Development
Submission date: June 2017
Supervisor: Oddbjørn Bruland, IBM
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Preface

This thesis titled "Water Resource Management for Integrated Use of Rivers and Reservoirs in Rural Areas of Developing Countries: Guder River Basin" was prepared to fulfil the requirement of Master of Science degree in Hydropower Development Engineering course 2015-2017, set by the Norwegian University of Science and Technology (NTNU), at the department of Civil and Environmental Engineering.

The aim of the project is to present the methods and scenario analysis procedures to address one of the major problems of our time, water resource management for integrated use in developing countries. Though the scope of this thesis work is limited to the sub-basin of the Blue Nile in rural region of Ethiopia, Guder River Basin (GRB), the applied analysis methods can be used to address similar problems in other regions. The work includes determination of hydrological trends in the GRB, projection of climate change and its impact on the streamflow, and the effect of reservoir construction on the flow. The level of impact on the flow due to irrigation and water supply was also addressed. AutoCAD, ArcGIS 10.4, and WEAP were the software used for analysis.

The project was started on the 15th of January and it was completed on the 11th of June in year 2017 under the supervision of Professor Oddbjørn Bruland and Tor Haakon Bakken. The sole purpose of this work is academic related and is not meant to offend any individual or organization. I take full responsibility for the work presented in this thesis and any result or idea that was used from other sources have been duly noted.

Executive Summary

Impact of climate change on runoff is a topic of great interest to hydrologists and hydropower developers. Often studies that involve effect of climate change on runoff in developing countries such as Ethiopia are conducted to analyse large scale hydropower. Very little research has been done on the impact of climate change on small catchments for the purpose of small scale hydropower. Since Ethiopia has 10% of untapped small scale hydropower potential, investment in small scale hydropower is one of the most productive ways to solve the energy problem in rural sides of Ethiopia. Bello catchment located in the Guder River Basin (GRB) was identified to have the capacity to produce 14.5 MW by the Ethiopian Ministry of Water Resource and Energy. When the prefeasibility study was conducted for this catchment, the effect of climate change, irrigation, and water supply demand within the area was not considered as a factor that might have impact on the future streamflow. The work that was done in this thesis addresses these problems.

The trend of the temperature, precipitation, and runoff of the catchment was analysed based on 18 years' data (1987-2004). The trend characteristics were considered as the basis for the climate projections in the 2020s, 2040s, 2060s, 2080, and 2090s. The impact of the climate change projections on the runoff were analysed using Water Evaluation and Planning Tool (WEAP). In general, a trend of increase in temperature and decrease in precipitation was noted in the area. As expected, runoff reduction when the temperature increases and precipitation decreases was found to be significantly higher than the runoff reduction only with temperature increase scenario. The impact of reservoir construction on the runoff was also analysed by considering minimum and maximum net evaporation from the reservoir. The runoff reduction after the mid-century under the maximum net evaporation scenario was found to be much higher than the expected runoff reduction under the minimum net evaporation scenario. The irrigation and village sites have less impact on the runoff if the sites are located either far upstream of the reservoir or downstream of the reservoir.

Conducting the impact of climate change and irrigation on the economic, social, and environmental aspects of the area has to be done in order to comprehend the full picture of the effects. The processes and methods utilized in this thesis can be used to study the degree of competition by different sectors on runoff of small catchments in other rural sides of the country.

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List of Abbreviations

BNB - Blue Nile Basin

CF - Confidence Factor

DPI - Dependable Precipitation Index D Dry Year

FAO - Food and Agriculture

GCM - Global Climate Models

GRB - Guder River Basin

IDF - Intensity Duration and Frequency

IFPRIF - International Food Policy Research Institute

NR - Normal Year

NSE - Nash-Sutcliffe Efficiency

RSD - Relative Standard Deviation

RSR - RMSE-Observations Standard Deviation Ratio

S - Mann-Kendall Static

STDEV - Standard Deviation of measured data

SWAT - Soil and Water Assessment Tool

UN - United Nations

W - Wet Year

WEAP - Water Evaluation and Planning Tool

WHO - World Health Organization

m.a.s.l - Meters Above Sea Level
MCM - Million Cubic Meters
Kw - Killo Watt
ha - Hectares
km - Killo Meters
MW - Megga Watt

1 Introduction

The aim of this thesis is to illustrate that proper water resource management is the most significant way to combat poverty in rural areas of developing nations. Should the current method of water resource management technique in developing countries continue, the International Food Policy Research Institute (IFPRI) predicts that by 2050 more than half of the world population- that is 4.8 billion people- will be at risk as a result of water stress (IFPRI, 2013). Water resource management is the process of determining the true water value of freshwater located at a given area. It is quite complex for it requires not only technical solution but also policy, social, and environmental adjustments as well. Hence, to acquire the ever-changing correct value of water, it is necessary to create an integrated water management technique (the key term being integrated). It is true that there are a number of studies done on different sector's single influence on the sustainable growth of rural communities. What is missing both in the social and scientific research fields is the integration methods of different sectors (water supply, agriculture, and energy) to optimize the use of multipurpose water resource in rural communities of developing nations (Cloke & Park, 2013). The central intent of my project is to address this problem. Management of water is more expensive and present different challenges in rural areas than urban cities due to smaller population residing over large areas. In far too many cases, communities in rural areas are left to handle both the surface and groundwater resource as they see it fit. The uninformed way of using freshwater has not only decreased the quantity of the water but also has compromised the quality of the water (Molden, Amarasinghe, & Hussain, 2001).

This project identifies energy, agriculture, and water supply as the three major sectors that will empower rural areas of developing nations. Each sector's role in creating water stress is also discussed in this thesis. The main objective of this project is to determine how these main sectors can coexist by optimizing the surface water resource of a given rural area of Sub-Saharan Africa country.

1.1 Significance of Study as Such

1.1.1 Energy Sector: Small Scale Hydropower Plant

United Nations reports that 1.2 billion people in developing nations, that is 23% of the world's population have no access to electricity (UN, 2013). World Bank has reported that 500 million people in Africa and 400 million people in India still have no electricity (WordBank, 2016).

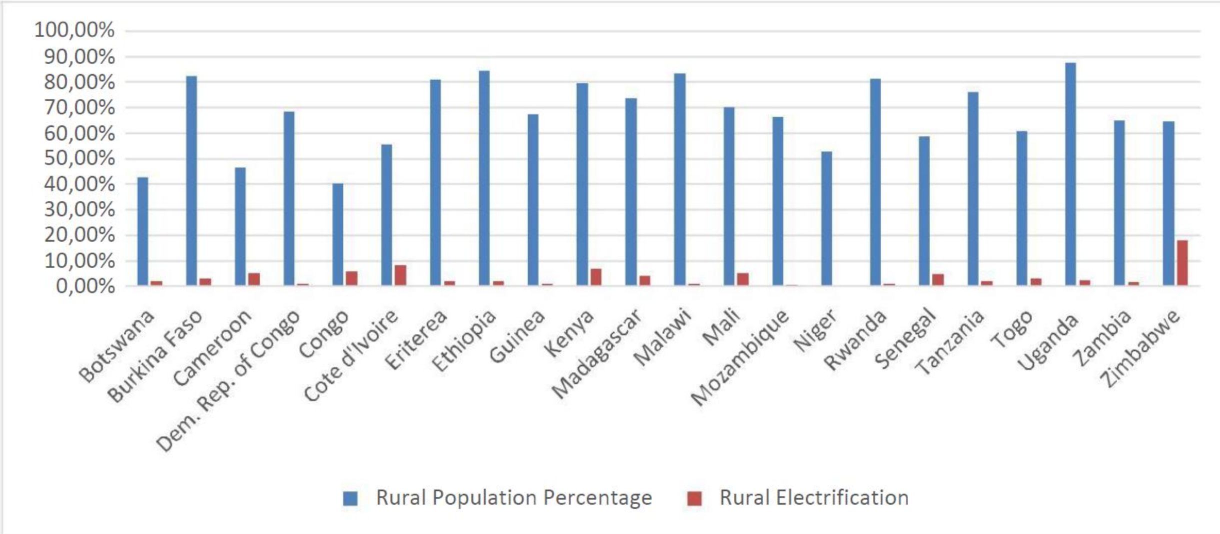


Figure 1.1-1 Percentage of the population having access to electricity in rural areas of countries in sub-Saharan Africa Source: (Shanker, Clement, Tapin, & Buchsenschutz, 2013)

Figure 1.1-1 illustrates the disproportion between the population and their access to electricity. This is a clear indication of the gap between the energy need that has to be met and the reality of today's world. Rural communities should be able to become energy independent in order to achieve a sustainable growth. Becoming energy independent is one of the significant ways rural communities in developing countries can fight poverty. FAO in its report points out that most people that reside in rural areas cannot afford to buy electricity provided by the central grid system (FAO, 2013). Small scale hydropower plant (pico hydro (<5kW), mini hydro (<500kW), micro hydro (<100kW) and small (1-10kW)) though it is smaller in size from large hydropower plants, it uses the same concept of "head" and "flow" to produce energy.

Small scale hydropower is an energy source that can be set on and\or off grid to provide electricity to rural communities. It is also renewable and clean energy. Hydropower is the most reliable environmental friendly energy source because energy in the form of water can be stored. It must also be noted that hydropower provides lowest cost per watt hour compare to solar or wind energy sources. Even though small scale hydropower is a highly recommended source of energy for isolated areas, its usage of water puts the energy system at the mercy of proper water management technique.

1.1.2 Agriculture

United Nations puts sustainable rural development at the center of its tactics to achieve the Millennium Development Goals plan (UN, 2015). This report specifically identifies empowerment of small scale farmers as one of the significant methods to create a sustainable growth in rural areas. Provided that 60% to 90% of the Sub-Saharan Africa total labor force is encompassed in the agricultural sector, empowerment of farmers is necessary (Thornton, et al., 2006). Within the agricultural sector, small scale farmers with 10 hectares or less of land, hold 80% of the business (FAO, 2012). Despite the staggering proportion of the small scale farmers' main role in Sub-Sharan Africa's economy, they represent 60% of people in poverty. That is out of 2.5 billion people with main source of income from agriculture, 1.5 billion small scale farmers live below the poverty line (FAO, 2012). Small scale farms play a vital role in providing food security for people in rural areas that otherwise cannot afford the high food price of the national market due to transport and marketing costs. The struggle of small scale farmers everywhere in today's global market, let alone small scale farmers from developing nations, can only be solved if smallholder agriculture is not isolated from other investment plans (Diao, Hazell, Resnick, & Thurlow, 2007). Globally, agriculture accounts for 70% of freshwater usage; this value is three times higher than what used to be 50 years ago (Global Agriculture, 2015). 20%, 40%, 70%, 80%, 80%, and 90% of fresh water in Europe, Northern America, Southern America, Asia, Africa, and South Asia respectively is consumed for agricultural purposes (Global Agriculture, 2015). Demand of freshwater for agriculture is expected to increase by 19% within the coming 35 years (FAO, 2014). Today 40% of world's food production is as a result of irrigated agriculture whereas the rainfed systems provide the 60% food production (RobecoSAM, n.d.). Especially in Africa millions are dependent on the rain fed agricultural system. This system has exposed farmers to high risk of failed production. According to (Schlosser, et al., 2014) by 2050, 1.8 billion people are expected to live in areas with moderate to severe water stress; where 80% of them are located in developing nations. These figures demonstrate that if nothing changes, the problems small scale farmers and hence, rural communities as a whole in developing countries face is only going to get worse (IFPRI, 2013). If indeed empowering small scale farmers is considered as an important method to combat poverty in developing nations, then it is must that one addresses the intense competition on the usage of freshwater and the freshwater becoming a scares resource.

1.1.3 Water Supply: Drinking Water

Surface water (lakes, reservoirs, streams, and rivers) provides 50% of the drinking water.
According to World Bank's report, 80% of people with lack of access to safe drinking water reside in rural areas; that is those that live in rural communities are 5 times more without access to safe water than city dwellers (UN, 2016). In Sub-Saharan Africa 40% of the 783 million people do not have access to clean water (Freitas, 2013). As the population in Sub-Saharan Africa continues to increase, especially in the rural regions, so does water stress.

Investment on proper management of surface water resource is not only an action that must be taken to fulfill the basic need of humans, but it is also a significant way to empower rural areas of developing nations. World Health Organization (WHO) reports that for every dollar spent on drinking water, $3 to $34 is generated in different regions of Sub-Saharan Africa (The Water Project, 2016).

1.2 Study Area

1.2.1 Abay River Basin

Abay River Basin or as it is commonly known, Blue Nile, is vital to the livelihood in all the basin riparian countries. The river is shared by Ethiopia, Egypt, Sudan, Uganda, Kenya, Tanzania, Burundi, Rwanda, and the Democratic Republic of Congo. Abay River is located North-West of Ethiopia. The total length of the river is estimated to be 1,450 km, of which 800 km is inside Ethiopia. Abay River also constitutes 17.5% of Ethiopia. 3000km^2 of the river is made up of Lake Tana, the largest fresh water lake in Ethiopia. The elevation of Abay ranges from 590 to 4000 m. Consequently, the temperature within the basin significantly differs from region to region. The temperature of the river is mild at the higher elevations and very hot at the lower elevations.

Table 1-1 Temperature of Abbay River Basin (Source: River Nile, History, Present, and Future Prosperity)

Elevation	Temperature
Above 2400 m	10 – 16 °C
1800 – 2400 m	16 – 20 °C
Below 1800 m	20 – 28 °C

This project analysis the impact of climate change and land use on one of Abay River's sub basins, Guder River Basin.

1.2.2 Guder River Basin

Area Description

Table 1-2 Guder River Basin area description

Location	Oromia regional state of Ethiopia
Total Area	7000 km^2
Catchment Name	Bello River Basin
Catchment Area	290 km^2
Proposed dam site location	at 8^o51'50" North and 37^o40'00" East

GRB is located in the Oromia regional state of Ethiopia. The sub-basin has neighbouring basins in the east, Guder, Awash to the south, and Fincha to the west. The Bello river, the river this thesis is mostly concerned about, originates from south-east of Jibat and Roge mountains of west Shoa. The length of the river to the dam site is 38km. The slope of the river is in the range of 1-5% in the different sections of the river, where the average slope of the river is 1.5%. 70% of the catchment is cultivated land and 30% of the area is grass land. Given how fertile the soil in the Guder basin is, the percentage of cultivation is expected to grow.

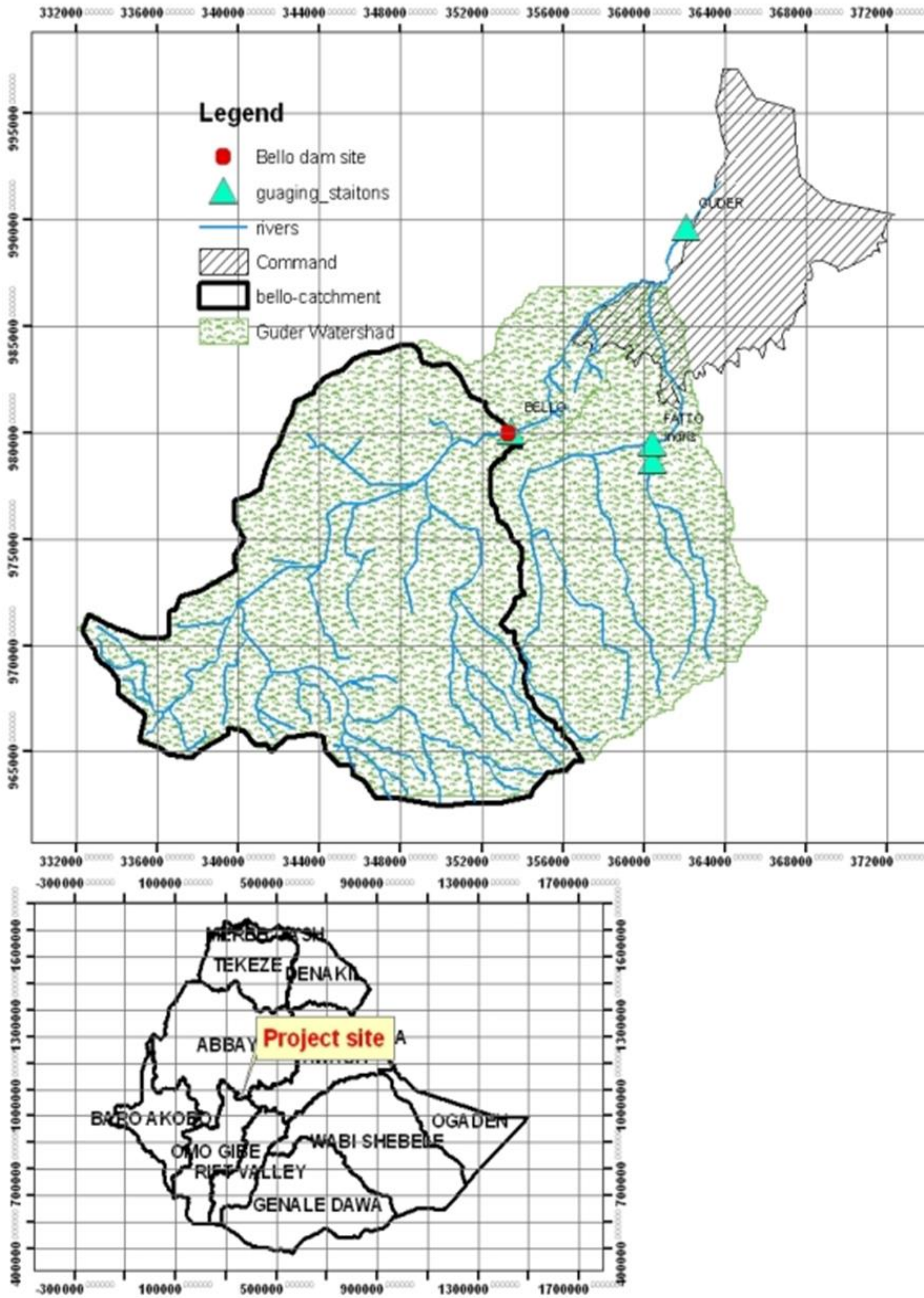


Figure 1.2-1 Location of catchment area of upper Guder multipurpose project (Adapted from Ministry of Water Resources and Energy. Feasibility study of Upper Guder Multipurpose Project)

1.3 Study Questions and Objectives

Questions

- What is the hydrological trend in the Guder River Basin (GRB)?
- Based on the determined trend characteristics, what can be projected about the climate in the GRB?
- What are the different scenarios that will have impact on the streamflow and to what extent is the impact?
- How does construction of reservoir affect the amount of streamflow?
- How will introduction of irrigation and water supply influence the water allocation system?
- What is the degree of competition between the energy sector, agriculture and water supply?

Objectives

- To present the optimal scenario for multi-purpose water management system at GRB.
- To investigate the balance that should be made on the use of the river as a result of climate change and/or land use.
- To determine the shortage of demand in different scenarios and to present the scenario at which demand shortage can be minimized.
- Based on the results obtained from this research to recommend other researches that can be done on this topic

2 Literature Review

2.1 "Climate change in the Blue Nile Basin Ethiopia: implications for water resources and sediment transport"

The study was conducted by the collaboration of Department of Biological Systems Engineering, Virginia Tech, Blacksburg, VA, USA 2 Abay Basin Authority, Beles Subbasin Organization, Assosa, Ethiopia 3 Abay Basin Authority, Tana Subbasin Organization, Bahir Dar, Ethiopia 4 Department of Agriculture, Food and Resource Sciences, University of Maryland Eastern Shore, Princess Anne, MD, USA 5 International Water Management Institute, Nile Basin and East Africa, Addis Ababa, Ethiopia.

The aim of the project was to analyze the impact of climate change on Blue Nile Basin based on the data collected from Tana basin and Beles basin. The study did also apply downscaled and bias corrected Coupled Model Intercomparison Project 5 (CMIP5) Global Climate Models (GCM) climate change scenarios in order to project the fluxes of water and sediment in the Tana and Beles basins. The projection analysis covered two periods i.e. 2041-2065 and 2075-2099. The study was conducted by applying the Soil and Water Assessment Tool (SWAT) software model developed by Easton et al. (2008, 2010, and 2011).

The study considered spatial data and baseline metrological data for the estimation of the model parameters and calibration. The scenarios that were studied were taken from the Earth System Grid Federation, four RCP scenarios. These scenarios were

a. RCP2.6 - peak in radiative forcing at 2.6 W/m2 before 2100 and decline thereafter
b. RCP4.5 - stabilization without overshoot to 4.5 W/m2 at 2100
c. RCP6 - stabilization without overshoot to 6 W/m2 after 2100
d. RCP8.5 - increasing radiative forcing to 8.5 W/m2 by 2100

Several results were presented in this report. The change on the temperature and precipitation and as a result its impact on the flow of both Tana and Beles basins were discussed. Across all climate models, the study showed that in Beles basin: -

i. The mean and annual precipitation increase by 11% with a standard deviation of 33.4%
ii. Maximum and minimum temperature increase by 8.6% and 18% with standard deviation of 0.2% and 9.5% respectively in 2041-2065 period and the maximum and minimum

temperature was predicted to increase by 2.4-24.5% with a standard deviation of -4.5% and 20.1% respectively in 2075-2099 period.

Across all climate models, the study showed that in Tana basin: -

iii. Precipitation increases by a mean of 17.6% with standard deviation of 35.0% s in the 2041–2065 period. And by 18.4% with a standard deviation of 25.3% in 2075-2099

iv. Maximum and minimum temperature increases by a mean of 15.7% and 25.5% with standard deviation of −16% and 20.1% respectively in the 2041–2065 period. Whereas in the 2075-2099, the maximum and minimum temperature increase is expected to increase by y 21.2% and 34.7%, respectively with standard deviations of −20.2% and 20.1%, respectively

Based on these projections the study concluded that the flow of Tana and Beles basin will increase by 27% and 21-22% respectively. The increase in flow will result increase in sediment concentration.

2.2 "Summer Rains and Dry Seasons in the Upper Blue Nile Basin: The Predictability of Half a Century of Past and Future Spatiotemporal Patterns"

This study was conducted by Agricultural Catchments Programme, Teagasc, Johnstown Castle Environmental Research Centre, Wexford, County Wexford, Ireland, Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden, Department of Geography and Environmental Studies, Addis Ababa University, Addis Ababa, Ethiopia, Ethiopian Institute of Water Resources.

The objective of their study was to determine the wet and dry seasons' timing, duration and intensity over 50 years' period, to analyse the impact of climate change for the after mid-century period (2050-20100), and to investigate the application of simple spatial model for describing rain pattern on the upper Blue Nile Basin (BNB). The data for the study was based on 19 metrological stations placed in different parts of the basin's region. The location of the stations represented a large range of time, space, and altitudes (between 678-2980 m) within BNB. The data represented 24 years, where some stations recorded minimum of 3 years' data and some maximum of 24 years' data between the years of 1952 and 2004.

Criteria for the characteristics of the seasons within the basin was investigated by applying linear regression against coordinates. Rain frequency was analysed by studying the duration curve and

Intensity Duration and Frequency (IDF) curves. The climate scenario and downscaling was obtained from the ECHAM5/MP1-OM.

Their research has found that over the coming 50 years, rainfall is expected to increase by a small amount in the upper BNB. Though, this increase was not evenly distributed and found to be true for all the sub-basins of the Blue Nile in Ethiopia. The increase of the rainfall is also predicted to happen during the rainy season where 93% of the 1490mm, spatially averaged annual rainfall was in the wet months. The number of wet days and the amount of rainfall on those wet days was found to be higher in the southwest than the north. In the southwest the wet days was fond to be 322 days whereas in the north the number of the days was only 136. The need for more research on the BNB by including climate adaptation and proper water management techniques has been indicated as the next most important phase of researches on this topic.

2.3 "Implications of Climate Change on Hydrological Extremes in the Blue Nile Basin"

Extreme hydrological events in the basin was studied by analyzing the historical precipitation and streamflow trends. Future projections on hydrological extremes was also analyzed by using GCMs. The trend results based on other literatures was summarized in this paper. The most vital findings that were indicated in the article include

a. Decreasing trend of extreme precipitation intensity in July, August, and September in the eastern, southwestern and southern parts of Ethiopia was observed in the 1965-2002 data (Seleshi and Camberlin (2006)). The decreasing of trend in precipitation during the rainy season in the southwestern and central parts of Ethiopia (where the southern part of the Blue Nile River is found) was also observed by Cheung et al. (2008). According to Cheung et al. (2008) the significant decrease that was observed was by 7.00 mm/year for the time period of 1960-2002.

b. No significant trend of extreme precipitation in the northwestern highlands was detected for the observed data in the 1953-2006 period. Shang et al. (2011)

c. Even though the total precipitation displayed no trend in central and northern Ethiopia, frequency of drought was noted to be increasing based on the data observed from 1972-2011 by Viste et al. (2012).

d. Significant decrease in the total precipitation during wet seasons with the rate of -2.3 and -9.25mm/year was observed for the data set in the 1954-2004 period in the upper BNR (Tabari et al. (2015)).

e. No significant trend was observed in the total precipitation at seasonal and annual scale for the period of 1981-2010 according to the 13 stations within the upper BNR basin (Tekleab et al. (2013))

The implication of precipitation increase or decrease in different parts of Ethiopia and hence in different parts of the Abay River is reflected on the flow of BNR's sub-basins. The article did also present the changes that were observed in the flow of sub-basins from different literatures.

I. Gilgel

a. Low flow decreased by 18.1% for the periods of 1982-2000 and by 66.6% for the 2001-2005 period.

b. High stream flow increased by 7.6% and 46.6% for the periods 1982-2000 and 2001-2005 respectively (Rientjes et al. (2011))

II. Chemoga

a. Decrease of daily and monthly flows at a rate of 0.6mm/year during the dry seasons (October-May) for the 1957-1998 periods. A 94% decrease of the monthly scale flow in February for the same time period was also noted (Bewket and Sterk (2005)).

b. No significant trend of the streamflow was detected in the wet seasons.

III. Koga – No significant trend was observed for both the low and high streamflow for the 1960-2002 period (Gebrehiwot et al. (2010)).

2.4 "The Implications of Changes in Population, Land Use, and Land Management for Surface Runoff in the Upper Nile Basin Area of Ethiopia"

The article examined the impact of population growth and land use on the upper Nile Basin by first acknowledging that there was no significant trend in the total annual rainfall data of 1965-2002 period. According to the article, the same was found to be true for the seasonal rainfall in the northern and northwestern Ethiopia as well. Whereas, the rainfall totals in the eastern, southern, and southwestern stations showed significant decline of trends since 1982.

The population in the highlands of Ethiopia increased from 16 million to almost 65 million, where 26.2 million of the people reside in the Nile Basin area. Which, of course, led to an increase of land use in the rainfed highlands. Consequently, the forest cover in the central part of the basin decreased to 0.3% in 1995 from 27% in 1957. The study was interested in determining if the population increase had a significant impact on the rainfall-runoff coefficients at the catchment level. To do so, a detailed assessment on different catchments with different population and type of land use characteristics and an analysis on the rainfall-runoff coefficients over time were conducted.

The study did not present a clear relationship between multi-annual runoff coefficients and population density, forest cover, grassland cover, or cultivated area. Hurni et al. (2005) argued that physical characteristics like soil type, annual rainfall and geology have as big of a role on the runoff as population density and/or land use. Based on the study of the research catchments, it was concluded that population density and intensified land use was not found to be a reason for higher runoff.

Effects of soil and water conservation on runoff was also analyzed by considering a series of experimental plots and comparing the results obtained from the experiments to non-conserved plots. The study showed that runoff coefficient decreased by 40-50% in the conserved plots relative to the non-conserved plots. The experimental test characters were in some form mimicked on the real catchments and the results were compared to one another. The catchment that has 110 ha area located in the central Gojam at an elevation of 2400-2600m, was 80% cultivated with no soil conservation measures in year 1984 and 1985. By Year 1986 the same area was fully cultivated. Runoff data of 17 years (1984-2000), during the period the area was fully conserved was analyzed. Unlike what was observed in the experimental plot tests, the rainfall-runoff coefficients did not substantially decrease when water in the area was conserved.

3 Climatic and Hydrological Data

3.1 Data Processing

Data availability was the main reason for the selection of GRB as the case study of the project. Reliable metrological data such as, precipitation, temperature, humidity, wind speed, and sunshine hour was available. Table 3-1 Precipitation measuring stations' descriptionTable 3-1 presents summary of the metrological stations found within and near the watershed.

The precipitation measuring stations named Ambo, Guder, Gedo, and Inchini are all located outside of the Bello catchment. Whereas, Inchini is a station that is both within the Bello catchment and is also quite near to one of the runoff measuring gauges (Bello gauge). Inchini station is 5 meters away from Bello gauge.

Table 3-1 Precipitation measuring stations' description

No.	Station Name	Lat, N	Long, E	Elevation, m a.s.l
1	Ambo	$08^0$58’	$37^0$52’	2050
2	Guder	$08^0$57’	$39^0$47’	2002
3	Gedo	$09^0$03’	$37^0$26’	2500
4	Inchini	$09^0$19’	$38^0$22’	2690

It must be indicated that all the stations didn’t collect data for the same period. Guder station has the longest data set with 59 years. Ambo and Gedo station each have 58 years of raw data. Inchini station has collected data for 47 years. Similar to the observed raw data period variation from station to station, percentage of missing data for each station also differs. For instance, the percentage of missing data is 9%, 8%, 6%, and 1.7% for Ambo, Gedo, Inchini, and Guder stations respectively. Summary of the data availability variation is presented in Table 3-2.

Table 3-2 Runoff measuring gauges missing data summary

S. No.	**Station Name**	**Altitude (m)**	**Period**	**Missed data by No. of months or (%)**
1	Ambo	2050	1954-2012(58yrs)	63 (9%)
2	Guder	2002	1964-2012(59yrs)	10 (1.7%)

3	Gedeo	2500	1954-2012(58yrs)	57(8%)
4	Inchini	2690	1976-2012(47yrs)	25 (6%)

Data of temperature, relative humidity, wind speeds, and sunshine duration was collected by Ambo station only. Provided that the data recorded by Ambo station can be a representative for the entire command area, this project utilized the observed data of temperature, humidity, wind speed, and sunshine duration from Ambo station.

Table 3-3 Ambo station data years

Station Name	Temperature Max & Min.	Relative humidity periods	Wind speed periods	Sunshine duration periods
Ambo	1951-1964& 1984-2012	1988&1989-1995	1990-2005	2010-2012

4 river gauging stations named Bello, Fatto, Guder, and Indris are available. The flow record period is the longest for Fatto and Guder stations with 51 years of raw data for each gauging station. Bello and Indris have 50 and 47 years of flow data respectively. The missing percentage data was 10%, 6.8%, 3%, and 1.1% for Bello, Indris, Fatto, and Guder gauges respectively. Summary of the distribution and record period of the river gauges are presented in Table 3-4.

Table 3-4 Runoff gauge's description

River/ Lake	Lat.	Lon.	Area covered by the station (km^2)	Average catchment elevation (m.a.s.l)	Available flow data period	Missed months (%)
Belo	$8^0$52'N	$37^0$40'E	290	2509	1960 – 2009 (50 yrs)	62 (10%)
Fatto	$8^0$52'N	$37^0$43'E	96	2551	1959 – 2009 (51 yrs)	18.57 (3%)
Guder	$8^0$57'N	$37^0$45'E	524	2518	1959 – 2009 (51 yrs)	6.56 (1.1%)

Indris	8°56'N	37°45'E	111		1976 – 2012 (47 yrs)	38.51 (6.8%)

The runoff data was the central component of this project. The data was used to determine the current availability of water within the watershed and to project how the current flow will change in different conditions.

Based on the data availability from each station and closeness to the project area, the data collected from each stations were used for different purposes. Table 3-5 summarizes what station was used for what purpose.

Table 3-5 Summary of data application

Name of Station	Applied Data	Representative of Area
Inchini	Precipitation	Catchment
Guder	Precipitation	Command Area
Guder	Temperature	Command Area
Ambo	Evapotranspiration	Command Area

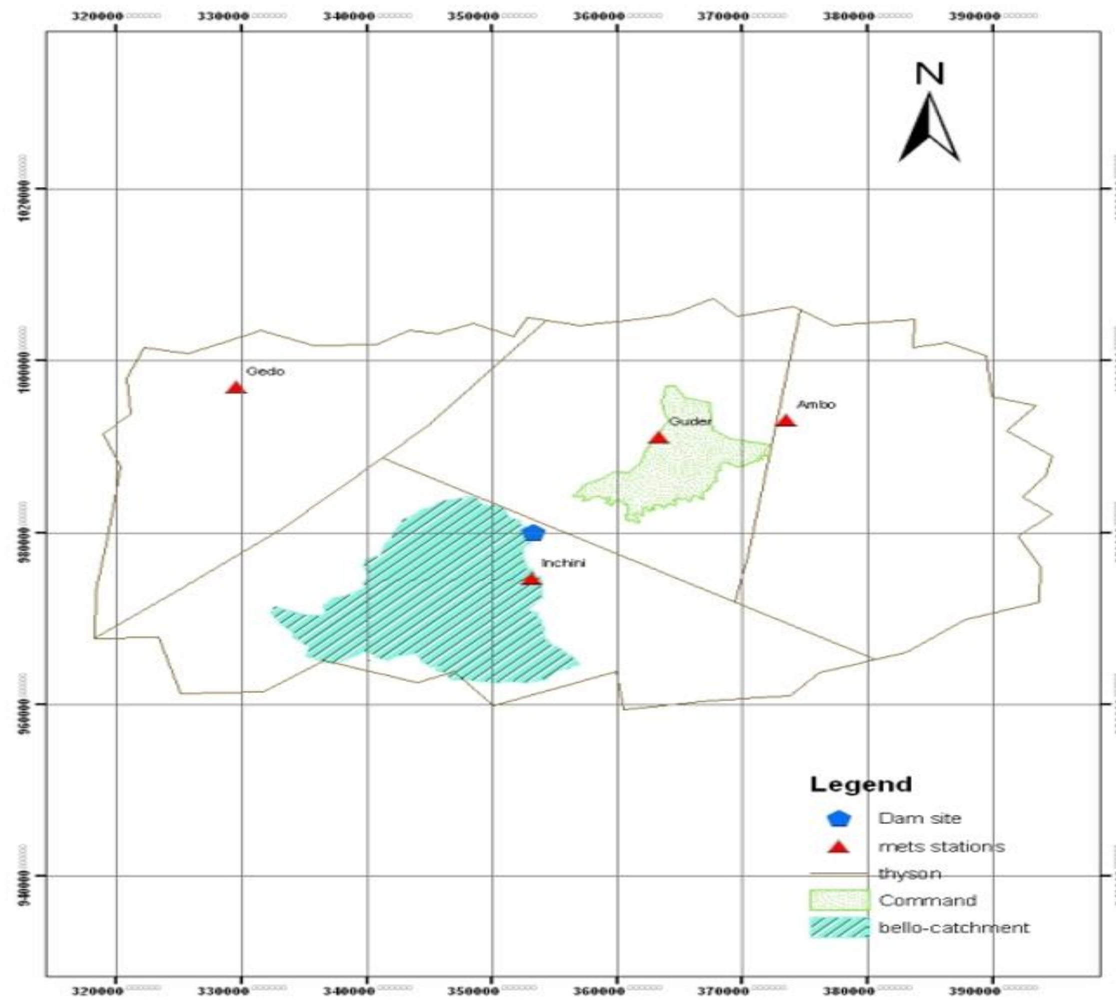


Figure 3.1-1 Rainfall measuring stations' location

3.2 Data Consistency and Homogeneity Test

3.2.1 Rainfall Data Consistency

Consistency of hydrological data was tested by applying double-mass curve method. This method compares a given station's data with the other stations that are within the area of interest. The double-mass curve is a representation of a cumulative data of one station versus a cumulative data of another station for the same period. The data can be of precipitation or runoff. If the data from the stations are proportional to one another, then the plot must be a straight line. In order to minimize effect of inconsistency in one station on the average cumulative values, several stations must be considered (Searcy and Hardison (1960)).

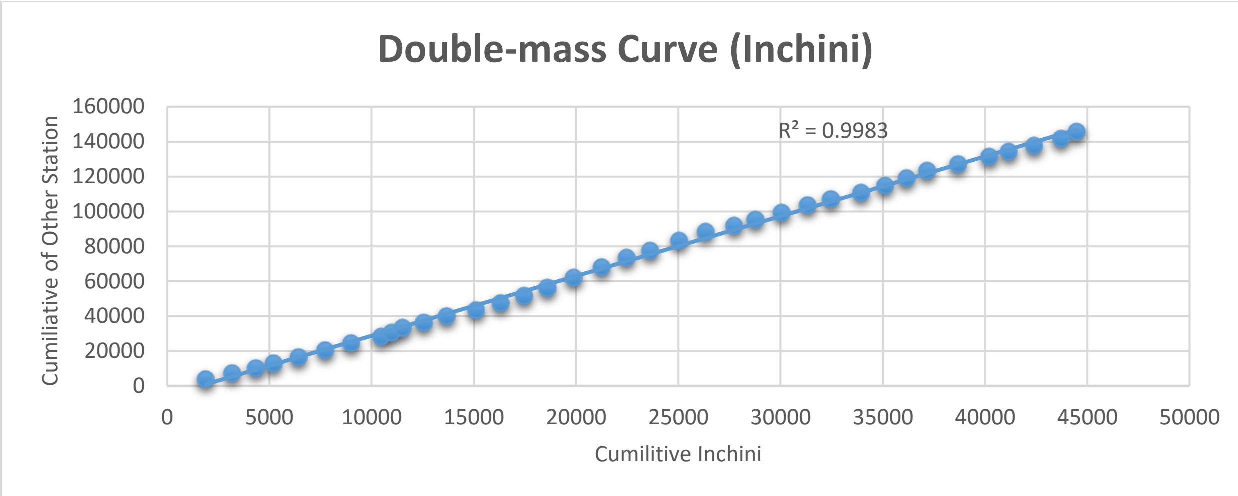


Figure 3.2-1 Double-mass curve of Inchini station

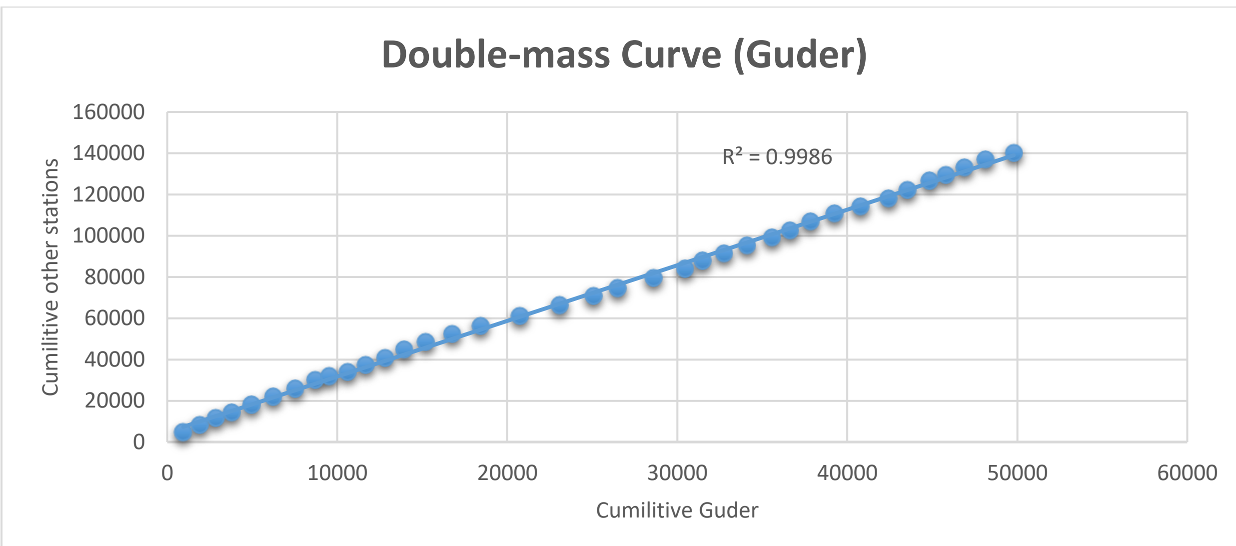


Figure 3.2-2 Double-mass curve if Guder station

As Figure 3.2-1 and Figure 3.2-2 show the rainfall data collected from each station is consistent with the other stations' data.

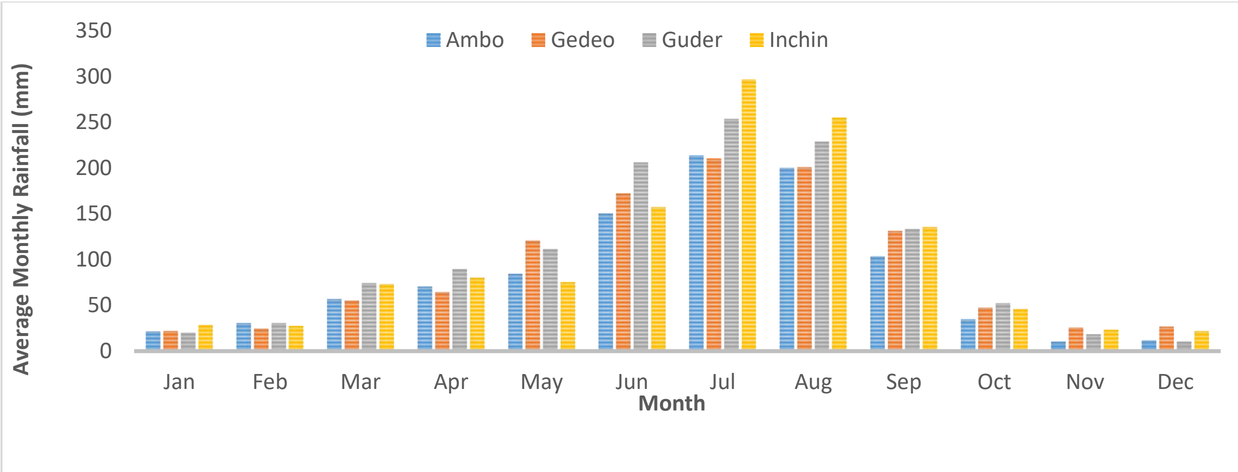


Figure 3.2-3 Average monthly rainfall of all the rainfall measuring stations

As it can be noted from Figure 3.2-3 peak of precipitation at all the gauges was observed in July and August. The second peak precipitation values are in June and September. January, February, November and December are the driest months.

3.2.2 Flow Data Homogeneity

Bello gauge is located at the dam site. Based on the location of the gauge, the data collected from the gauge was considered to represent the entire Bello catchment's flow. As Table 3-4 showed, 62 months of data within 50 (1960-2009) years of period, which is, 10% of data was missing. Guder station has the least percentage of missing data (1.1%) relative to the other gauges within the area. The homogeneity test was conducted between the mean monthly flow of Bello and Guder in order to determine if the missing data of Bello gauge has a significant impact on representing the season variability of the command area.

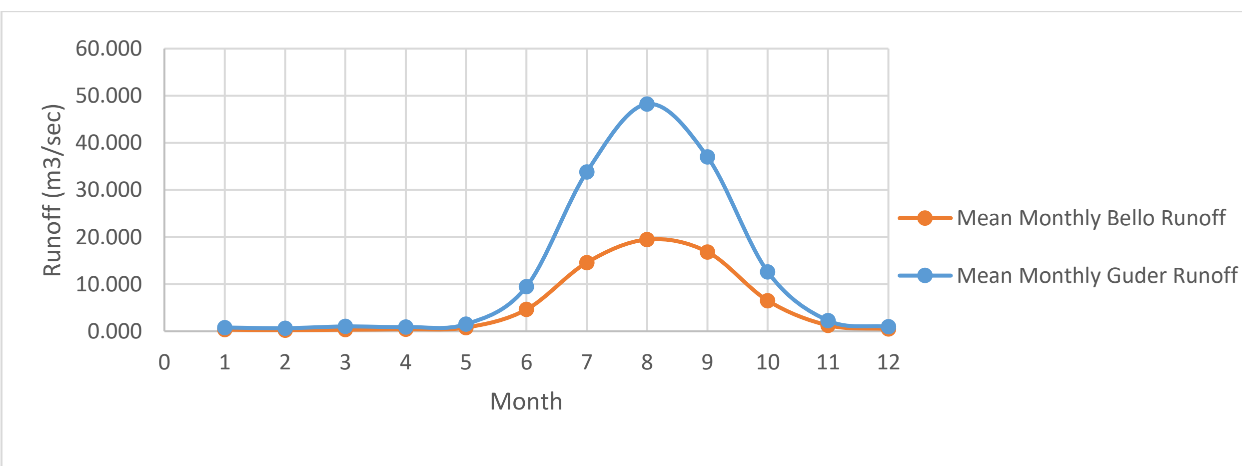


Figure 3.2-4 Mean monthly runoff of Bello and Guder station

The mean runoff from Bello Gauge represents similar data variability from Guder gauge. This makes the data set from Bello gauge pass the homogeneity test.

3.2.3 Duration Curve

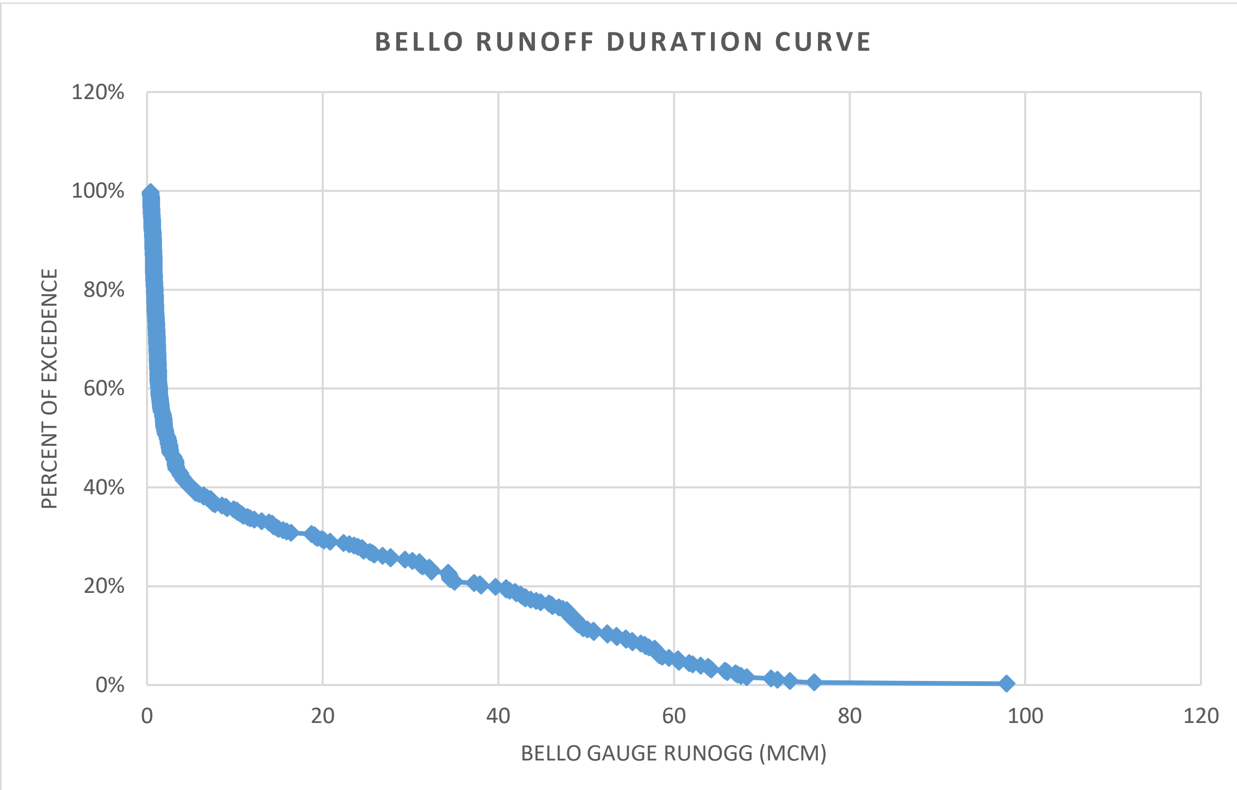


Figure 3.2-5 Bello runoff duration curve

The flow duration curve of the Bello catchment based on the current data was used to compare Figure 3.2-5 with the flow duration curves of different scenarios. At its current state, the flow of the catchment can reach or exceed the turbine capacity flow, 16.2 MCM, 30% percent of the time.

4 Calibration and Simulation

4.1 Calibration Performance

In order to validated the level of correspondence between the simulated and observed runoff data, the Nash-Sutcliffe efficiency (NSE) and RMSE-Observations Standard Deviation Ratio (RSR) accuracy quantification methods were applied.

4.1.1 Nash-Sutcliffe efficiency

NSE measures accuracy by comparing the residual variance, “noise,” to the observed data variance, “information” (Nash and Sutcliffe, 1970). NSE is a normalized statistic that quantiles reliability of a simulated data by weighing the model simulation’s mean square error against the “variance of the target output sequence” (Schaefli and Gupta, 2007). NSE is computed as shown in equation

$$1-\left(\frac{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs}-Y^{mean}\right)^2}\right)=\text{NSE}$$

Where:- Y_i^{obs} is the ith observation data

Y_i^{sim} is the ith derived simulated value

Y^{mean} is the mean of observed data

n is the total number of observations

The normalized measure ranges from -∞ to 1. The goal of this method is to determine how the observed data plot against the simulated data plot fits 1:1 line. Therefore, NSE value of 1 is the most favoured value. The performance of the model is considered acceptable, if the NSE value is between 0 and 1. Whereas, negative NSE value is an indication that the model performance is not acceptable for negative NSE represents the higher quality of the mean observed value than the simulated value.

Besides NSE being a commonly used calibration performance tester, the method’s ability to properly represent the fit of the hydrograph, makes NSE the best mechanism to test this project’s calibration accuracy. Though, as Legates and McCabe (1999) pointed out in their critics of the NSE method, the extreme values have an impact on NSE performance, this accuracy measurement method performance was still found to be acceptable for this study.

4.1.2 RMSE-Observations Standard Deviation Ratio (RSR)

RMSE is also a commonly applied error analysis method with many reported values in different literatures (Chu and Shirmohammadi, 2004; Singh et al., 2004). Despite the RMSE method being used in many studies, where the smaller the RMSE value is the better the correspondence between the simulated and observed data, the quantification of the acceptable smaller value was defined years later by Singh et al. (2004). The better explained, modified version of the RMSE method is what is known as RMSE-Observations Standard Deviation Ratio (RSR). RSR is the ratio of RMSE and standard deviation of measured data (STDEV)

$$\frac{(\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2})}{(\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2})} = \frac{RMSE}{STDEV_{obs}} = RSR$$

Where:- $Y_i^{obs}$is the ith observation data

Y_i^{sim} is the ith derived simulated value

Y^{mean} is the mean of observed data

n is the total number of observations

The closer the RMSE value is to zero, the lesser the residual variation, which is an indication of an acceptable level of simulation performance by the model.

4.2 Calibration Simulation

Figure 4.2-1 is a plot that represents the monthly observed data versus the simulated data over 18 years (1987-2004). The NSE value for this figure was found to be 0.7. Since this value is significantly greater than 0 and smaller than 1 by 0.3 margin, the calibration was determined as acceptable by NSE standard. The missing data were handled by linear interpolation and replacement method. WEAP conducts interpolation between the previous and the next value of the provided data. Since some of the missing data do not represent the extreme values, a replacement method instead of interpolation was applied in some instances.

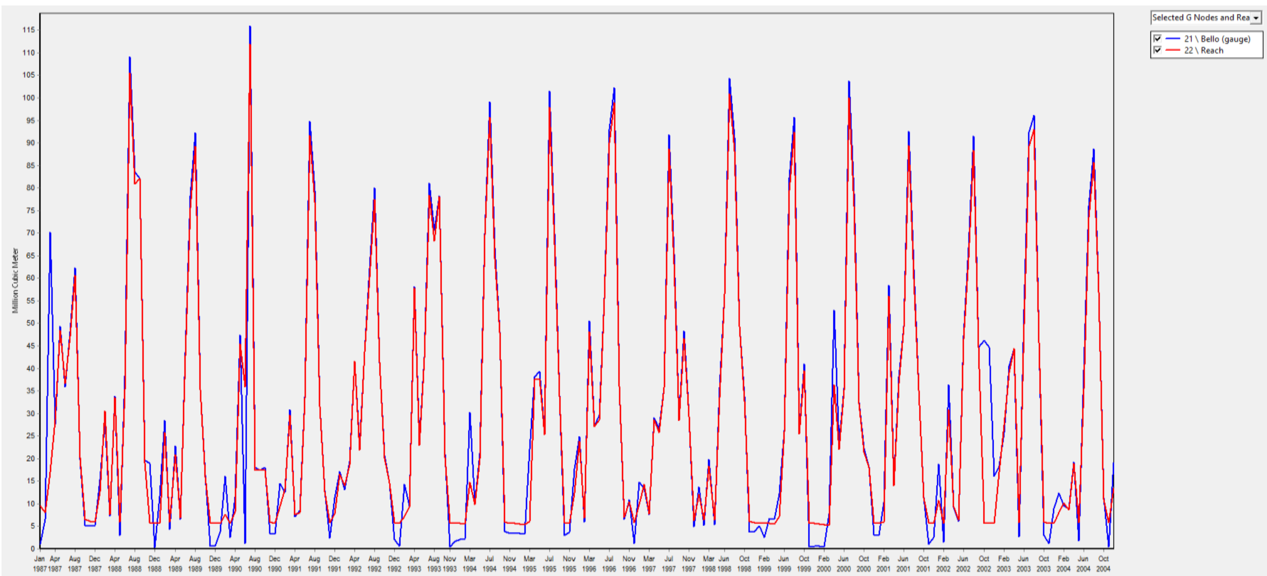


Figure 4.2-1 Simulated vs. observed monthly runoff (1987-2004)

The RSR value, on the other hand, was found to be 0.25. Since 0.25 is close to 0, the calibration performance was also deemed to be acceptable by the RSR standard. As far as both the NSE and RSR methods are concerned, the uncertainties that may have been introduced during interpolation or replacement to handle the missing data did not affect the calibration performance. Hence, the simulated data was considered as the basis for projections.

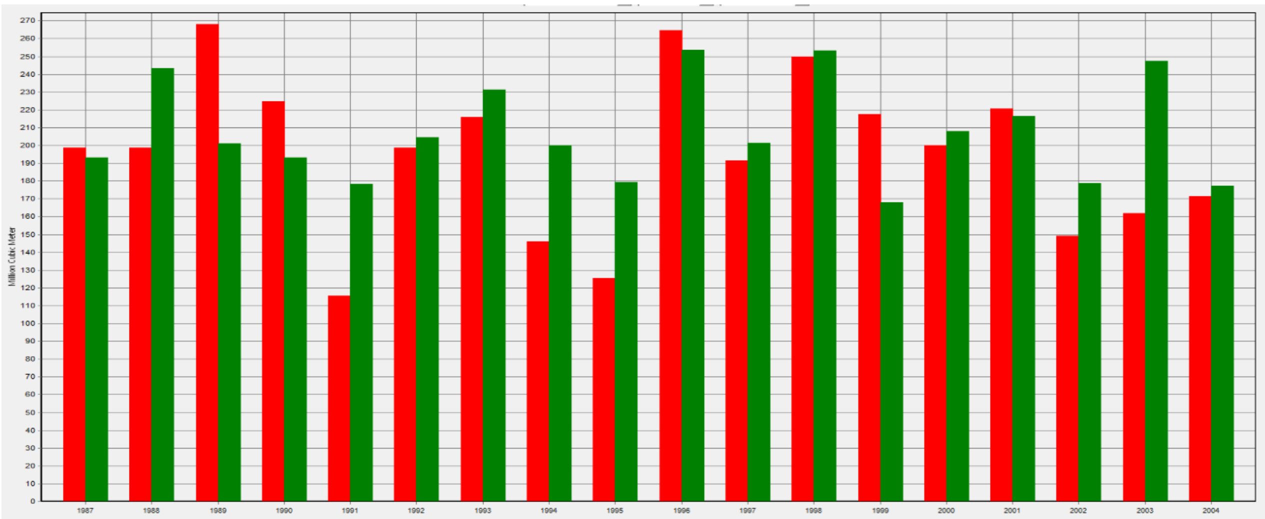
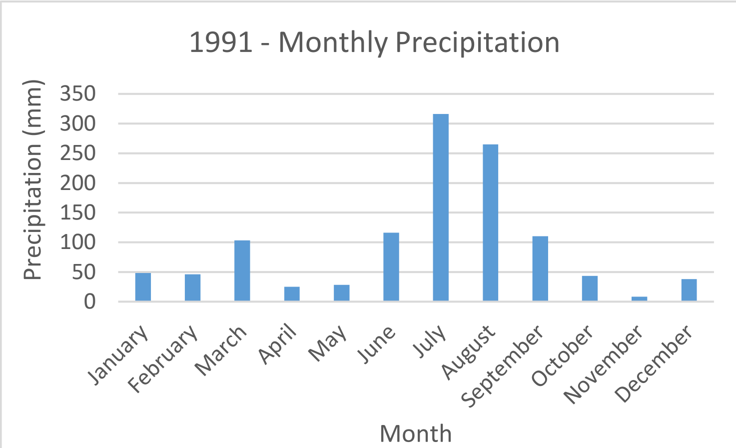
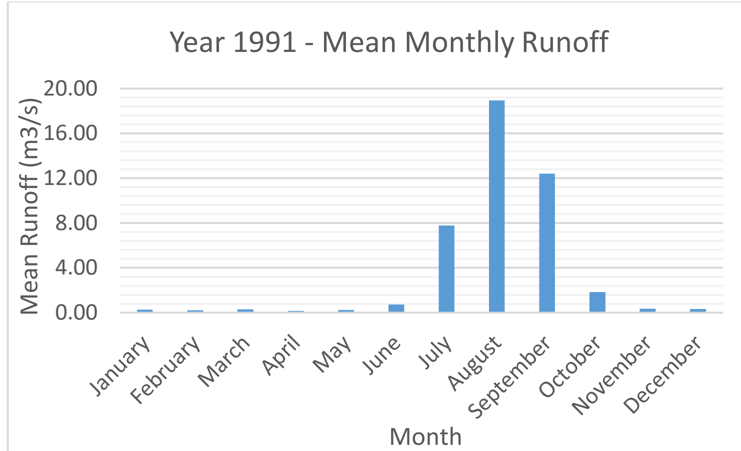
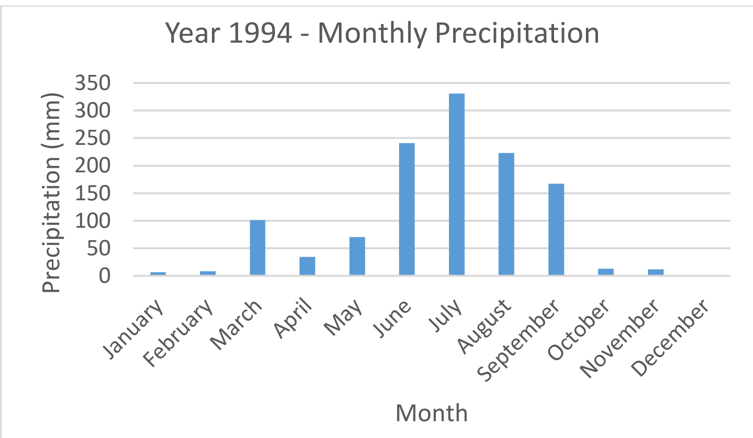


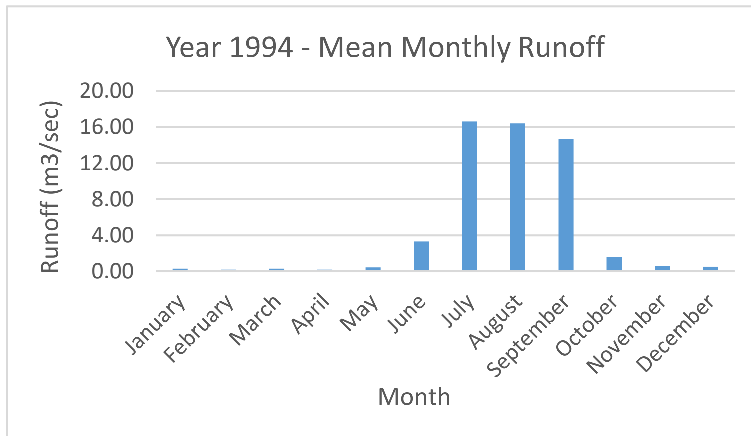
Figure 4.2-2 Simulated vs. observed yearly runoff (1987-2004)

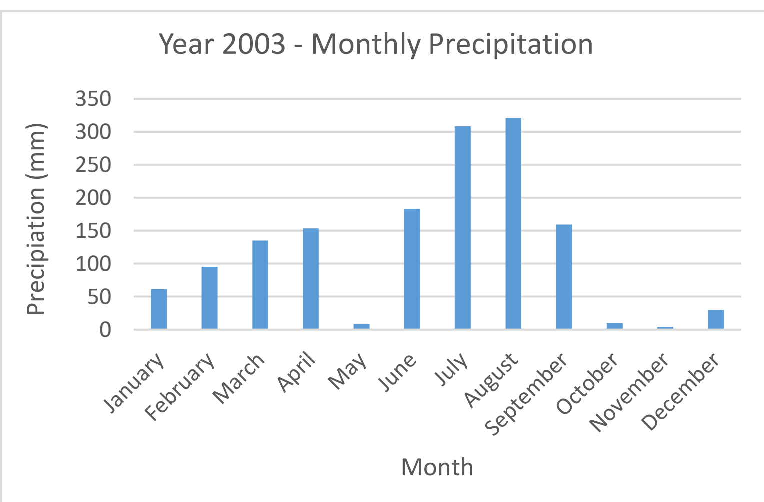
Figure 4.2-2 is the annual observed versus simulated runoff data of the 18 years. As it can be seen from Figure 4.2-2, the simulated data was not able to correspond with the observed data for the year 1991, 1994, and 2003.











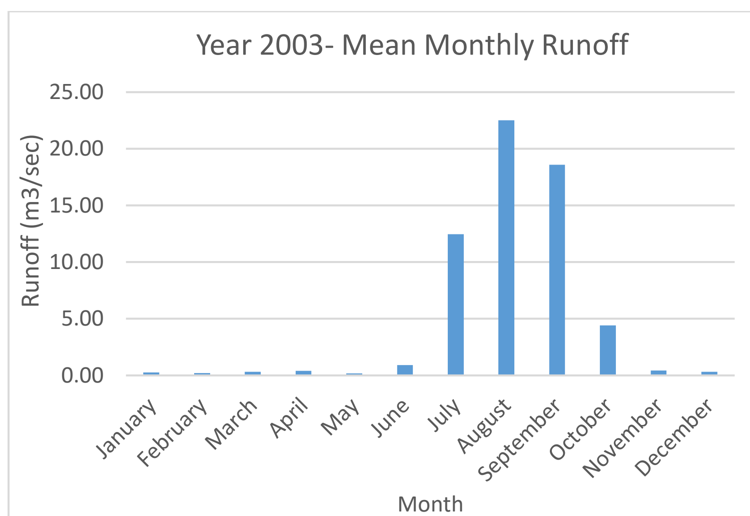


Figure 4.2-3 (a) Monthly precipitation, 1991 (b) Mean monthly runoff, 1991 (c) Monthly Precipitation, 1994 (d) Mean monthly runoff, 1994 (e) Monthly precipitation, 2003 (f) Mean monthly runoff, 2003

The discrepancy between the observed runoff and the simulated runoff that was calibrated based on the observed precipitation values, can be attributed to the uncertainties that may have been caused during aggregation of the minute precipitation data into monthly. The highest temperature values were also recorded in year 1991, 1994, and 2003. Especially in year 2003, the temperature has increased on average by 11% relative to the previous year.

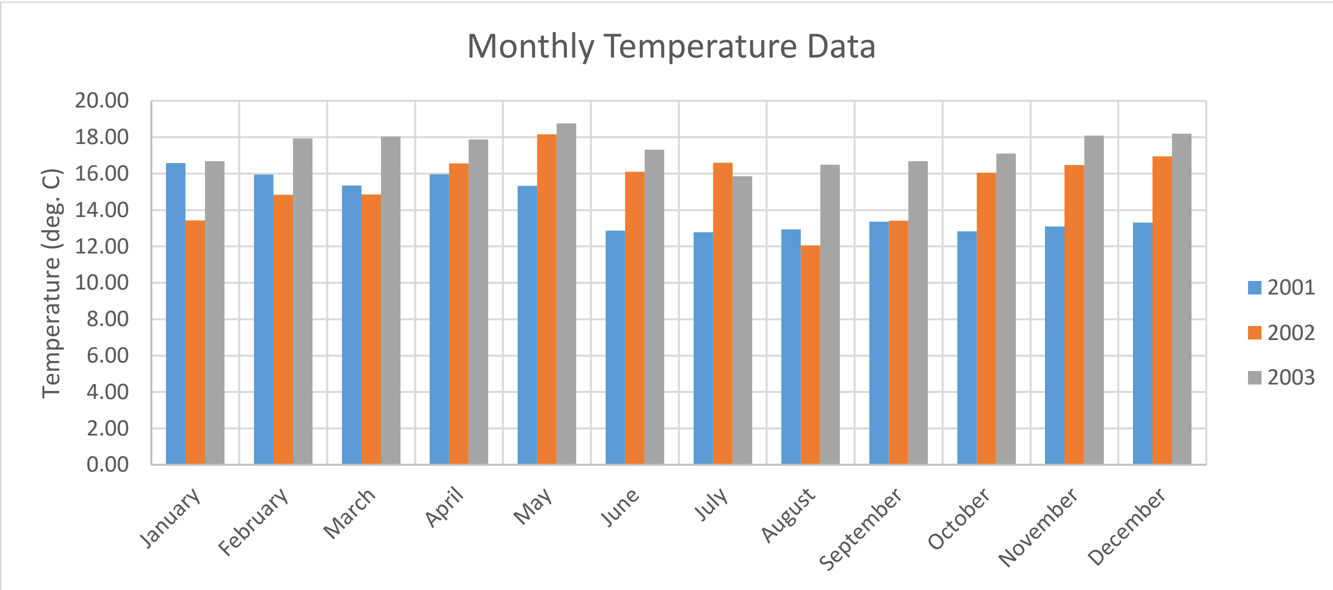


Figure 4.2-4 Mean monthly temprature data over the 18 years (1987-2004)

The temperature increment of 2003 from 2002 in percentage is as follows: - 19% in January, 17% in February, 18% in March, 7% in April, 3% in May, 7% in June, 27% in August, 20% in September, 6% in October, 9% in November, and 7% in December. Even though a 5% decrease of temperature in July 2003 from July 2002 was recorded, the 2003 temperature was still 19% higher than the year 2001.

The impact of the significant temperature increase in 2003 can clearly be seen in Figure 4.2-3 (e) and (f). These figures show that as the temperature increases, so does evapotranspiration. Resulting a loss of runoff downstream of the river. As it can be noted from the figures, in January, February, March, April, May, and June the runoff values were almost non-existent. This is because the precipitation values recorded during these months were relatively low and hence, the loss of water for these months due to evapotranspiration will be significantly higher than the months that had high rainfall. The relation between the temperature increase and decrease of runoff was also noted during the calibration of the data on WEAP.

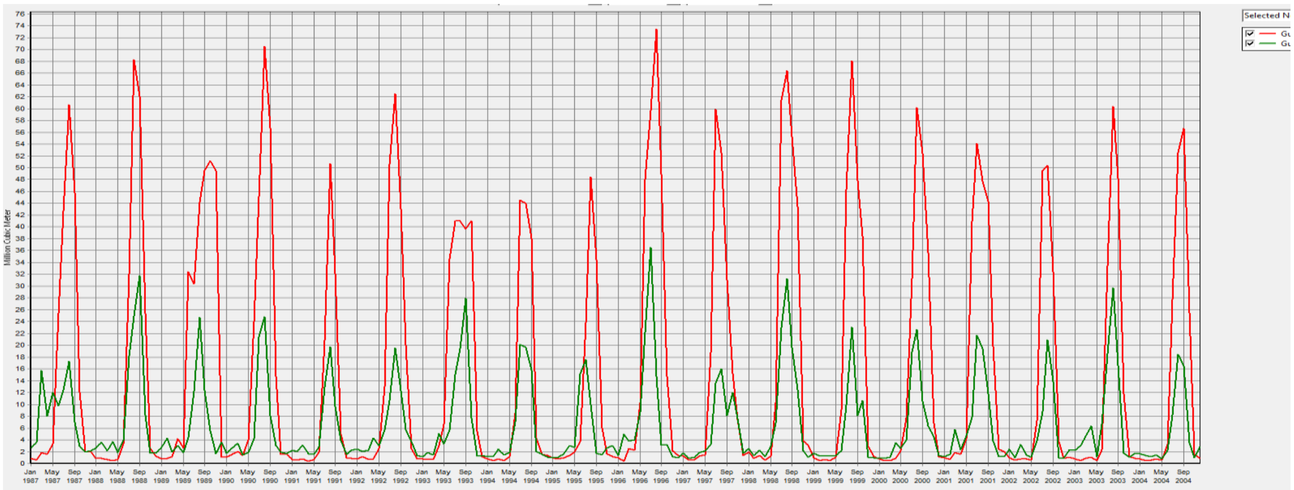


Figure 4.2-5 Simulated vs. observed monthly runoff data with humidity set at 10%

The simulated runoff data during the dry seasons better correspond with the observed data when the percentage of humidity is set low (which in this case humidity was set to 10%). Low humidity percentage means there is less water in the atmosphere; allowing for the air to have more capacity to hold water. This will result a higher rate of evaporation. A higher rate of evaporation has a much more significant impact on the discharge values during low precipitation seasons. It is for this specific reason that the simulated runoff was able to better match the lower discharge values of the observed data when humidity was set low, as demonstrated on Figure 4.2-5.

5 Trend Analysis

5.1 Methods

Projection of both temperature and precipitation on global scale mostly do not reflect the metrological characteristics at a regional level. Therefore, a detailed analysis of observed data at a regional level and projection of future temperature values based on regional scale analysis provides a more reliable result.

5.1.1 Mann-Kendall

Mann-Kendall test's non-parametric character was the main reason for the selection of this method to analyse the trend within the data. Unlike parametric data analysis approach, a method that requires for a normally distributed data set, Mann-Kendall test does not reckon any assumptions about the data distribution.

$$S = \sum_{i<j} a_{ij}$$

Eq. 5-1

Where:

$$a_{ij} = sign(x_j - x_i) = sign(R_j - R_i) = \begin{cases} 1 & x_i < x_j \\ 0 & x_i = x_j \\ -1 & x_i > x_j \end{cases}$$

x_i and x_j are the time series observations made and Ri and Rj are the ranks of the respective observations.

In order to determine the existence of trend, if any, the Mann-Kendall test was applied on the 18 years' (year 1987 -2004) observed temperature, precipitation, and 35 years' (year 1970-2004) runoff data.

5.1.2 Relative Standard Deviation

The spread of the amount of variability relative to the mean is presented by the Relative Standard Deviation (RSD) value. RSD is derived by taking the ratio of the standard deviation (σ) to the mean (μ). The strength of the trend characteristics determined in the Mann-Kendall test is tested by applying the RSD, which will help determine the confidence factor in the S value.

$$\frac{\sigma}{\mu} = RSD$$

Eq. 5-2

5.2 Determination of Trend

5.2.1 Precipitation

The Mann-Kendall Static (S) value provides the general character of the data by providing either a positive (generally increasing) or a negative number (generally decreasing). The level of confidence on the obtained S value is presented by the Confidence factor (CF). CF is directly associated with the significance level α. The significance level at which the CF was measured against was 5% and 10% for this study. Meaning, if the confidence value is greater than 90% and less than 95%, the status of the trend can be concluded as "presumably increasing or decreasing." Whereas, if CF is found to be greater than 95% it can be concluded that the provided data set is indeed either increasing or decreasing with high confidence.

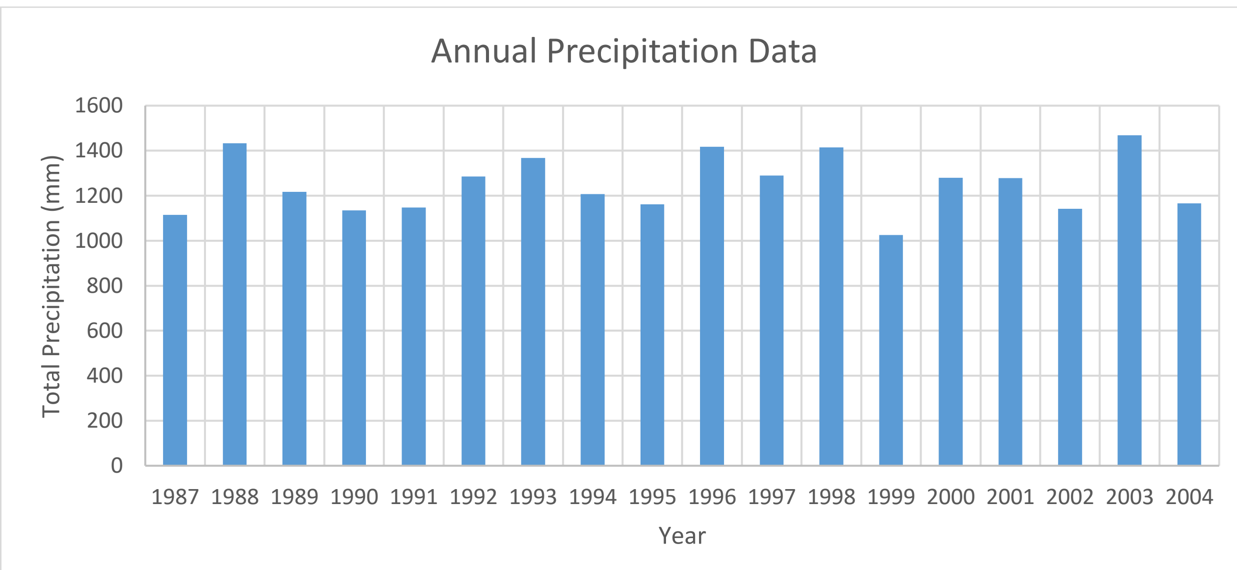


Figure 5.2-1 Annual precipitation data for the Bello catchment

Table 5-1 Summary of the trend analysis for the annual precipitation data

RSD	0.1
Mann-Kendall (S)	13
CF	67.30%
Trend	No Trend

No trend was detected in the annual precipitation data over the 18 years. As it has been indicated before, there are a number of missing daily rainfall data in some of the years. Hence, the determination of no trend based on the annual precipitation data is not to completely be trusted. The missing data are not expected to have an impact on both the maximum and minimum values. Great interest also resides in the behaviour of the extreme values in different seasons and over the years.

The peak precipitation values of each year were selected by considering the values that are greater than 60 mm per month within each year. 60 mm was found to be the minimum value of all the peak rainfall data over the 18 years and for that reason it was considered as the starting point for the observed maximum precipitation values.

Table 5-2 Maximum precipitation trend analysis within each month of the 18 years (1987-2004)

Month	**RSD**	**Mann-Kendall**	**CF**	**Trend**
January	0.58	-25	77%	Stable
February	0.29	-1	50%	Stable
March	0.46	-34	91%	Presumably Decreasing
April	0.34	-5	85%	Stable
May	0.38	-21	91%	Presumably Decreasing
June	0.39	-17	93%	Presumably Decreasing
July	0.24	-21	90%	Presumably Decreasing
August	0.43	-26	87%	Stable
September	0.39	-11	93%	Presumably Decreasing
October	0.34	-19	58%	Stable
November	0.18	-42	36%	Stable
December	0.39	17	73%	No Trend

The peak precipitation values that are greater than 60mm were mostly observed in the earlier years (from 1987-1996). During these years the peak precipitations were observed in the months of February, March, April, May, June, July, August, September, and October. Whereas for the years from 1997-2004, the precipitation values that are greater than 60mm were recorded only during the rainy season i.e. in the months of June, July, August, and September. It must be noted that even within these months, except in August, as Table 5-2 shows, the trend of the peak precipitation values is "presumably decreasing." The maximum rainfall values in the month of August over the 18 years was found to have a generally decreasing trend. Even though the trend was determined to be stable for the months of January, February, October and November, it is important to notice that, similar to the month of August, the Mann-Kendall Statistic value (S) was determined to have a negative number. Indicating a general decrement of peak precipitation values within these months. Especially in the month of August, the confidence factor (87%) is close to the 90% CF. The negative S values are an indication that generally speaking less and less of peak precipitation values were observed in all the months except in the month of December. With RSD of 0.39, S of 17, and CF of 73%, no trend was detected in the month December.

5.2.2 Temperature

Table 5-3 Maximum temperature trend analysis within each month of the 18 years (1987-2004)

Month	**RSD**	**Mann-Kendall**	**CF**	**Trend**
January	0.16	7	59%	No Trend
February	0.12	43	94%	Presumably Increasing
March	0.14	3	93%	Presumably Increasing
April	0.06	15	90%	Presumably Increasing
May	0.08	73	95%	Increasing
June	0.16	45	90%	Presumably Increasing
July	0.1	58	84%	No Trend
August	0.14	21	87%	No Trend
September	0.11	17	96%	Increasing
October	0.13	8	90%	Presumably Increasing
November	0.14	15	93%	Presumably Increasing
December	0.15	15	91%	Presumably Increasing

The most interesting aspect of the trend analysis was noted in the study of the temperature trend characteristics within the months over the years. As it was discussed and presented in Figure 4.2-4 relative to year 2001 and 2002, the temperature was noted to be increasing in year 2003. Table 5-3 shows the trend of the maximum temperature in each month over the 18 years. For this analysis, 16 ^{o}C was considered as the minimum peak temperature value. Therefore, the trend analysis was conducted for the values greater than 16 ^{o}C within each month over the years. Most of the peak temperature values were recorded in the year 2002, 2003, and 2004. In the year 2003, 11 months had temperature values greater than 16 ^{o}C. Whereas temperature values greater than 16 ^{o}C was recorded in the 10 months and 7 months of year 2004 and 2002 respectively. To put this in perspective, in 2001 only in the month of January was it possible to record a temperature that was greater than 16 ^{o}C (16.58 ^{o}C). The increment of temperature with each month over the years was better demonstrated by the Mann-Kendall test. According to the results obtained from this trend analysis test, it can be concluded that when the significant level α is 0.1, the temperature values are presumably increasing in the month of February, March, April, June, October, November, and December. Whereas in the months of May and September, the peak temperature values were found to be increasing with the confidence factor of 95% and 96% respectively. Table 5-3 also shows that no trend was detected in January, July, and August. However, in all the three months, the S value was found to be positive (7, 58, and 21 respectively); indicating a general increment of temperature. When the annual maximum temperature values trend analysis was conducted, it was determined that the RSD, S and CF values are 0.07, 26, and 83%. Since the S value is positive, it can be said that there is an increase of temperature over the years. However, the confidence factor for this observation is less than 90% and hence it can be concluded that there is no trend in the annual peak temperature values.

5.2.3 Runoff

As expected, the general decrement of peak precipitation and the increment of maximum temperature within the different months has resulted a general decreasing trend of the peak runoff values in the 9 months over the 34 years. Though, the status of the trend was determined as no trend for January, March, June, and November, the S value was negative with the confidence factor of 74%, 65%, 83%, and 86% respectively. The S values was also negative for February. But since the RSD value is less than 1 and the CF is less than 90%, the status of the maximum runoff trend was found to be stable. July, September, and December also had a negative S value with a CF of 91%, 90% and 90% respectively. Making the status of the trend presumably decreasing for these three months. It was in the month of August that a definitive runoff decreasing trend with S value of -20 and CF of 96% was found. No trend was detected in the rest of the three months, April, May, and October.

Table 5-4 Peak runoff trend analysis within each month of the 18 years (1987-2004)

	RSD	Mann-Kenall	CF	Trend
January	1.09	-40	74%	No Trend
February	0.55	-26	66%	Stable
March	1.03	-23	65%	No Trend
April	1.03	54	79%	No Trend
May	0.99	7	64%	No Trend
June	1.13	-64	83%	No Trend
July	0.25	-19	91%	Presumably Decreasing
August	0.36	-20	96%	Decreasing
September	0.91	-1	90%	Presumably Decreasing
October	0.5	11	57%	No Trend
November	1.13	-26	86%	No Trend
December	1.33	-12	90%	Presumable Decrasing

6 Climate Projection & Scenario Analysis

6.1 Overview of Climate Condition in Ethiopia

6.1.1 Temperature

Similar to the rainfall variability within the country, the temperature also differs from place to place and year to year. However, the temperature trend has been noted to be increasing across the country. A study conducted by NMSA also points out that the minimum temperature is increasing at a higher rate than the maximum temperature.

According to the report prepared by Climate-Resilient Green Economy Climate Resilience Strategy: Agriculture, Forestry and Land-Use Draft, the temperature of Ethiopia is expected to increase by more than 5^{o}C by 2080.

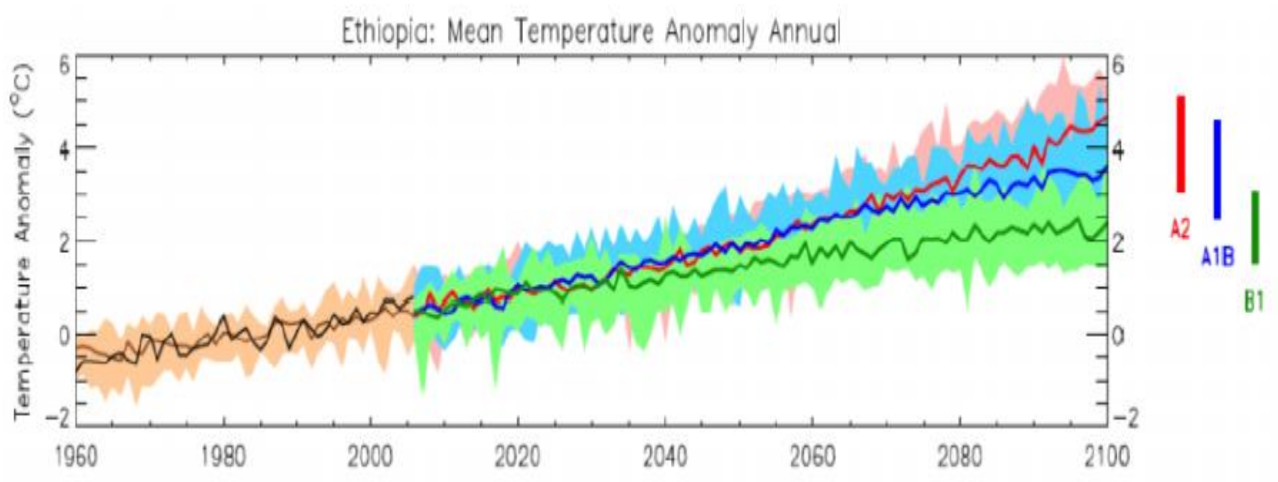


Figure 6.1-1 Mean temperature projection for Ethiopia till the end of the century (Adapted from FDRE, 2011, original source: C.McSweeney et al., 2011)

6.1.2 Precipitation

Provided that Ethiopia is a country with high spatial variability, the climate condition of the country also varies from region to region. For instance, it has been reported that the annual rainfall trend has been decreasing in the northern region of Ethiopia and the opposite is true for the southern part of the country (NMSA,2001). In fact, World Bank reports that in the future the southern region is expected to show increase of rainfall by 20% while the precipitation is expected to decrease in the north.

Though the report by Climate-Resilient Green Economy Climate Resilience Strategy: Agriculture, Forestry and Land-Use Draft was able to project the temperature of the country based on different emission scenarios and historical observed temperature data, it was not able to predict the trend of precipitation due to lack of historic data and Ethiopia's complex climate variability. Nonetheless, the report has gone on to present Figure 6.1-2 to indicate that at least based the data available and Global Climate Models, the precipitation trend of Ethiopia in the future is expected to stay somewhat stable.

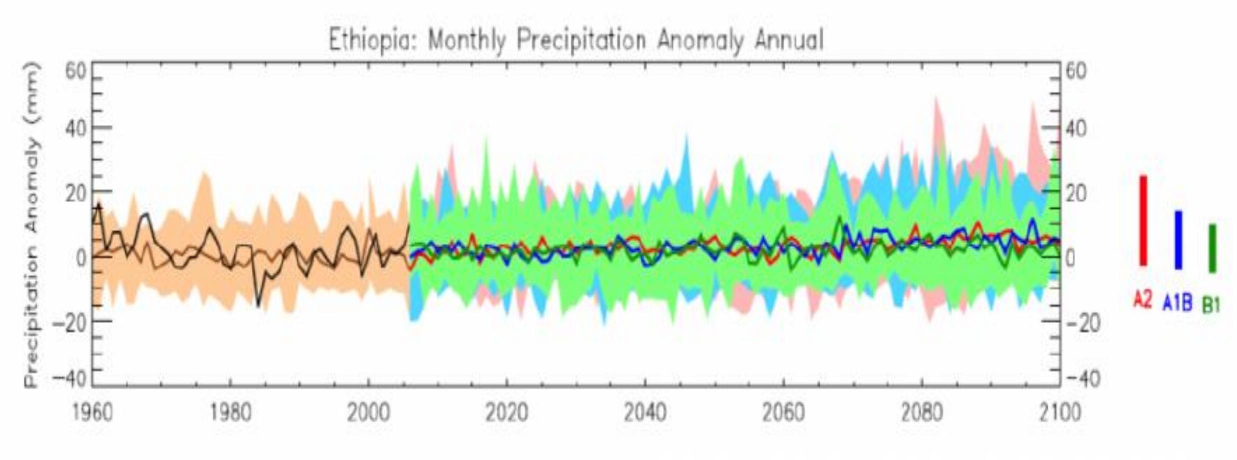


Figure 6.1-2 Precipitation projection for Ethiopia (Adapted from FDRE, 2011, original source: C.McSweeney et al., 2011)

It must be noted that the GCM method often fails to represent all the factors associated with a given climatic condition of a country, especially a country like Ethiopia that has a high rainfall variably, so the Figure 6.1-2 was further examined before direct application.

6.2 Climate Projection for Guder River Basin

6.2.1 Temperature

The main purpose of the trend analysis conducted in this study is to avoid the uncertainties that may occur during the downscaling of GCM into a regional model. From the trend analysis it was possible to determine that, similar to what was projected for the country's temperature scenario, the temperature has been increasing and it is expected to increase till the mid and end of the century in the Guder Basin as well.

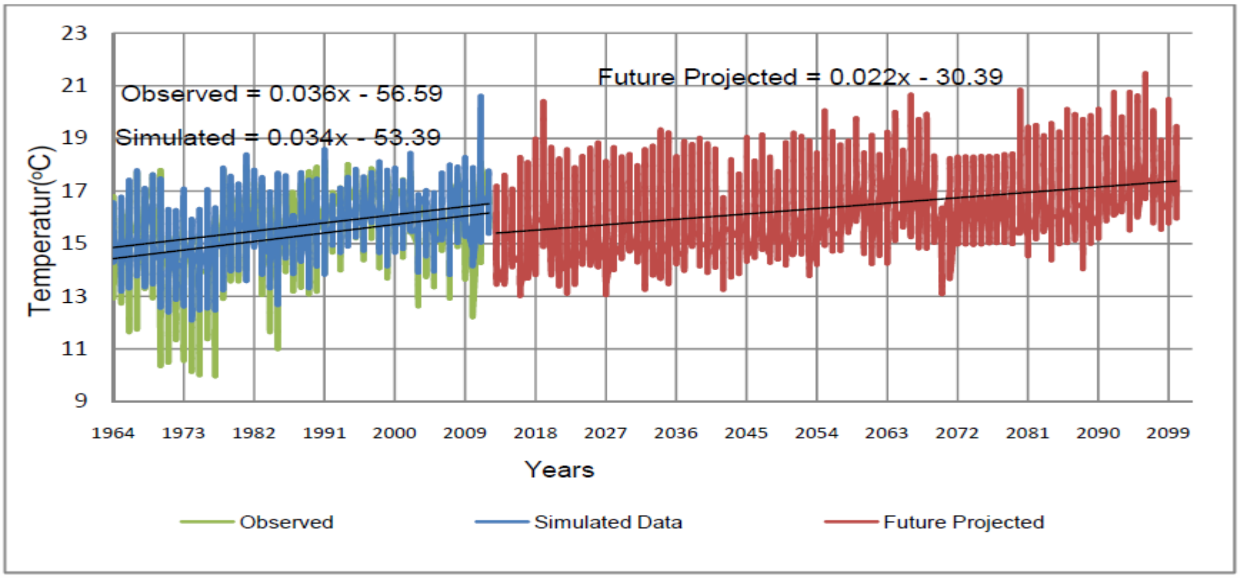


Figure 6.2-1 Mean temperature projection for Guder River Basin (Source: by Climate Change of Upper Guder MPP)

The correlation between the observed and the simulated temperature variables was found to be R^2=0.74. This R value was determined to be acceptable and the future projections were based on the simulated values. Based on the CUGR's report of future temperature projection, the temperature was increased by 0.27 °C, 0.56 °C, 1.25 °C, 2.91 °C, and 5 °C for the 2020s, 2040s, 2060s, 2080s, and 2090s respectively for this study.

6.2.2 *Evapotranspiration*

Projection for evapotranspiration was conducted by applying Thornthwaite's method.

$$16 * \left(10 * \frac{T_i}{I}\right)^a * \left(\frac{N}{12}\right) * \left(\frac{1}{30}\right) = ET_o$$

$$I = \sum_{i=1}^{12} (\frac{T_i}{5})^{1.514}$$

$$a = (492390 + 17920I - 771I^2 + 0.675I^3) * 10^{-6}$$

Where:

T_i is the mean monthly temperature [°C],

N is the mean monthly sunshine hour

The simplicity of Thornthwaite method by requiring only the temperature data, is the one of the main reasons why this method is often applied for the calculation of evapotranspiration.

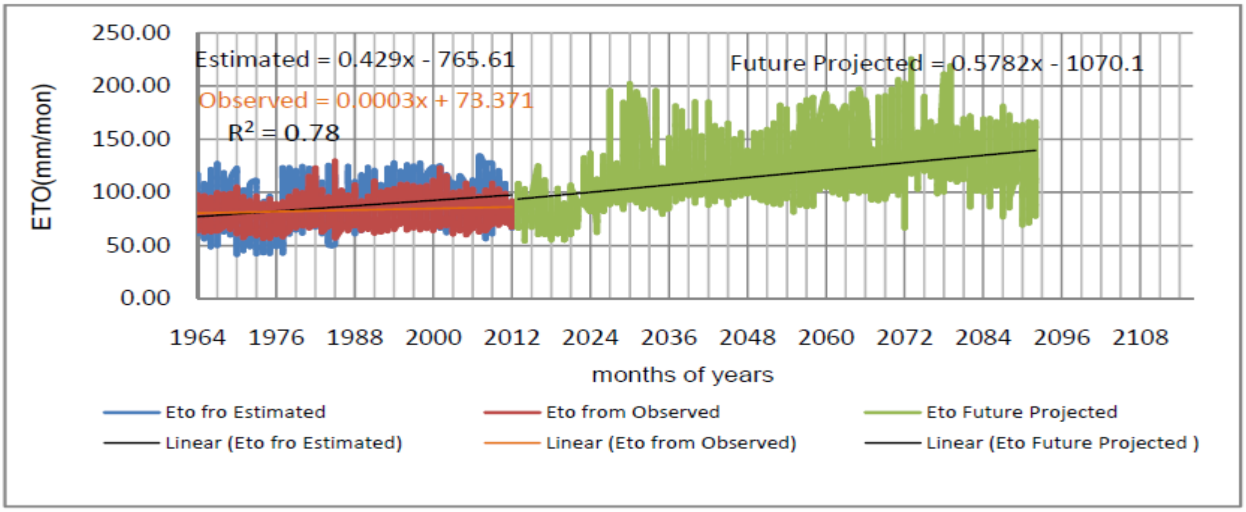


Figure 6.2-2 Evaporation Projection for Guder River Basin till the end of the Century (Source: by Climate Change of Upper Guder MPP)

However, it must be noted that Thornthwaite method is well known for its “underestimating” behavior for dry areas and “overestimating” behavior in humid areas (Alkaeed et al. 2006). Since, in order to better match the simulated data with the observed data, the humidity of the basin was set to relatively high value of 73, the evaporation values taken from CUGR were adjusted accordingly. In order to compensate for the overestimated values of evapotranspiration by CUGR, the data was reduced by 1.65% before it was fed into WEAP.

7 Model Tool Applied: Water Evaluation and Planning Tool WEAP

7.1 Introduction to the Model

WEAP model was developed by the primary support of Stockholm Environment Institute. The model's ability to perform calibration on single catchments or complex transboundary river systems, address different scenarios like population change, climate change, allocation priority, groundwater and streamflow simulations, and reservoir operation has made WEAP the most appropriate model to apply for this study.

The model requires clear definition of several steps before providing comprehensive results. Study definition, current accounts, and scenario construction are the three major steps that allow for WEAP to simulate. The spatial boundary, time steps, and baseline data is set up at the study definition stage of the model. Design of the problem occurs in the current accounts step. In this step the water demand and supply of the different systems is defined. The assumptions that may play a role during calibration are also set at this step of the model. The third step, scenario building is a stage at which different conditions are set to the problem presented in the study definition step. The impact of the different scenarios set in this system allows for the exploration and determination of optimal values. Based what was set in the three steps, scenarios are evaluated at the final stage of the model.

7.2 Model Scheme

WEAP's schematic view includes river, diversions, reservoir, groundwater, demand site, catchment, runoff or infiltration, return flow, run of river hydro, flow requirement, and streamflow gauge. In this case study two rivers, four diversions, three demand sites, one catchment, three different infiltration percentages, return flow from all the demand sites, one streamflow gauge, and the environmental flow in the flow requirement section were set up. Transmission links that are used to include man made water transmission methods such as canals and channels are included on each demand site.

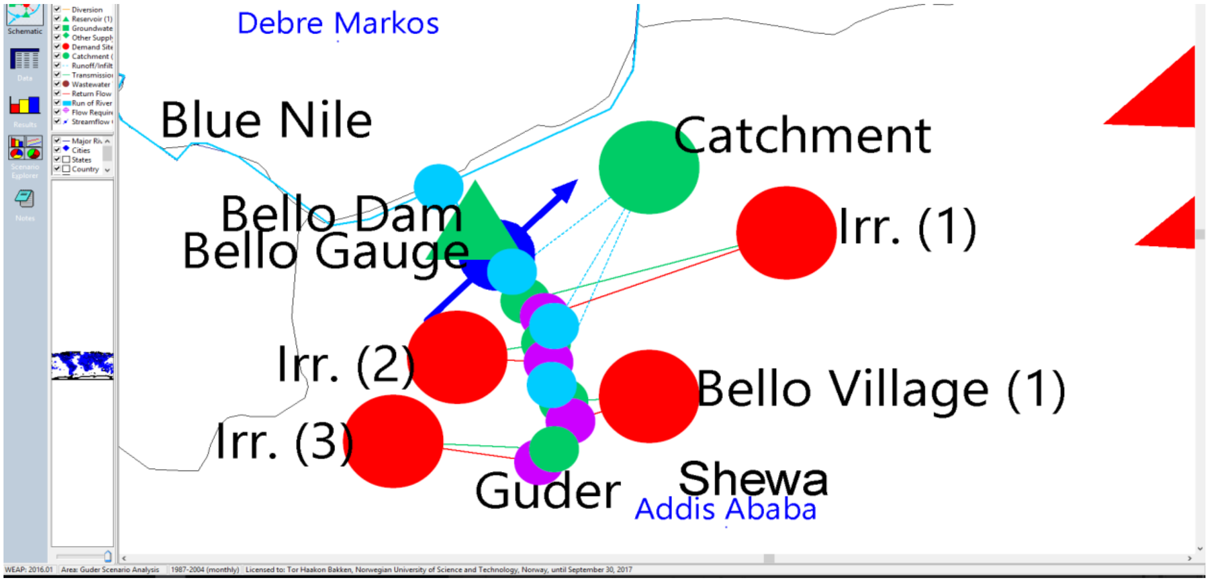


Figure 7.2-1 WEAP model scheme for Bello catchment

7.3 Catchment Simulation Method

WEAP has built in algorithms to calculate crop water requirements and yields, surface water and ground water interactions that were applied in this case study. Based on the level of complexity of the study and data availability, WEAP's rainfall runoff, irrigation demand – FAO crop requirement, soil moisture method, or the plant growth model approach can be applied. For this project, soil moisture method was applied.

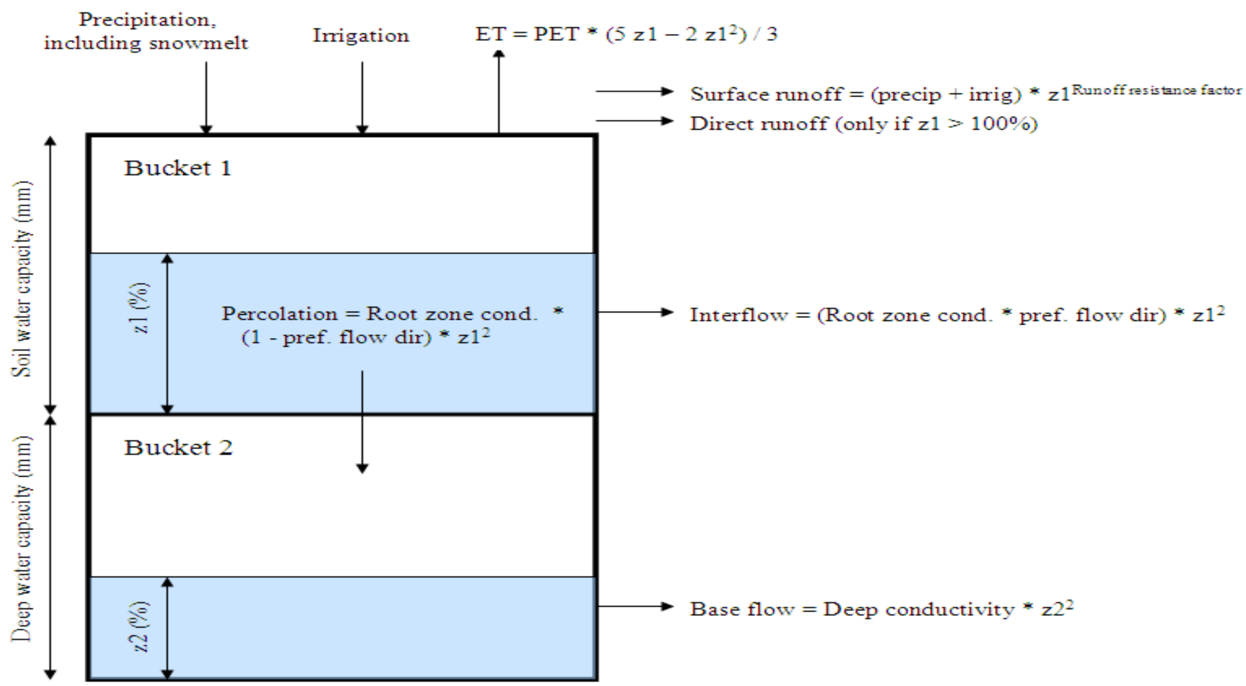


Figure 7.3-1 WEAP soil moisture method model

The soil moisture method was selected based on the relatively high complexity of the project site and data availability. This method has a one dimensional, 2 "bucket" soil moisture accounting scheme. These two schemes are made of evapotranspiration, surface runoff, sub-surface runoff. The land type and the soil characteristics, that have high impact on the infiltration capacity of the set up and hence affect groundwater and runoff water amounts, is included in the soil moisture method.

7.4 Priorities for water allocation

The demand proprieties set by the user is what determines the allocation order. The demand priority is associated to all the demand sites, catchment, reservoir filling or hydropower production, or flow requirement. The priority parameter that ranges from 1 to 99, 1 being the highest and 99 the lowest, is given to all the demand sites and reservoir based on the scenario analysis. WEAP considers 99 as the default value for reservoir to indicate that satisfying the demand is the model's first priority. To analyse the impact of allocation order on the availability of runoff, equal and different priority level was assigned to demand sites and hydropower in different scenarios. When the priority is equal in all the cases, then shortage of water is equally shared. Whereas, the different priority level set up is useful for water shortage management technique. The assigned allocation numbers represent the order in which WEAP carries its calculation in order to allocate water.

7.5 Monthly Demand and Supply

$$MonthlySupplyRequirement_{DS,m} = \frac{MonthlyDemand_{DS,m} * (1 - -ReuseRate_{DS}) * (1 - DSMSavings_{DS})}{(1 - LossRate_{DS})}$$

Eq. 7-1

There is a significant difference during wet and dry months in the Guder basin. Based on the monthly variation of water availability, the monthly demand does also differ from month to month. The monthly demand is the amount of water required by the demand site each month. But the demand requirement doesn’t directly correspond to the amount of water that can be taken from the supply. That is determined by the supply requirement. The supply requirement adjusts the demand to accommodate internal reuse, demand side management strategies for reducing demand and internal losses. This adjustment is represented in Equation 7-1.

8 Scenario Analysis: Impact of Climate Change on Runoff

8.1 Temperature Decrease

Based on the temperature projection for Guder Basin, simulation of future scenarios for 2020s, 2040s, 2060s, 2080s, and 2090s was conducted. Figure 8.1-1 represents the result of this simulation. While Figure 8.1-2 is a presentation of by what percentage the runoff at the downstream point has decreased due to temperature rise relative to the historical data. Since different literatures have different values for precipitation projection, the first simulation was conducted by assuming the precipitation values will be stable till the end of the century.

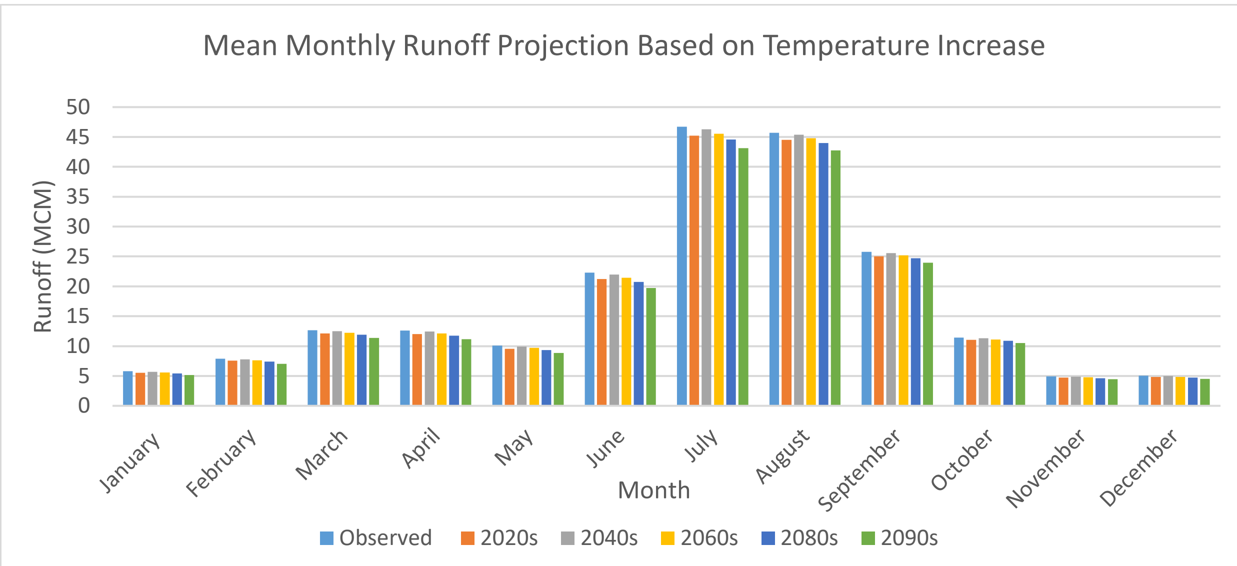


Figure 8.1-1 Mean monthly runoff projection based on temperature increase at Bello catchment

When the temperature was projected to increase by 0.27 °C in the 2020s, the runoff values decreased by 1% throughout the 12 months, relative to the current runoff data. Of course, as the temperature increased in different decades, it's effect on the amount of runoff available downstream was also gradually increasing. In the 2040s, when the temperature was raised by 0.56 °C from the current temperature data, the runoff values decreased by 2-4%. Whereas in the 2060s and 2080s the runoff decrease percentage was 3-5% and 4-7% when the temperature was raised 1.25°C and 2.91°C respectively. As expected the largest runoff percentage decrease was noted at the end of the century. When the temperature is projected to increase by 5°C, 7-12% of decrease in discharge was found. As Figure 8.1-2 shows, 7-12% is a loss of approximately 1.2 to 1.8 million cubic meter water from the river. The highest decrease in all the decades was noted in the months of January, April, May, and June. The second highest runoff losses were found to be in the months of February, March, October, and December. Provided that these are the dry months of a given year, this finding is not surprizing.

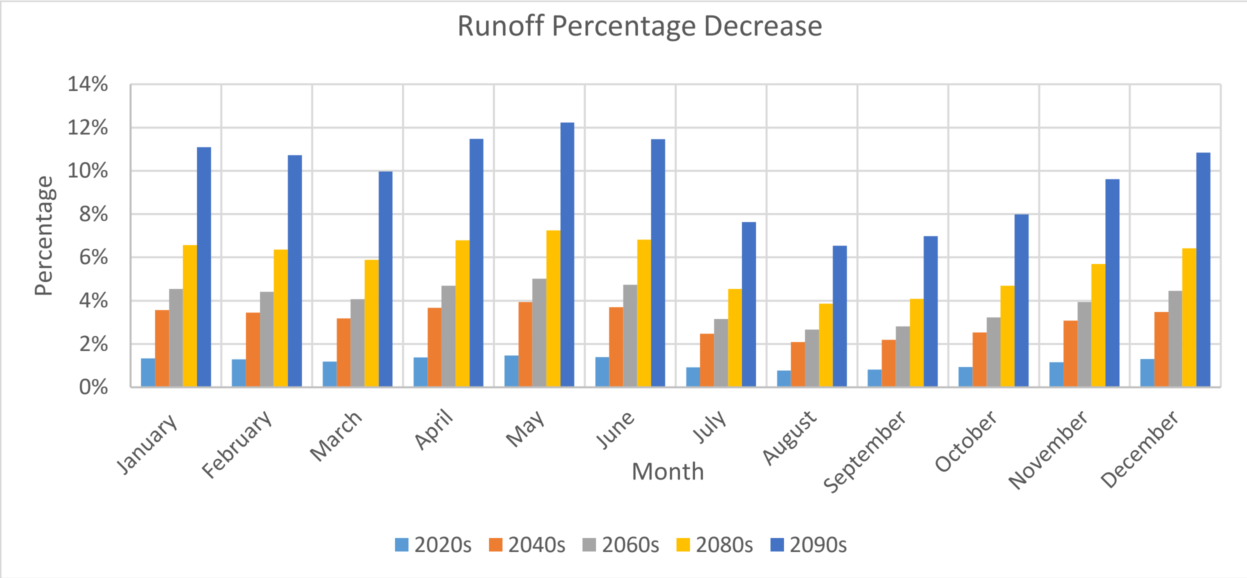


Figure 8.1-2 Monthly runoff percentage decrease projection based on temperature increase

8.2 Temperature Increase and Precipitation Decrease

The second simulated future scenario is based on the projection of temperature increase and precipitation decrease for the 2020s, 2040s, 2060s, 2080s, and 2090s. The temperature increase projection for each decade was kept similar to the first scenario analysis. Whereas the precipitation decrease projection was 3% in the 2020s, 5% in the 2040s, 7% in the 2060s, 9% in the 2080s, and 11% at the end of the century.

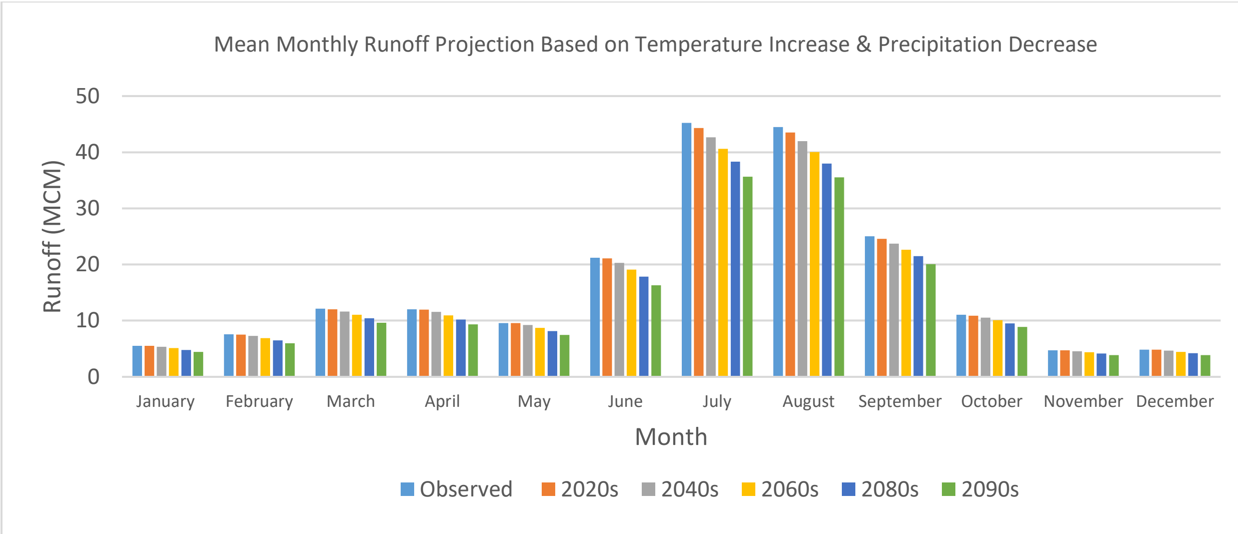


Figure 8.2-1 Mean monthly runoff projection based on temperature increase and precipitation decrease at bello catchment

The runoff decrease percentage in the 2020s and 2040s were in somewhat of a similar range to what was observed during the only temperature increase future scenario analysis. As it can be seen from Figure 8.2-2 the percentage decrease in the 2020s was 1-2% and in the 2040s it was 3-6%. The substantial runoff decrease percentage was found to be after the mid-century. For instance, in the 2060s and 2080s, 8-10% and 13-16% of runoff decrease was determined respectively. In the 2090s, the runoff decrease percentage was from 19-22%. The 2090s represent the worst case scenario of an 11% precipitation decrease. The loss of an 8-10%, 13-16% and 19-22% of runoff represents 0.4-2 MCM, 0.6-3.3 MCM, 2.2-4.9 MCM of runoff respectively. To put this in perspective, the amount of water that would have been lost in the in the 2090s by considering only the temperature increase without the precipitation decrease, is lost in the 2060s (40-50 years early) in this scenario. The other interesting observation from this analysis is the months at which the highest and lowest percentage decrease was determined. The precipitation decrease projection has affected the wet months more than the dry months. Especially, after the mid-century, in the 2060s, 2080s, and 2090s, the highest runoff decrease percentage was noted in June, July, and August. This is due to the significant decrease on the precipitation values. As the precipitation decreases along with the temperature increase, months that have more water will be able to experience the impact more than the dry months that have little to no water to begin with. But this is only true when the precipitation decrease values are significantly high.

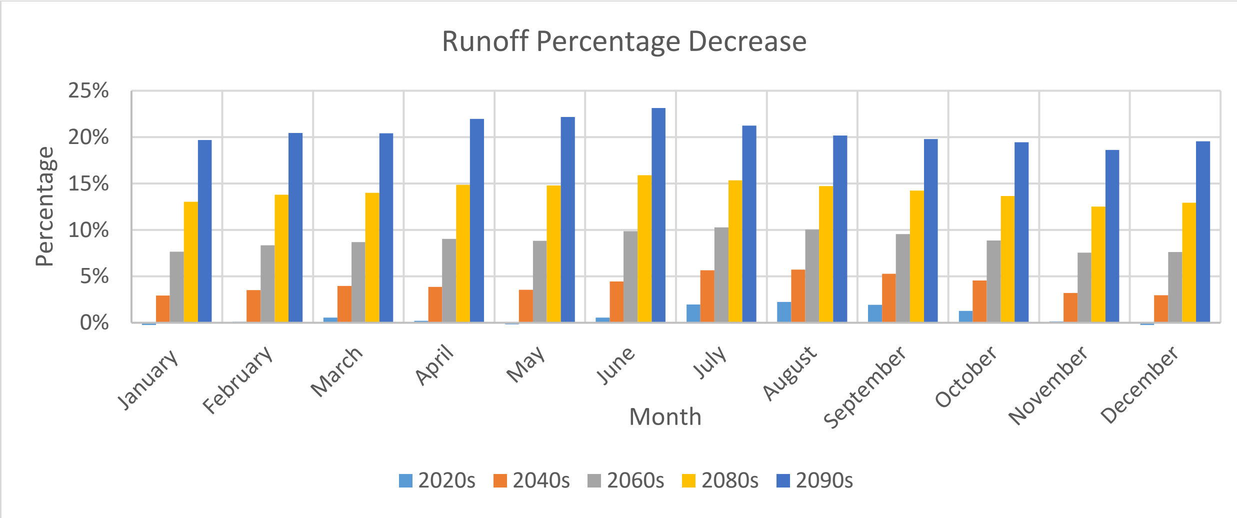


Figure 8.2-2 Monthly runoff percentage decrease at Bello catchment

8.3 Future Scenario Analysis with Reservoir

The two main purposes of the future scenario analysis with reservoir is:

(i) to determine the impact of evaporation from the reservoir on the flow amount
(ii) to study the usage of the reservoir as a multipurpose reservoir (hydropower, irrigation, and water supply).

8.3.1 Modeling Reservoir Operation

Flood control zone, conservation zone, buffer zone, and dead pool or inactive zone are the four sections WEAP reservoir storage is divided into. The inactive zone, as the name indicates, is the section in which water is not utilized from for downstream purpose. The buffer and the conservation zones, on the other hand, are sections of the reservoir that water is taken out from for different purposes. WEAP refers to these two sections as "active." The maximum water level within the reservoir that is allowed by WEAP is the top of the conservation zone. Based on the requirements set downstream of the reservoir, WEAP allows for water to be released from the conservation zone of the reservoir without restrictions. If the water level is in the buffer zone, then WEAP applies a buffer coefficient (that have a value between 0 and 1) to regulate the amount of water that must be released from the reservoir. The buffer coefficient is used to determine the fraction of water that can be released from the buffer zone. WEAP's water release technique can be presented in equation as follows.

$$S_C + S_f + (b_c * S_b) = S_r$$

Eq. 8-1

Where: -

S_C is the amount of water in the conservation zone

S_f is the amount of water in the flood zone

S_b is the amount of water in the buffer zone

b_c is the buffer coefficient

S_r is the release of the water from the reservoir

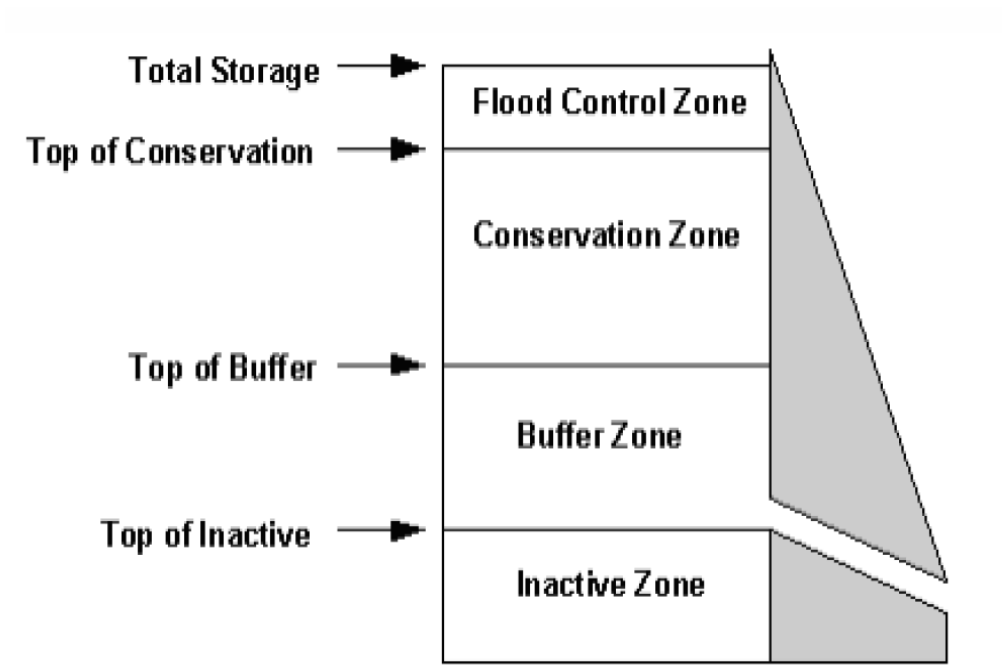


Figure 8.3-1 WEAP reservoir storage model

8.3.2 Reservoir simulation inputs

The planned reservoir has 2446msal as the maximum topographic value and 2420msal as the minimum value. Based on the geographic capacity, the reservoir has a storage space up to 282.2 MCM. Figure 8.3-2 shows the elevation curve of the reservoir.

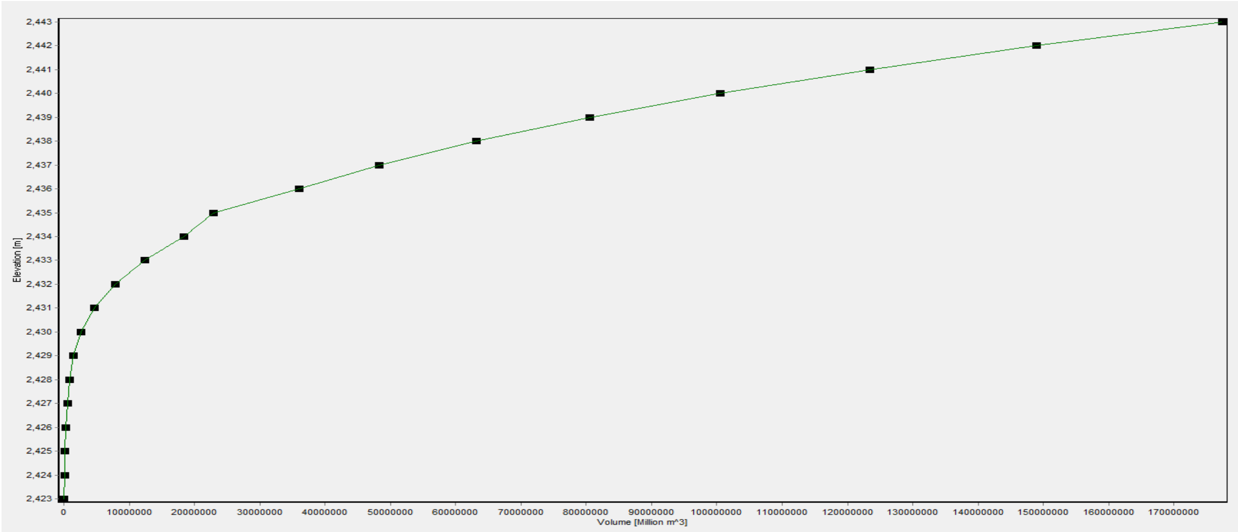


Figure 8.3-2 Volume elevation curve for the hydropower production in Bello catchment

The discharge values were obtained from the station located the same as the dam site for 49 years (1960-2009). The water release was set in such a way that guaranteed optimum power production throughout the year.

The net evaporation loss from the reservoir was calculated by applying Meyer's formula.

Meyer's formula: -

$$E = C * (e_w - e_a) * K$$
$$K = 1 + 0.1 * K$$

Eq. 8-2

Where:

E= evaporation rate, in 30-day month

C= empirical coefficient

e_w=saturation vapor pressure, in (mm), of mercury

e_a=actual vapor pressure, in (mm), of mercury, in air

w=monthly mean wind velocity, mi/h (km/h),

K =wind factor

Based on this calculation the new evaporation values were determined as follows: -

Table 8-1 Calculated potential net evaporation from planned reservoir at Bello catchment

Months	Average temperature(°C)	Es	Ea	Net Evaporation from reservoir(mm/month)
January	14.3	19.9	12.4	85.9
February	15.2	20.5	13.4	75.1
March	16.3	20.8	13.9	36.3
April	16.3	21.1	14.2	22.7
May	16.2	20.6	14.7	8.2
June	15.8	18.3	13.9	-100.8
July	15.4	17.1	14.3	-261.7
August	15.1	16.8	14.5	-226
September	14.7	17.8	14.3	-90.6
October	13.8	19.1	13.4	35.6
November	13.4	19.4	12.7	73.7
December	13.4	19.4	12.5	82.9

The negative net evaporation values indicate that June, July, August, and September are the wet months in which water is added to the reservoir. Hence, negative evaporation indicates an increase in water.

After daily simulation of the Bello dam, The Minimum Operating Level (MOL), the Dead Storage Level (DSL), and the Minimum Bed Level (MBL) was determined to be 2428.9m, 2428.43m, and 2420.0m respectively.

8.3.3 Net Evaporation Projection

The net evaporation projection is a complex subject that has a number of uncertainties due to the uncertainties associated with both temperature and precipitation projection. The future simulation scenario was conducted by considering the minimum and maximum net evaporation projection. The projection for the maximum net evaporation values in the 2020s, 2040s, 2060s, 2080s, and 2090s as the temperature increased and precipitation decreased was set to increase by 7.4mm, 14.82mm, 38.24mm, 71.7mm, and 119.5mm per month respectively. Whereas the minimum net evaporation was set to 2.4mm, 3.7mm, 6.3mm, 17.9mm, and 56.4mm per month in 2020s, 2040s, 2060s, 2080s, and 2090s respectively.

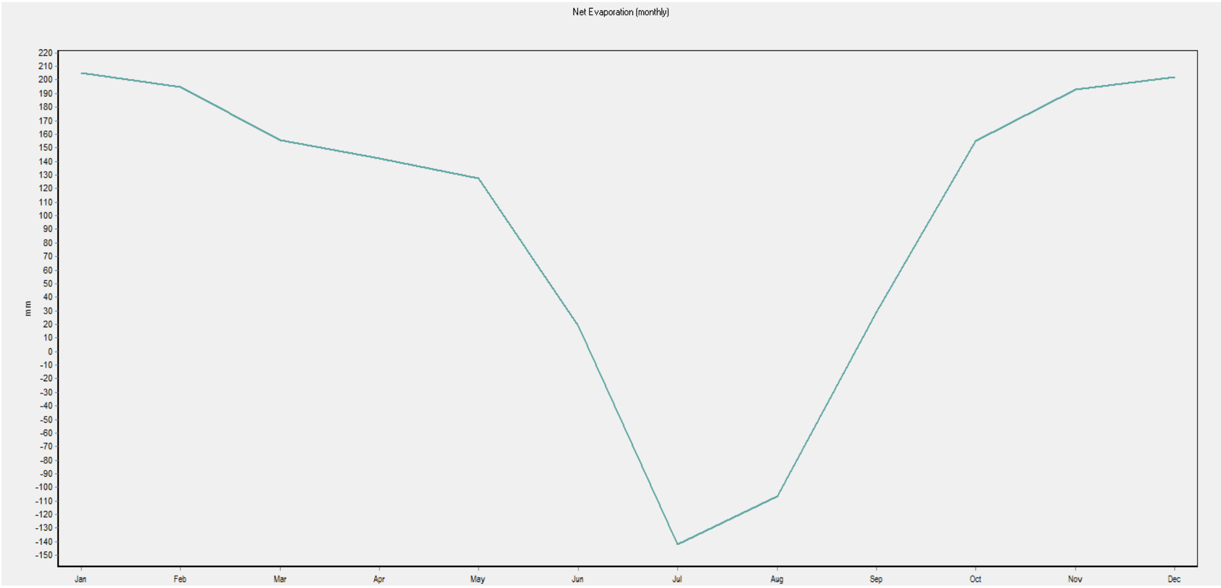


Figure 8.3-3 Monthly estimated net evaporation from the planned reservoir at Bello catchment

8.3.3.1 Minimum Net Evaporation

Figure 8.3-4 shows the flow values when reservoir is present and the projected net evaporation values are set to minimum. Whereas Figure 8.3-5 shows the flow percentage decrease in different decades from the current flow if there was reservoir placed today. It must be noted that in this case scenario analysis, the buffer coefficient was set to 1. Which means, despite the precipitation decrease, the release of water from the reservoir is not restricted. Consequently, the flow was expected to decrease substantially.

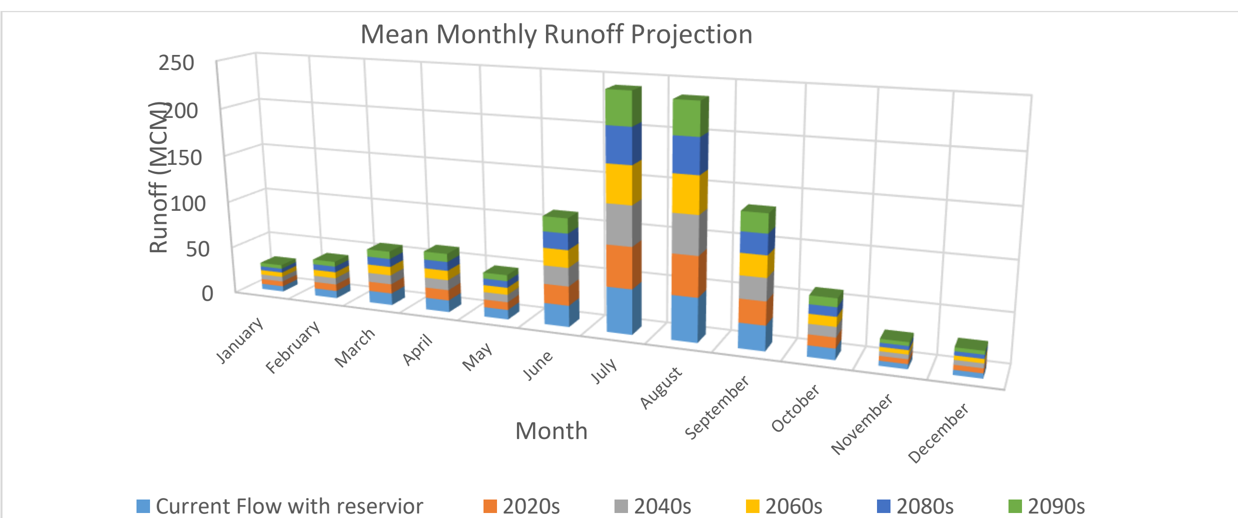


Figure 8.3-4 Mean monthly runoff projection based on projected minimum net evaporation from planned reservoir

As expected, the runoff percentage decrease at the presence of reservoir was significantly higher than without the introduction of the reservoir to the system. Even if the net evaporation is set to the minimum, the loss of water due to evaporation is quite noticeable. For instance, in the 2020s, 2040s, 2060s, 2080s, and by the end of the century, the runoff is projected to decrease by 4-18%, 7-22%, 14-25%, 18-30%, and 24-34% respectively as shown in the figure below.

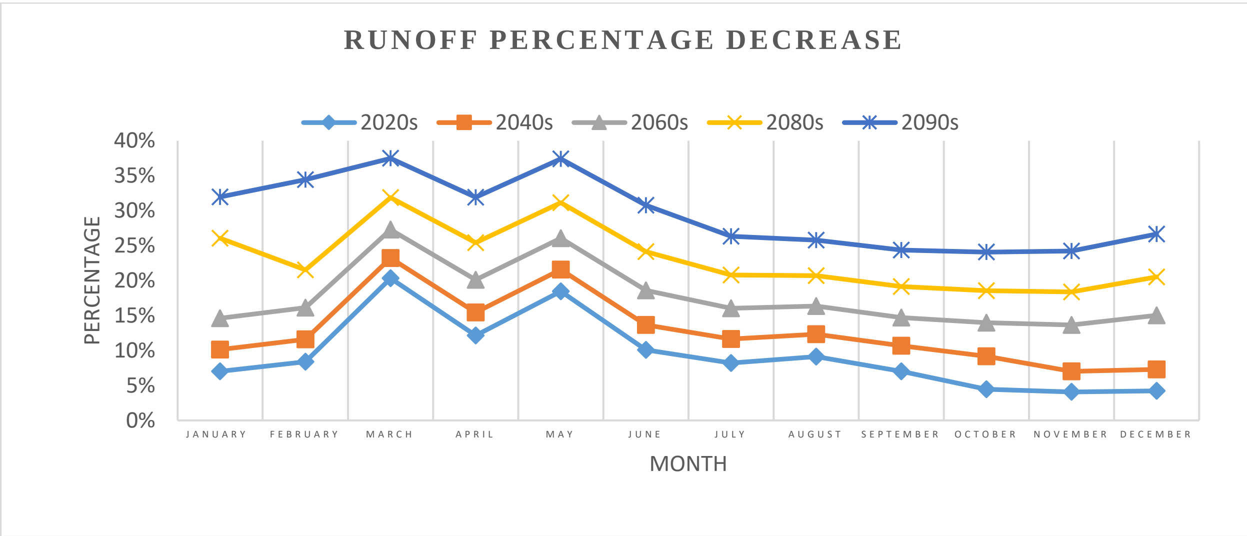


Figure 8.3-5 Runoff percentage decrease based on the estimated minimum net evaporation from planned reservoir

8.3.3.2 Maximum Net Evaporation

When the net evaporation was set to the worst case scenario (maximum evaporation), the flow was significantly affected in January, February, March, November, and December. Of course, though the impact on the wet months was relatively lower than the dry months, the percentage of flow decrease in the May, June, July, August, September, and October are also quite noticeable.

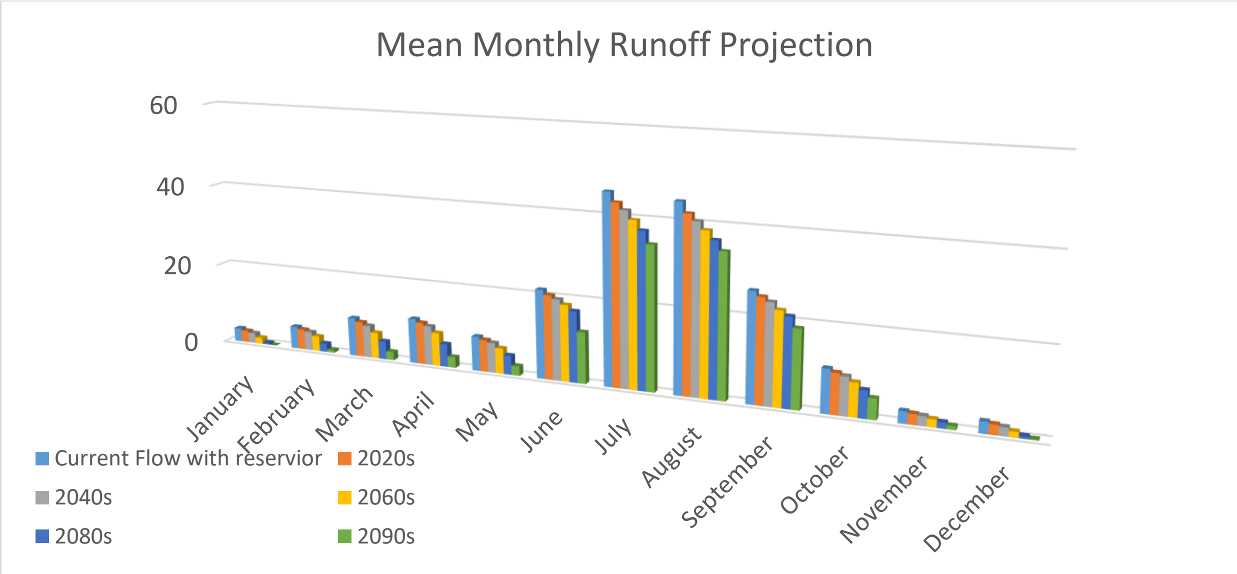


Figure 8.3-6 Mean monthly runoff projection based on maximum net evaporation from the planned reservoir

This impact was highly noted after the mid-century, where the maximum net evaporation scenario was 38.24mm, 71.7mm, and 119.5mm per month for the 2060s, 2080s, and 2090s respectively. Though the runoff decrease percentage is quite high in the 2060s and 2080s, the reduction is not as drastic as it was in the 2090s. It can be seen from Figure 8.3-6 that by the end of the century, if evaporation from the reservoir is increased by 119.5mm per month, with an increase of temperature by 5°C, decrease of precipitation by 11%, and buffer coefficient of 1 for the reservoir, it can be concluded that the flow will decrease by 100% in the month of January, 93% in December, 88% in February, 79% in March, 76% in April, and 73% in May.

These two scenario analyses, level of impact on flow under minimum and maximum net evaporation scenario, clearly demonstrate the importance of accurate evaporation projection. As Figure 8.3-5 and Figure 8.3-6 show, flow loss percentage gap between probable minimum and maximum net evaporation is notable. For instance, the streamflow decrease that was projected for the 2090s under the minimum net evaporation scenario was observed in the 2060s under the maximum net evaporation scenario analysis.

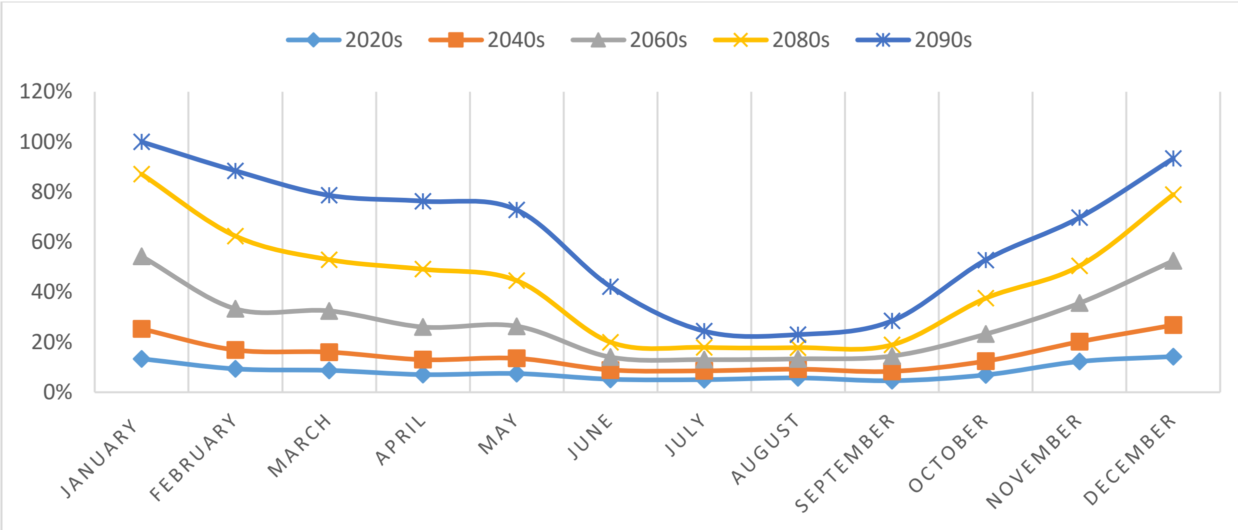


Figure 8.3-7 Flow percentage decrease based on the estimated maximum net evaporation from the planned reservoir

On the other hand, the flow percentage decrease in the 2020s and 2040s under both scenarios is in the similar ranges. For the 2020s the projected flow decrease is in the range of 4-17% and 5-18% under the minimum and maximum evaporation scenarios respectively. And for the 2040s the projected flow decrease is 7-23% under the minimum evaporation scenario and 8-27% under the maximum evaporation scenario. This indicates that if the projection for evaporation is not reliable, the significant impact it will have on the flow will only be noted after decades have passed.

9 Irrigation and Water Supply

Unless data is provided about the demand for irrigation within the description of the catchment, WEAP assumes there is no irrigation in the system. Since the demand for irrigation is little to none at the current state of the catchment, the scenario analysis so far did not include the impact of irrigation on runoff. Even when the data for irrigation is included in the scheme, irrigation runoff is not included in the total runoff value at first. WEAP first conducts calibration by assuming there is no demand for irrigation. Once that is determined, the model preforms calculation by comprising irrigation runoff. Based on the irrigation runoff, that is dependent on the supply requirement, the average irrigation runoff fraction that goes to the river is determined.

9.1 Rainfall Dependability

Different literatures have pointed out that usage of dependable level of rainfall provides a more reliable result than the usage of mean monthly rainfall values. (Haque, 2004) (Doorenbos and Pruitt (1977). Dependable rainfall (number of years that have expected rainfall occurrences out of a total number of years) for irrigation systems capacity is often 75%-80% (Weerasinghe, 2015).

Meaning, out of 10 years the expected rainfall is for 7.5 – 8 years. The dependable rainfall value was determined based on the Dependable Precipitation Index (DPI). Once the DPI for precipitation measuring station of Inchi and Guder was found, the average of the two stations' dependable rainfall was considered for this thesis.

$$DPI = 0.8 * \sqrt[n]{P_1 * P_2 * P_3 * \dots \dots . . * P_n}$$

Eq. 9-1

Where: -

P is the given years' rainfall value

n is number of annual rainfall observations

0.8 is constant coefficient.

The observed precipitation value can be classified as normal rainfall (NR), dry-year threshold (D) and wet-year threshold (W).

Where: -

$NR = DPI \leq P \leq GM$

D = P < DPI

W = P > GM (GM is mean of rainfall values observed during the study period)

Table 9-1 (1976-2012) each year's rainfall condition based on observed data from Inchi Station

Year	Condition	Year	Condition
1976	W	1994	W
1977	W	1995	NR
1978	NR	1996	W
1979	D	1997	W
1980	W	1998	W
1981	W	1999	NR
1982	W	2000	NR
1983	W	2001	NR
1984	D	2002	NR
1985	D	2003	NR
1986	NR	2004	NR
1987	NR	2005	NR
1988	W	2006	NR
1989	W	2007	W
1990	NR	2008	W
1991	NR	2009	NR
1992	W	2010	W
1993	W	2011	W
1994	W	2012	D

Table 9-2 (1976-2012) each year's rainfall condition based on observed data from Guder Station

Year	Condition	Year	Condition
1976	D	1995	W
1977	D	1996	W
1978	D	1997	W
1979	D	1998	D
1980	NR	1999	NR
1981	NR	2000	W
1982	NR	2001	W
1983	NR	2002	NR
1984	D	2003	NR
1985	NR	2004	W
1986	NR	2005	W
1987	NR	2006	W
1988	NR	2007	NR
1989	NR	2008	NR
1990	W	2009	D
1991	W	2010	NR
1992	W	2011	NR
1993	W	2012	W

The dependable rainfall was found to be 89% and 81% for the Inchi and Guder station respectively. Therefore, 85% was considered as the dependable rainfall value for the irrigation scenario analysis.

9.2 Irrigation Integrated Scenario Analysis

Downstream flow with vs. without change in irrigation

Currently the water consumption for irrigation in the Guder sub-basin is estimated to be 55-60% in the rainy season. The irrigation sites are located far upstream the river. 85% of rainfall dependability was considered for all the irrigation analyses. The first irrigation related scenario analysis involved comparison of the projected downstream flow without changing the current consumption of irrigation against the consumption increase by 6% in the 2020s and then again another 6% in the 2040s at the same location.

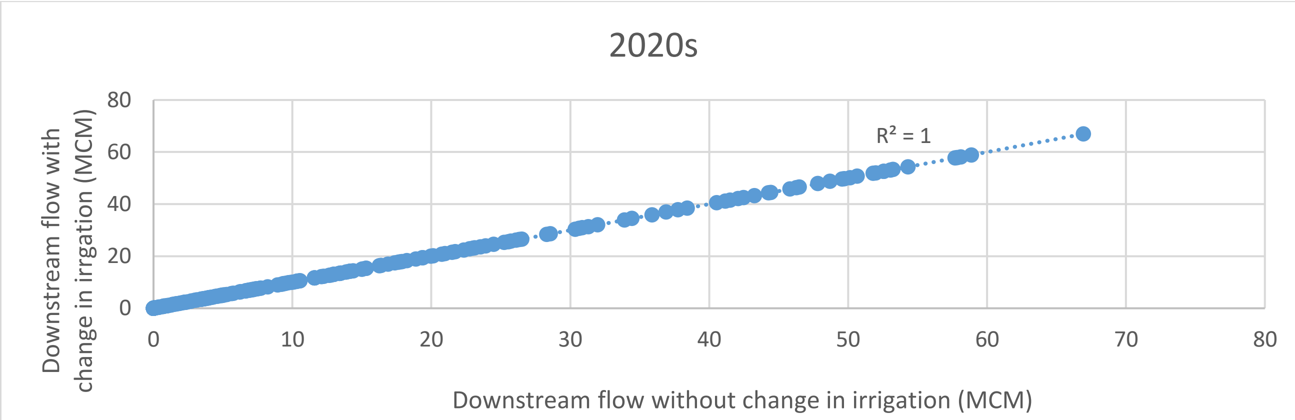


Figure 9.2-1 Downstream flow with vs. without change in irrigation in 2020s

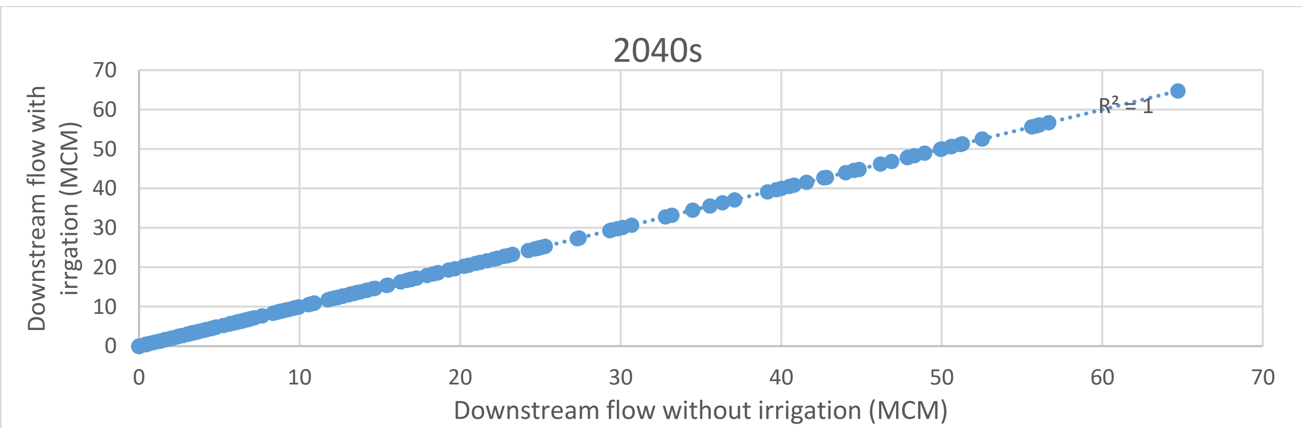


Figure 9.2-2 Downstream flow with vs. without change in irrigation in 2040s

The current state of water consumption for irrigation purpose upstream of the reservoir did not significantly affect the level of flow downstream. This was found to be true for the years in the 2020s, 2040s and 2060s as well, where the consumption of water was increased by 6% every 20 years. This can be explained by the location of the irrigation fields. The fields are located, far upstream of the reservoir and hence have a limited impact on the flow downstream. Since the production of energy was set as a priority level 1, the WEAP model allocates water accordingly. Meaning, the model restricts the amount of water that can be taken out from the river to ensure energy production to the best of its ability. The expected increase in water consumption for irrigation purpose is notably lower than water lost due to the net evaporation from the reservoir.

Therefore, it is not surprising to discover that 6% water consumption increase every 20 years from the river does not make a significant difference.

However, it is must to emphasize that the irrigation that was considered in this particular analysis is a small-scale irrigation. If indeed the irrigation size increases to a large scale, where the fields come close to the reservoir area, demanding consequential amount of water from the river, with a high priority level, then the level of the flow is expected to decrease and the percentage of unmet demand will increase at a faster rate.

Location of Irrigation Field and Village Sites Dependent Scenario Analyses

Scenario #1 (Irr (1)- Bello Village- Irr (2)).

The scenarios in which the location of the village and irrigation sites change, while keeping the demand and consumption percentage the same over the years, has been analysed to study the impact of location on the flow and unmet demand.

The first scenario set up includes two irrigation fields with an area of $22km^2$ and $40km^2$ and Bello village with $20km^2$. The first irrigation site is located near to the dam site (Irr 1). Whereas, Bello village and the second irrigation site (Irr 2) are located far upstream of the dam site, as shown in Figure 9.2-3. The priority level for all the cases was set to 1 and the monthly share of annual demand for Bello village and the second irrigation was set at 8.3% while the monthly demand variation for irrigation site 1 is set as shown in Figure 9.2-3 (b) . The consumption was set at 30% for irrigation site 1, 10% for irrigation site 2, and 20% for the Bello village.

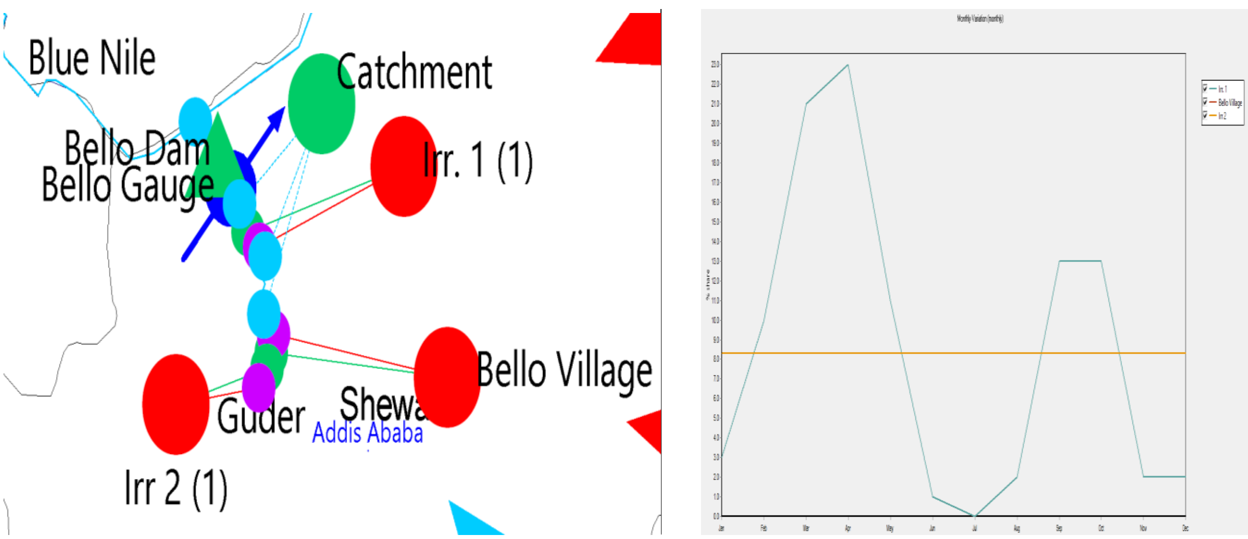


Figure 9.2-3 (a) Scenario #1 (Irr (1)- Bello Village- Irr (2)) WEAP scheme (b) Irr (1) monthly demand

The annual water use rate is one of the most significant factors the model is sensitive to; and the value of it is highly variable from crop types to crop types. As farming technologies and irrigation techniques continue to change, both efficiency and amount of water consumption is expected to optimize. For this case study the irrigation sites' annual water use rate was estimated based on the water need for crops like potatoes and onions (where the water consumption is 3.5-4.5 mega-litres per hector annually).

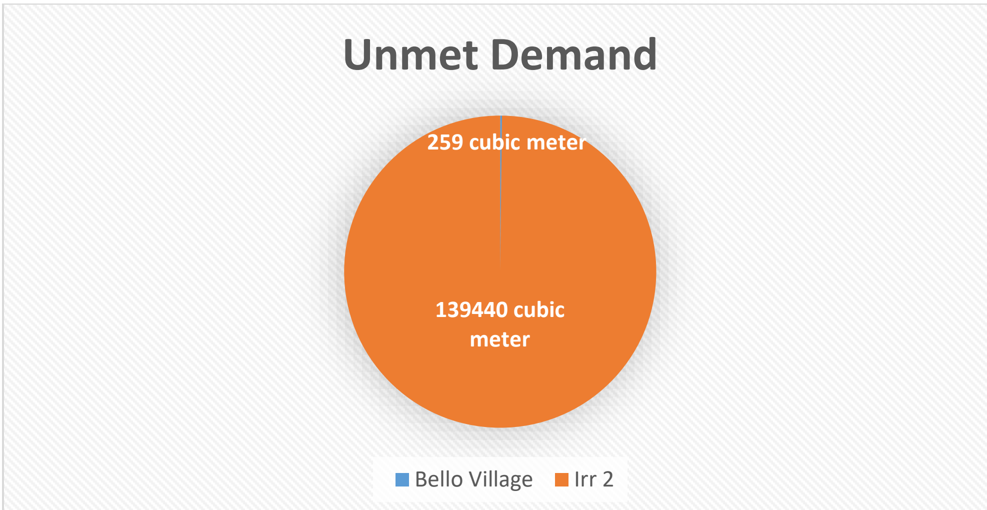


Figure 9.2-4 Unmet demand under scenario #1

When the evaporation was set to minimum, the average downstream flow was 18% higher than when the net evaporation was set to the maximum under scenario #1. Whereas the unmet demand for irr 1, irr 2, and Bello village was found to be 0, 139,699 cubic meter, and 259 cubic meter respectively; making the total unmet demand value 139,699 cubic meter. The value of the unmet demand did not change when the evaporation values changed, that was the case only for the flow. When the annual water use rate of 1000m^3/ha was considered (the amount of water needed to grow carrots), the unmet demand for irrigation site 2 decreased to 40 cubic meter. While the unmet demand both for Bello village and irrigation site 1 stayed the same.

Scenario #2 (Irr(1) – Irr (2) – Bello Village)

In the second scenario, Irr 2 was set to be closer to Irr 1 site as shown in Figure 9.2-5. All the variables were kept the same (the annual water use rate was set back to 3.5 mega-litters per hector).

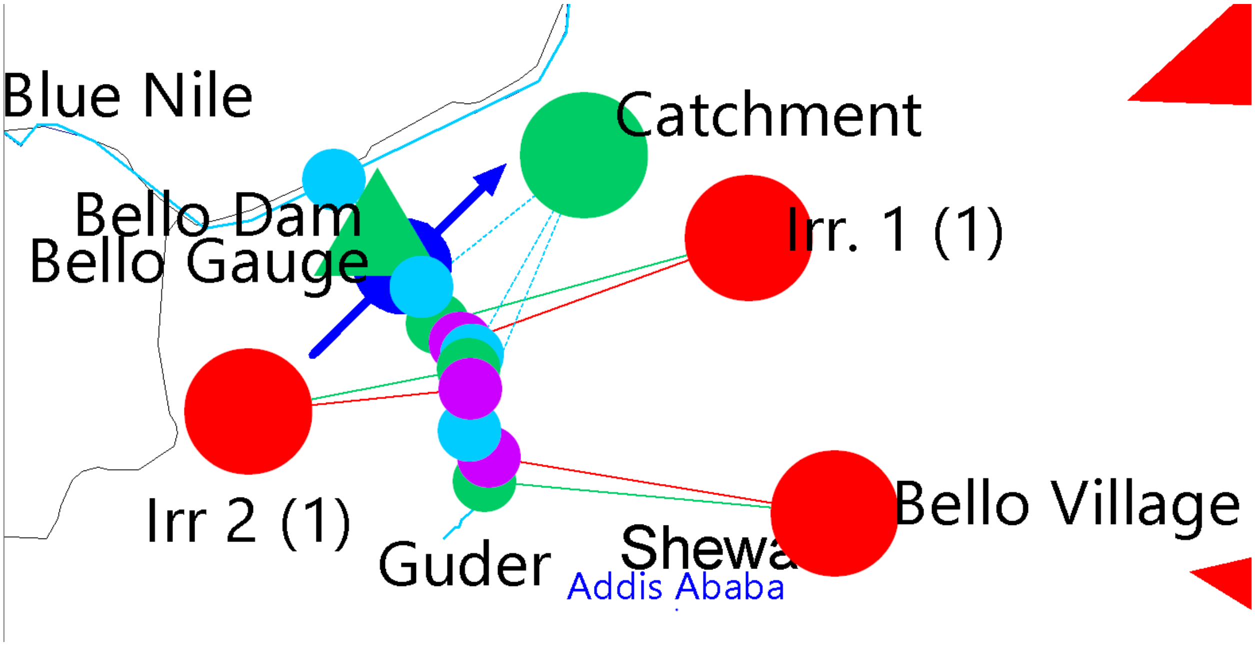


Figure 9.2-5 Scenario #2 (Irr(1) – Irr (2) – Bello Village) WEAP scheme

The result for scenario #2 showed that, Bello village was the only site with unmet demand of 259 cubic meter. This is the same amount that was determined in the first scenario analysis. The change of the annual water use rate from 3500m^3/ha to 1000m^3/ha annually did not change the unmet demand of any of the sites. No change was also observed on the unmet demand value when the net evaporation value changed from minimum to maximum.

When the evaporation was set to minimum, the flow increased on average by 8,739 cubic meter relative to the flow that was observed in the first scenario. On the other hand, when the evaporation was set to maximum, the average flow under scenario #2 was found to be 159 MCM. Which means, the flow in scenario #2 decreased by an average of 3.5 MCM from scenario #1. As the water consumption near the reservoir increases, while at the same time water is lost due to evaporation, then a significant decrease in the amount of the flow was noted.

Scenario #3 (Irr (1) & Irr (2) downstream the reservoir and Bello village far upstream the reservoir)

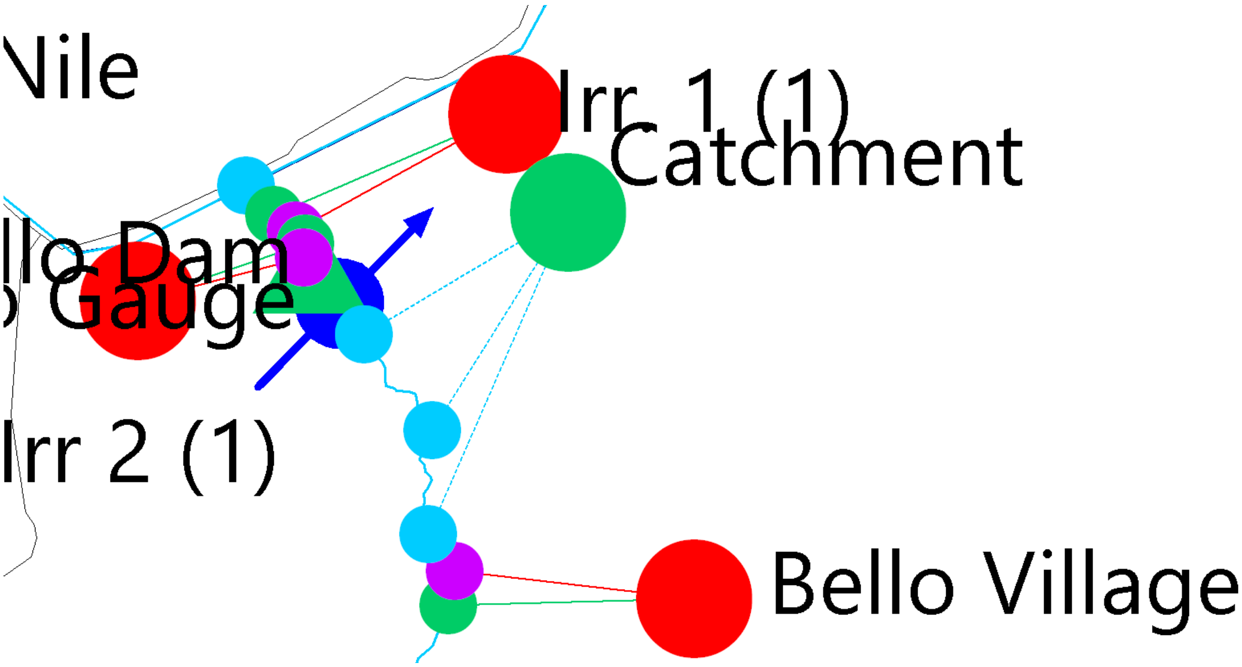


Figure 9.2-6 Scenario #3 (Irr (1) & Irr (2) downstream the reservoir and Bello village far upstream the reservoir) WEAP scheme

The third scenario is based on setting the irrigation sites downstream of the reservoir, instead of upstream. Where the annual water use rate was set at 1000 m^3/ha. Bello village was still located far upstream the reservoir and the buffer coefficient was set to 1. In this scenario, with a minimum net evaporation, the flow increased by 44,286 cubic meter on average relative to scenario #1. When the buffer coefficient was changed to 0.2, the flow did not show any significant change. When the evaporation was set to maximum, the flow also increased by an average of 18.25 MCM from scenario #1. Since the consumption of water upstream the reservoir is minimized by moving the irrigation sites downstream the reservoir, the impact of evaporation is not as much realized in scenario #3 as it did in scenario #2. It is for that reason; the flow was noted to decrease under scenario #2 and increase under scenario #3. The effect of changing crop types under scenario #3 was also analysed. When the annual water use rate was changed to 3500 m^3/ha, and the evaporation was set to the maximum values, the flow decreased only by an average of 0.03% from when the annual water use rate was set to 1000 m^3/ha. Both irrigation sites demand was met. The only unmet demand was at Bello village site with the same value (259 cubic meter).

9.3 Consumption Based Scenario Analysis

The irrigation integrated scenario analysis that was done so far was mainly dependent on the annual water use rate and location of the irrigation and village sites, while keeping the consumption at a constant rate. Similar to all the other scenario analysis cases, the precipitation decrease and temperature increase projection was also applied for the scenarios below. Instead of the dry and wet months' analysis for each decade, the analysis was conducted by assuming 85% of dependable rainfall, like it was done before for the irrigation related analysis.

What if consumption of water for irrigation and water supply purpose increases by 10%, 17%, 24%, 30% and 38% in the 2020s, 2040s, 2060s, 2080s and 2090s respectively?

Increase in Consumption – Under Scenario #1

In scenario #1, Irr (1) was located close to the reservoir while Irr (2) and Bello Village were located far upstream from the reservoir. The consumption percentage increase was equally shared between the two irrigation sites and Bello Village.

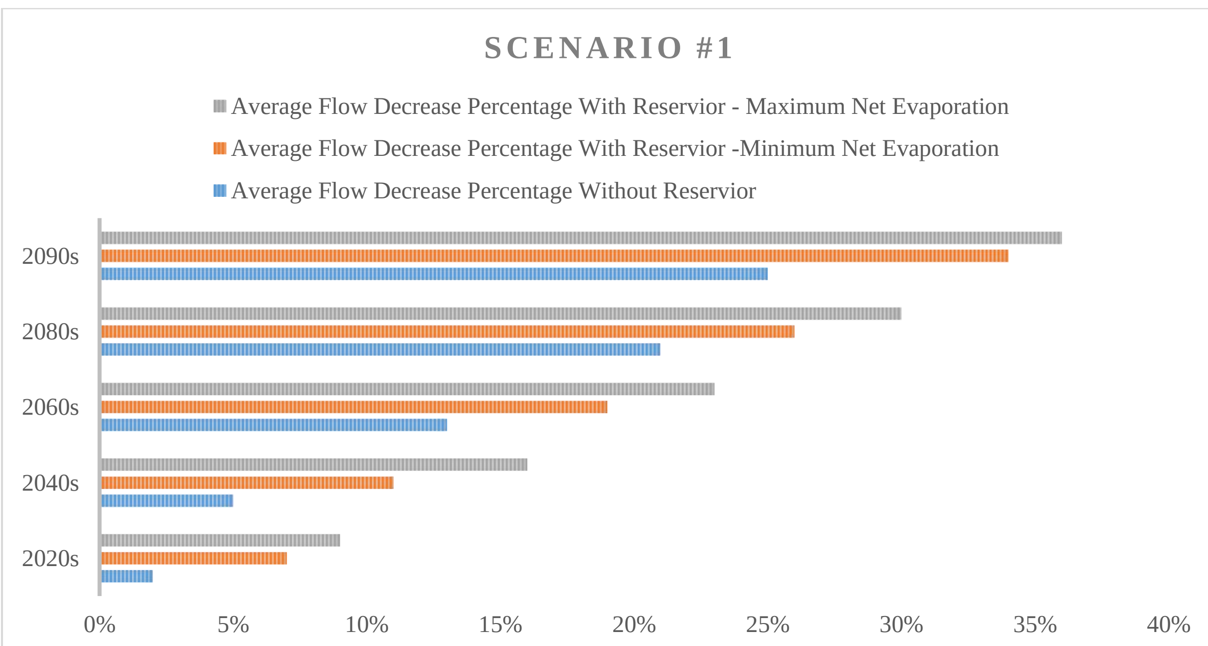


Figure 9.3-1 Average flow percentage decrease based on increased consumption under scenario #1

The decrease in flow without the reservoir was found to be significantly lower than when reservoir was present in the scheme. The percentage decrease of the flow from the reservoir under the scenario of minimum and maximum net evaporation, however, did not show an outstanding difference from one another. This projection was found to be a surprising finding for under location based scenario #1 analysis, it can be recalled that the flow decreased by 18% when the net evaporation changed from minimum net evaporation to maximum net evaporation. Whereas in this part of the analysis, the average decrease of the flow was found to be only by 2%. This may be due to the proportional water consumption division between the three sites. It can also be explained by how the impact of evaporation is not as notable as the big amount of withdrawal of water from the river.

Increase in Consumption – Under Scenario #2

In scenario #2, Irr (2) was moved closer to Irr (1) (closer to the reservoir) while Bello village was set at the same site. In this scenario, the decrease of flow without the reservoir was found to be marginally higher before the mid-century and marginally lower after the mid-century than the flow decrease percentage with reservoir present and minimum evaporation loss. This finding is also different from the result acquired during the location based scenario analysis, in that the flow was found to increase (though not by a significant amount) when the net evaporation was set to the minimum. Since the withdrawal amount was made to increase, the decrease of the flow is an acceptable projection. On the other hand, the percentage decrease of the flow was notably higher during the maximum net evaporation scenario than the minimum net evaporation and no reservoir scenario analysis.

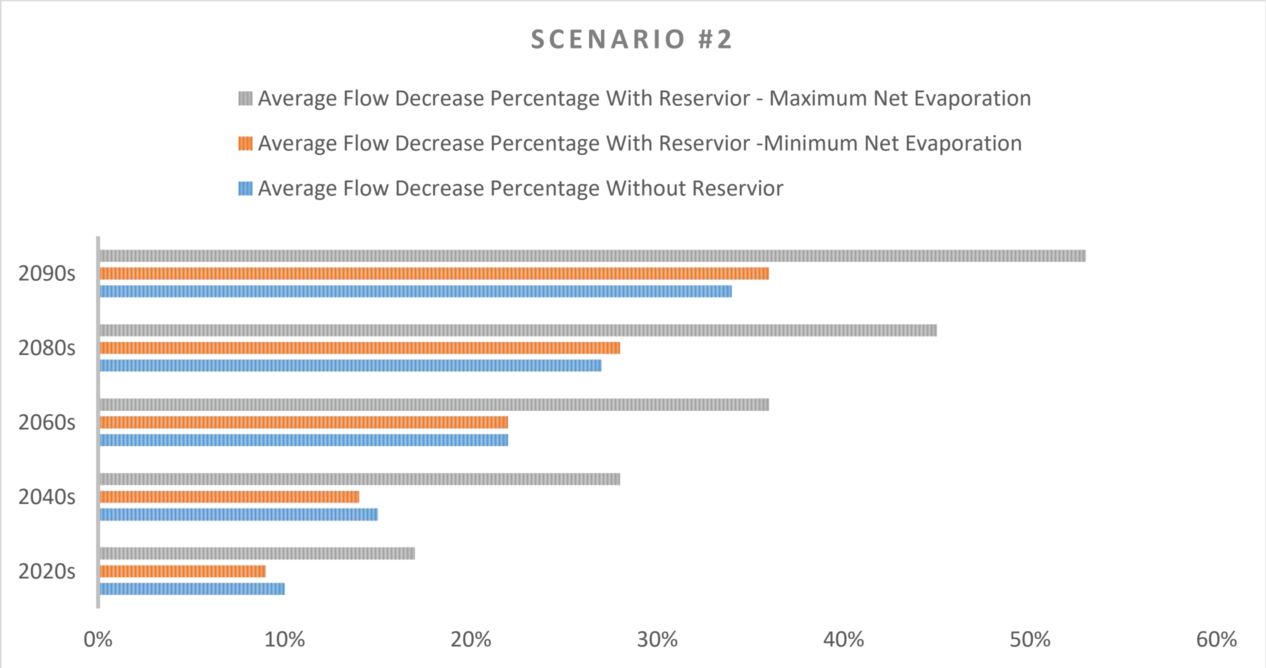


Figure 9.3-2 Average flow percentage decrease based on increased consumption under scenario #2

Increase in Consumption – Under Scenario #3

In scenario #3 both irrigations were placed downstream of the reservoir, while Bello village was set at the far upstream of the river.

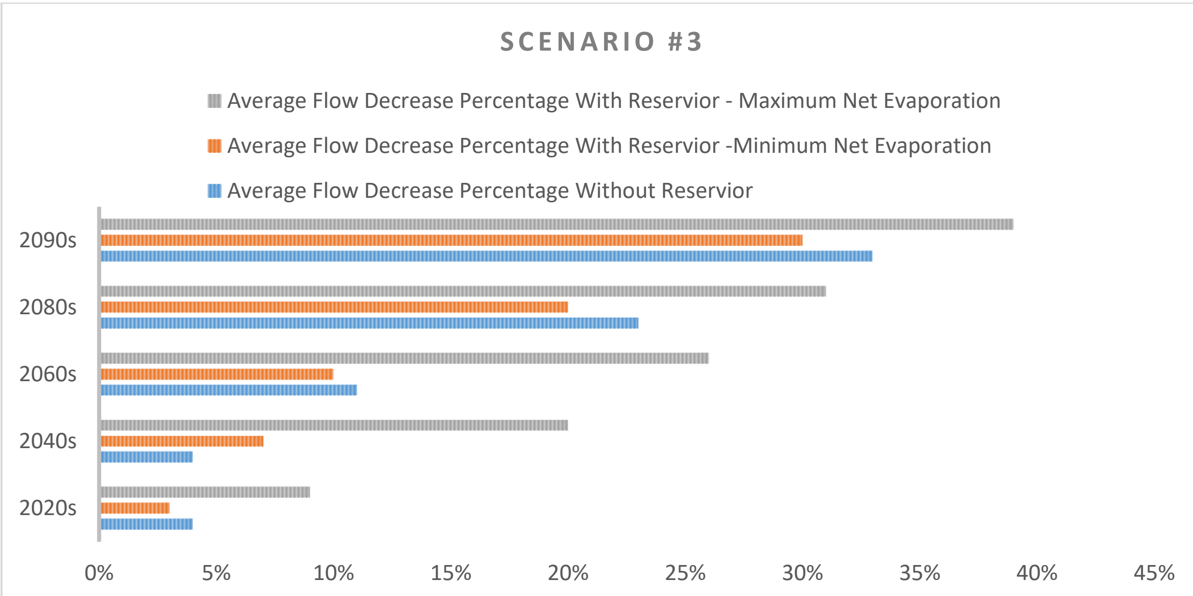


Figure 9.3-3 Average flow percentage decrease based on increased consumption under scenario #3

As Figure 9.3-3 shows, if the net evaporation is kept at the minimum, the flow percentage decrease is the lowest if reservoir is present in the scheme. If the net evaporation is projected to be maximum in the coming decades, then 26% flow will be lost in the mid-century and almost 40% by the end of the century. It is important to notice that the flow percentage decrease in scenario #3 is significantly lower than the flow decrease that was determined in scenario #2. This finding concurs with what was determined in location based scenario #3 analysis. The flow decrease percentage in scenario #3 without reservoir present was also marginally lower than what was found in scenario #2. In fact, under scenario #3 with reservoir present in the scheme and minimum net evaporation, the flow loss was the smallest relative to the same conditions under scenario #1 and #2.

Hence, it can be concluded that placing the irrigation sites downstream of the reservoir with a controlled buffer coefficient, is the optimal arrangement of the scheme in order to minimize flow decrease.

9.4 Effects on the Flow Duration Curves

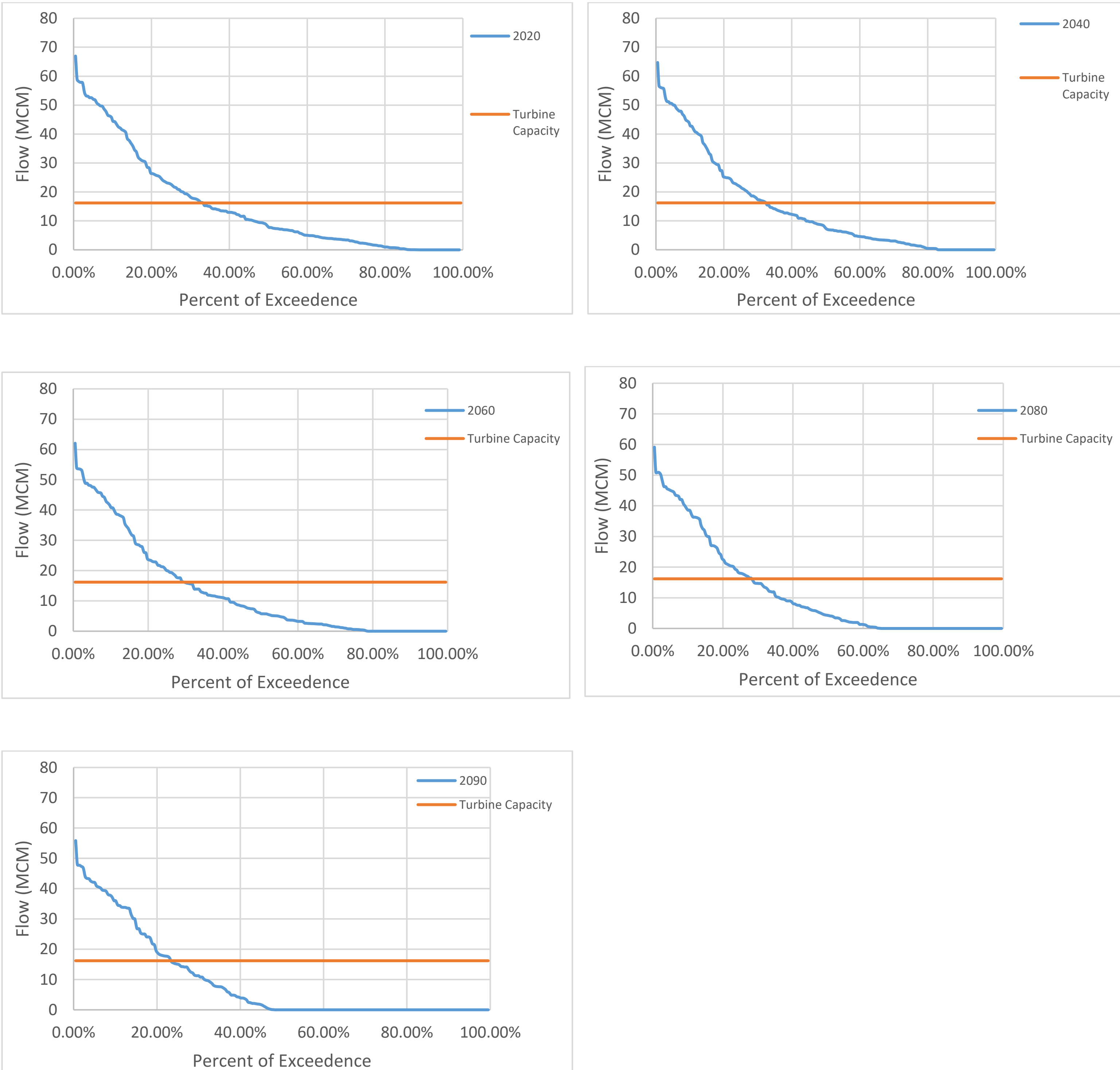


Figure 9.4-1 (a) Duration for simulated flow in the 2020s (b) Duration curve for the projected flow in the 2040s (c) Duration curve for projected flow in the 2060s (d) Duration for simulated flow in the 2080s (e) Duration for simulated flow in the 2090s

The flow duration curves were prepared by considering average net evaporation from the projected minimum and maximum net evaporation values for the 2020s, 2040s, 2060s, 2080s, and 2090s. For this analysis, the irrigation sites were place downstream of the reservoir (the scenario that was determined to be the optimal scenario), and of course the precipitation decrease and temperature increase projection was also applied for each year accordingly.

According to the prefeasibility report for the small scale hydro power production at the Guder River Basin, the turbine capacity was determined to be 6.25 (m^3/s), i.e. 16.2 million cubic meters. As it can be seen from the figures above, the percent of exceedance for the turbine capacity continuously decreases as the years go by. In the 2020s the flow is expected to reach or exceed 16.2 MCM, 12% of the time. In the 2040s, that flow will be reached or exceeded 11% of the time. We notice a faster rate of flow decrease after the mid-century. In the 2060s flow of 16.2 MCM is predicted to reach or exceed 9.2% of the time. Whereas, in the 2080s and 2090s the percent of exceedance for the same value is estimated to be 7.8% and 4.6% respectively. Since the climate change projection with an increment of withdrawal from the river for irrigation purpose is projected to increase at a faster rate after the mid-century, the decrease of flow at a higher rate is not surprising.

Figure 3.2-5, the duration curve of runoff from the Bello gauging station shows that currently flow of 16.2 MCM can be reached or topped 30% of the time. So based on the projection and findings of this study, by mid-century the percent of exceedance for the turbine capacity is estimated to decrease by 14%. The dramatic decrease is noted by the end of the century, where the percent of exceedance is predicted to decrease by 25% from the current value.

10 Discussion

The hydrological trend in the GRB was found to differ from month to month for the 18 years' data (1987-2004). Similar to what was determined in (Hurni et al. 2005) study for the upper Nile Basin based on the 1965-2002 data, annual precipitation for the Bello catchment was found to have no trend. However, the result that was obtained in this thesis is different from what was reported for the seasonal rainfall pattern in the northwestern Ethiopia by (Hurni et al. 2005); in that, a decreasing seasonal precipitation trend was found in this thesis. Though it can be argued that the confident factor for the determined trend characteristic for all the months in the study of the extreme precipitation trend analysis was found to be less than 95%, it is must to acknowledge that the confident factor was still in the acceptable range with Mann-Kendall alpha value of 0.10 for the rainy season. Nonetheless, the decreasing trend in the peak precipitation values cannot necessarily indicate a general decreasing trend of the precipitation in the Bello catchment for, again, no trend was determined for the annual precipitation values. It is for this particular reason that the impact of temperature on the runoff of the catchment (without introducing the precipitation decrease trend) scenario was analysed. As predicted by many literatures, this thesis was also able to determine that the maximum temperature has been increasing in the past years. The increase of the temperature was noted in the months of February, March, April, June, August, October, November, and December. No trend was detected in the peak flow characteristics for 7 months of the year. What was found to be interesting though, was the months in which the flow had a decreasing trend. The presumably decreasing trend was found in July, September, and December. Whereas, a definitely decreasing trend was determined in August. July, September, and August are the rainy seasons of the area. This finding agrees to what was reported by (Gebrehiwot et al. 2014) about the significant decreasing trend of streamflow in Guder based on data analysis of 1960-2004year period.

The educated assumption of the observed temperature increase trend in the past will continue in the future, was found to have a negative impact on the streamflow. However, relative to the streamflow percentage decrease of the other scenarios, the flow decrease for this scenario was found to be the lowest. Unfortunately, the change in temperature is bound to have implication on the other hydrological factors such as evaporation and precipitation. Consequently, the scenario analysis in which it involved decrease of precipitation along with increase of temperature resulted a significantly higher negative impact on the stream flow. The impact was highly noted after the mid-century.

Though it is certain that the increase of temperature will increase evaporation, it is hard to accurately project the level of impact on evaporation. To minimize the uncertainty on the scenario analysis of evaporation impact on streamflow, probable minimum and maximum evaporation projections were made based on the adjustment that was made on the evaporation results acquired from Thornrhwaite method. The decrease on the streamflow for both cases were quite significant. The streamflow percentage decrease under both evaporation scenarios were in the same rage before the mid-century. But by the end of the century, the streamflow decrease under maximum net evaporation scenario was, on average, 35% higher than the runoff percentage loss projected to occur under minimum evaporation scenario. This observation emphasises the necessity of proper evaporation projection to estimate the loss of runoff in the Bello catchment after the mid-century.

Construction of reservoir at Bello catchment is necessary for the power production. The existence of the reservoir was found to have a positive impact to regulate water release for downstream irrigation. The increase of evaporation due to the construction of reservoir was the one factor that was determined to have a negative impact on the streamflow.

For the data period of 1976-2012, 5 years were found to be dry years because those years' precipitation value was found to be less than the determined dependable precipitation index. Based on this finding an average of 85% was established as the rainfall dependability value for the Bello catchment. This value is an acceptable rainfall dependable percentage for irrigation purpose (Haque, 2005). The location of irrigation and village sties was found to have the most significant impact on the percentage decrease of the streamflow. As long as the sites are located far upstream the reservoir with small consumption of water, then the impact of irrigation on the streamflow is not highly noted. Determination of the proper types of crops to grow on the sites (crops that do not require high annual usage rate) is also found to be quite important to properly manage the water in the catchment. The priority level of irrigation has to come after hydropower for to minimize the loss of water for power production. Therefore, the water allocation system has to place energy at number one in order to maximize the power production potential. If irrigation sites have to be within the Bello catchment, close to the reservoir, then the sites have to be located downstream of the reservoir with a controlled buffer coefficient. The placement of irrigation downstream of the reservoir or far upstream of the reservoir also decreases the unmet demand percentage significantly.

11 Conclusion

Based on the observed temperature, precipitation, and runoff data of 18 years (1987-2004) for the Bello Catchment, the hydrological trend characteristics of the area was determined by applying the Mann-Kendall Static (S). No trend was found in the annual precipitation data. Whereas, the trend of maximum precipitation in March, May, June, July, and September over the 18 years was found to be presumably decreasing. On the other hand, the maximum temperature was found to have a presumably increasing trend with a confidence factor greater than 90% but less than 95% for 7 of the months. The maximum temperature trend was found to be increasing in May and September with a positive Mann-Kendall value and confidence factor greater than 95%. The peak runoff values in the rainy season was found to be presumably decreasing in July, September, and December and decreasing in August.

Based on the determined trend characteristics of the climate within the catchment area, temperature increase and precipitation decrease by different factors in the coming decades till the end of the century was projected. The impact of these projections on the runoff was analysed using (WEAP).

Increase of temperature is expected to reduce runoff by 3-5% in the mid-century and 7-12% by the end of the century. Increase of temperature and decrease of precipitation at the same time will reduce runoff by 8-10% and 19-22% by the mid and end of the century respectively. Impact of reservoir construction on the runoff was analysed by considering minimum and maximum net evaporation from the reservoir. The runoff is projected to decrease by 7-22% and 24-34% in the mid and end of the century respectively, under the minimum net evaporation scenario. Whereas the reduction in the 2090s is expected to be an average of 84% under the maximum net evaporation scenario. The significant gap in the reduction of flow under these two scenarios stresses the point of accurate climate projection.

Location, size, consumption, and annual water use rate for irrigation and water supply purpose were found to have consequential impact on the runoff. It was determined that placing the village and irrigation sites far upstream the reservoir or downstream of the reservoir is the best way to optimize runoff for power production. In order to prioritize hydropower within the catchment, the water allocation system in the area must place hydropower as number one to minimize water loss within the catchment.

12 Recommendation

The current prefeasibility study for the suggested hydropower production in the Bello catchment did not include a detailed analysis of how changes upstream of the reservoir can affect water availability for power production in the future. To partially comprehend the impact of climate change and water withdrawal from the river for irrigation and water supply purpose, it is recommended for the results in this thesis to be considered before deciding on investment in the Bello Hydropower project. To fully comprehend the impact of the projected changes in the area, it is recommended for further studies on its impact on the social, economic, and environmental aspects of the catchment.

Based on the future flow duration curves presented in this thesis, the current proposed turbine flow is reached at low percent of time. Hence, in order to guarantee power production at all time, other sources of energy alongside hydropower have to be introduced in the area; especially after the mid-century.

Location of irrigation sites and villages, crop types (to minimize annual water use rate), and optimal consumption percentage has to be determined by involving farmers and engineers in the area.

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Appendices

Mean monthly Rainfall (mm) For Command area (Guder Station)													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1957	43.0	59.0	192.0	87.0	118.0	102.0	237.0	228.0	56.0	0.0	8.0	0.0	1130.0
1958	0.7	11.0	26.0	45.0	17.0	160.0	288.0	195.0	147.0	44.0	0.0	0.0	933.7
1959	3.0	35.0	37.0	87.0	100.0	150.0	295.0	261.0	136.0	41.0	12.0	0.0	1157.0
1960	27.0	31.0	65.0	103.0	109.0	81.0	234.0	231.0	175.0	0.0	0.0	0.0	1056.0
1961	0.0	12.0	16.0	137.0	64.0	104.0	350.0	241.0	75.0	62.0	0.0	0.0	1061.0
1962	3.3	0.0	35.0	0.0	91.0	0.0	146.5	247.5	42.5	20.5	39.0	0.0	625.3
1963	0.0	14.3	38.7	0.0	88.0	0.0	146.2	116.5	66.5	128.5	0.0	0.0	598.7
1964	8.5	3.5	13.0	44.5	117.5	89.0	203.0	200.0	190.7	25.0	0.0	39.5	934.2
1965	13.5	9.9	55.6	88.5	50.5	66.4	112.8	264.0	170.0	111.0	10.0	6.5	958.7
1966	0.0	68.0	67.0	139.0	56.8	197.0	237.5	202.0	253.0	54.9	3.5	0.0	1278.7
1967	0.0	3.3	107.1	4.0	122.0	119.1	267.9	209.9	184.6	0.0	52.3	0.0	1070.2
1968	30.4	71.3	0.0	46.4	66.1	163.7	274.8	215.0	102.7	0.0	10.0	24.9	1005.3
1969	10.3	85.1	93.4	180.7	93.8	216.6	170.0	266.5	183.4	29.0	13.0	0.0	1341.8
1970	32.4	64.4	170.1	28.8	10.5	233.7	300.4	165.2	84.6	0.0	0.0	5.0	1095.1
1971	25.3	0.0	93.0	20.3	217.7	209.6	112.1	206.8	108.5	32.0	37.4	6.0	1068.7
1972	6.0	90.0	29.3	48.6	78.0	100.7	135.8	94.8	93.3	1.3	49.0	43.5	770.3
1973	0.0	0.0	0.0	36.7	163.1	99.5	173.5	197.3	269.7	34.0	0.0	20.5	994.3
1974	0.0	45.5	102.0	9.0	164.2	153.0	152.5	265.1	57.7	25.0	0.0	0.0	974.0
1975	8.0	20.1	25.9	112.7	105.5	194.2	250.8	190.5	52.1	0.5	0.0	6.9	967.2
1976	49.8	10.6	51.8	77.8	105.7	105.4	154.5	233.5	108.0	0.0	27.6	17.7	942.4
1977	0.0	12.0	128.1	17.2	76.0	186.3	255.1	196.6	49.5	56.0	0.0	0.0	976.8
1978	57.1	8.0	80.1	20.2	121.1	129.1	264.0	112.0	85.5	20.9	0.0	42.0	940.0
1979	4.8	21.0	65.5	7.5	198.3	133.1	211.0	166.5	78.4	44.5	0.0	0.8	931.4
1980	30.0	22.7	47.2	134.6	36.4	136.0	317.0	274.6	138.3	14.9	1.4	14.2	1167.3
1981	40.2	25.5	124.3	91.1	61.7	135.7	360.1	237.2	80.3	122.7	2.3	0.6	1281.7
1982	10.2	93.5	92.0	37.3	110.9	344.3	205.0	193.8	37.1	47.0	116.9	9.2	1297.2
1983	0.0	8.7	79.1	58.6	194.1	159.4	266.8	165.9	82.3	75.8	62.4	8.0	1161.1
1984	17.8	34.2	4.5	7.4	109.5	171.3	260.4	91.5	102.5	8.6	12.3	16.4	836.4
1985	0.2	0.0	25.1	122.5	114.8	191.3	231.0	218.4	155.9	15.5	10.5	1.8	1087.0
1986	5.2	25.2	80.4	107.9	55.4	285.1	155.9	149.3	116.0	85.2	0.0	0.0	1065.6
1987	35.3	18.3	140.1	70.5	205.6	156.4	170.2	210.0	103.0	22.6	2.5	11.0	1145.5
1988	0.8	78.5	14.2	28.6	31.1	171.7	282.6	299.9	91.1	123.0	0.0	0.0	1121.5
1989	8.5	39.0	73.6	105.8	173.0	243.1	215.9	180.7	143.7	17.9	6.5	59.2	1266.9

Mean monthly Rainfall (mm) For Command area (Guder Station)													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	69.0	84.8	98.3	98.2	81.2	324.0	417.7	269.5	73.4	21.6	3.4	4.0	1545.1
1991	91.4	78.4	127.2	61.5	71.3	472.3	343.4	215.8	190.1	16.0	1.0	4.7	1673.1
1992	11.2	156.6	237.0	276.3	63.1	654.0	363.8	326.2	191.9	26.3	0.0	2.0	2308.4
1993	0.0	24.9	27.0	286.5	189.0	499.3	508.2	509.0	205.4	71.8	6.0	0.0	2327.1
1994	2.3	2.8	152.3	69.8	114.4	307.7	240.2	577.2	517.2	1.9	13.0	0.0	1998.8
1995	15.8	17.3	43.4	107.8	169.5	127.4	300.8	310.2	278.7	8.4	4.6	45.2	1429.1
1996	28.4	25.5	304.3	212.9	319.3	273.2	356.5	414.2	143.8	0.0	26.3	5.9	2110.3
1997	54.0	0.0	45.8	244.9	150.4	398.0	243.7	361.2	91.4	123.2	140.5	6.7	1859.8
1998	46.5	22.5	94.7	14.8	119.3	188.7	246.6	126.3	56.2	104.0	0.1	0.0	1019.7
1999	0.0	3.9	10.3	14.1	196.0	335.4	271.3	158.2	89.5	176.4	0.0	0.0	1255.1
2000	31.4	0.0	26.9	82.9	148.0	231.3	268.2	298.3	109.7	61.0	92.0	15.0	1364.7
2001	37.0	37.1	114.5	71.4	205.0	199.2	270.5	264.9	215.4	33.8	7.1	2.9	1458.8
2002	70.2	23.2	48.4	62.1	97.8	270.7	252.9	70.7	153.7	0.0	0.0	25.5	1075.2
2003	45.7	52.6	81.4	204.3	18.5	219.3	190.8	249.5	73.2	2.4	21.6	21.5	1180.8
2004	43.7	10.4	53.1	198.5	18.6	228.3	305.8	328.2	200.1	25.0	4.8	13.2	1429.7
2005	0.4	0.0	126.6	154.8	76.2	347.6	359.1	188.1	256.6	10.1	13.1	1.3	1533.9
2006	29.2	21.6	114.9	324.4	103.5	225.3	284.3	368.2	58.9	68.4	19.2	41.7	1659.6
2007	0.0	57.0	100.3	17.3	116.3	217.5	232.9	302.7	49.1	11.0	0.0	0.0	1104.1
2008	55.6	0.0	5.0	57.6	220.2	93.7	222.3	227.6	198.5	91.9	105.2	19.2	1296.8
2009	7.4	49.2	58.7	139.2	62.9	142.8	292.4	47.3	141.3	0.0	17.6	7.9	966.7
2010	7.1	12.0	68.6	110.2	154.5	285.8	175.4	109.4	115.1	3.6	34.3	9.6	1085.6
2011	0.0	9.9	44.4	93.0	123.1	270.3	306.1	218.5	118.6	40.2	18.6	0.0	1242.7
2012	0.0	0.0	0.0	8.6	0.0	241.0	318.4	148.7	135.0	766.1	19.6	11.4	1648.8
Mean	20.0	30.5	74.2	89.6	111.5	206.1	253.7	228.9	133.6	52.3	18.3	10.2	1228.8
STDV	22.6	32.3	59.8	76.8	63.2	117.7	77.3	96.5	80.8	105.7	30.8	14.3	366.6
CV	0.9	0.9	1.2	1.2	1.8	1.8	3.3	2.4	1.7	0.5	0.6	0.7	3.4
Skew	1.1	1.6	1.5	1.2	0.7	1.4	0.5	1.2	2.2	5.8	2.5	1.8	1.3

Mean monthly Rainfall (mm) at dam points (Inchin Station)													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1976	49.7	12.9	50.6	132.3	102.7	253.6	469.3	493.1	176.2	46.2	58.8	36.2	1881.6
1977	144.9	18.1	23.6	185.7	392.6	288.8	54.7	124.1	22.9	28.7	0.0	19.3	1303.5
1978	45.6	49.7	49.7	21.5	58.0	167.3	257.0	215.5	174.2	11.4	5.7	102.1	1157.7
1979	39.3	54.2	62.5	40.0	6.9	128.9	203.0	160.6	78.4	3.7	4.1	75.2	856.7
1980	28.0	15.8	32.1	181.2	38.8	173.5	330.8	269.7	108.8	41.0	9.5	0.0	1229.2
1981	10.4	2.4	155.8	190.5	35.4	73.6	433.0	212.2	80.2	119.0	4.5	2.9	1319.9
1982	12.0	14.8	81.0	45.2	108.2	93.9	278.0	293.3	106.2	105.9	115.0	10.5	1264.0
1983	8.5	52.0	67.4	97.8	258.5	128.5	311.7	338.9	112.7	37.8	43.7	8.4	1465.9
1984	9.1	2.5	0.0	0.0	0.0	35.4	188.8	111.2	153.4	0.2	0.0	0.0	500.6
1985	0.0	19.4	0.0	0.0	0.0	159.3	171.5	68.3	61.0	38.4	12.2	18.1	548.2
1986	0.0	14.5	78.8	104.9	55.0	273.4	150.6	144.3	114.1	83.3	2.3	11.6	1032.8
1987	3.6	24.3	234.0	95.2	164.4	124.0	160.7	207.7	70.0	17.6	0.0	13.3	1114.8
1988	51.0	105.0	24.4	116.8	9.7	132.0	364.0	279.2	284.8	65.4	0.0	0.8	1433.1
1989	38.9	105.0	14.4	78.8	21.7	149.8	261.0	308.0	123.2	54.9	1.8	59.1	1216.7
1990	12.5	59.2	95.8	4.2	39.8	157.9	386.7	258.6	73.6	22.9	12.0	11.1	1134.3
1991	48.4	46.0	103.0	24.9	28.1	116.2	316.2	265.1	110.4	43.5	8.4	37.8	1148.0
1992	57.3	48.2	64.7	143.5	75.5	150.8	207.6	267.1	144.1	69.2	50.4	7.0	1285.4
1993	1.9	53.0	31.6	200.6	79.3	146.3	270.4	235.7	271.1	70.0	1.5	5.7	1367.1
1994	6.8	8.1	100.9	34.2	70.4	241.2	330.7	222.7	167.3	12.7	11.6	0.0	1206.6
1995	0.0	12.2	73.8	131.4	88.5	338.8	233.3	117.2	11.5	12.7	59.1	82.9	1161.4
1996	21.8	168.6	93.8	99.0	191.7	310.5	341.3	124.2	23.4	37.6	3.8	1.2	1416.9
1997	49.3	0.0	25.6	100.0	89.0	123.3	306.1	218.1	99.6	161.2	101.4	16.3	1289.9
1998	46.0	19.4	66.2	18.4	119.5	195.0	348.2	304.4	171.5	113.0	13.0	0.0	1414.6
1999	16.7	9.3	22.6	22.5	41.0	90.4	274.7	319.1	89.8	136.6	1.3	1.8	1025.8
2000	0.0	0.0	26.1	182.2	77.7	122.8	346.3	263.1	113.4	74.8	62.5	10.5	1279.4
2001	9.9	38.2	195.0	48.4	127.1	170.1	308.9	207.0	122.7	38.5	3.4	8.6	1277.8
2002	62.8	5.5	121.1	32.0	20.6	163.1	222.6	305.1	155.7	0.0	0.0	53.8	1142.3
2003	61.1	95.1	135.1	153.3	9.1	182.9	308.2	320.9	159.5	10.1	4.1	29.6	1469.0
2004	41.1	35.3	29.9	66.2	6.0	136.5	253.5	296.0	197.9	37.7	1.7	63.9	1165.7
2005	43.7	0.0	107.3	93.7	113.4	130.4	191.1	188.1	134.7	34.4	7.6	6.3	1050.7
2006	0.0	107.3	93.7	113.4	130.4	191.1	188.1	133.2	35.9	7.6	6.3	4.3	1011.3
2007	15.9	173.0	96.8	62.3	174.1	364.6	351.5	170.1	28.4	33.4	30.5	2.8	1503.5
2008	39.2	27.5	38.5	56.9	176.0	371.9	368.7	297.4	159.3	9.6	0.0	1.6	1546.6

Mean monthly Rainfall (mm) at dam points (Inchin Station)													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2009	9.3	49.1	58.1	134.7	62.1	138.1	280.4	47.3	138.2	2.3	19.1	10.3	949.1
2010	9.0	2.6	48.9	186.5	238.7	310.8	224.5	69.0	41.3	68.5	0.0	36.3	1236.1
2011	33.6	104.8	62.0	95.6	240.0	210.3	234.0	210.6	85.0	17.5	20.5	2.8	1316.8
2012	29.5	46.2	32.1	5.2	64.7	81.2	131.4	201.0	155.3	2.0	8.0	0.0	756.6
Average	28.6	27.5	73.3	80.2	75.4	157.3	296.8	255.3	135.6	46.1	23.4	22.0	1221.5
SDVE	28.2	44.9	51.3	61.6	86.7	83.4	87.3	91.1	62.7	40.7	28.4	26.4	263.4
CV	1.0	1.6	0.7	0.8	1.1	0.5	0.3	0.4	0.5	0.9	1.2	1.2	0.2
Skew	2.0	1.5	1.3	0.3	1.5	0.9	-0.1	0.3	0.6	1.2	2.1	1.7	-0.5

Mean Maximum Temperature (oC) At Guder Station /Command area													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1964	26.9	27.5	27.2	27.4	27.4	26.5	24.6	24.6	25.5	25.0	24.9	26.2	26.2
1965	26.7	28.7	29.6	29.2	29.2	25.0	24.3	24.1	25.2	25.9	26.3	26.4	26.7
1966	26.6	26.7	28.7	28.1	28.1	26.0	21.8	23.3	24.1	25.0	24.8	27.5	25.9
1967	26.2	26.2	26.7	28.5	28.5	25.6	24.1	24.0	25.1	27.0	28.1	26.0	26.3
1968	28.2	28.8	27.3	29.0	29.0	26.6	24.5	24.7	25.5	26.7	28.0	28.5	27.2
1969	27.9	28.5	28.6	28.6	28.6	27.0	24.0	22.4	23.5	25.8	25.9	29.3	26.7
1970	26.2	27.4	27.9	27.1	27.1	23.3	23.3	23.0	24.8	26.0	25.2	25.8	25.6
1971	27.6	29.6	30.7	30.0	30.0	26.5	24.0	23.6	24.8	27.0	27.9	25.4	27.3
1972	28.0	26.9	26.5	27.5	27.5	26.0	24.0	24.0	24.2	26.4	27.3	27.3	26.3
1973	27.0	27.7	29.4	28.4	28.4	24.5	24.0	24.2	24.2	27.0	25.0	26.7	26.4
1974	27.5	28.8	28.9	27.3	27.3	24.5	23.4	22.3	23.3	25.7	26.2	27.0	26.0
1975	27.6	25.6	26.8	26.9	26.9	24.8	22.5	23.1	24.2	26.4	24.8	25.7	25.4
1976	27.0	28.0	27.3	28.0	28.0	25.3	23.7	24.2	26.1	27.8	26.2	26.7	26.5
1977	27.4	26.9	27.6	29.0	29.0	25.7	24.2	24.7	26.1	26.1	27.9	27.4	26.8
1978	24.6	27.0	26.9	26.7	26.7	25.5	24.5	24.8	27.4	27.2	27.1	25.9	26.2
1979	27.3	28.1	26.5	28.3	28.3	25.5	24.1	26.3	26.7	27.3	27.5	26.3	26.8
1980	27.9	28.8	31.3	30.4	30.4	28.5	25.9	25.8	26.5	28.3	29.4	28.7	28.5
1981	28.4	28.4	28.1	28.7	28.7	26.9	24.8	23.5	26.5	27.2	25.5	26.8	27.0
1982	28.0	28.7	27.9	29.6	29.6	27.2	25.7	25.2	24.2	24.7	27.1	27.0	27.1
1983	27.5	28.1	29.2	27.5	27.5	26.7	24.5	23.9	24.2	26.5	27.0	26.6	26.6
1984	28.1	27.7	27.6	26.9	26.9	25.3	23.2	23.8	24.6	26.6	27.3	27.9	26.3

Mean Maximum Temperature (ºC) At Guder Station /Command area													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985	27.7	29.0	27.4	27.3	27.3	26.4	24.8	24.5	26.3	26.2	27.2	27.4	26.8
1986	28.3	27.3	29.7	29.9	29.9	25.9	25.3	23.3	26.5	27.6	28.1	28.2	27.5
1987	28.4	28.6	28.2	26.7	26.7	26.4	22.7	26.2	25.0	26.9	29.4	29.4	27.0
1988	29.6	26.5	28.0	28.4	28.4	26.5	26.7	23.5	27.6	29.0	29.1	27.8	27.6
1989	27.3	30.3	30.2	29.1	29.1	26.1	24.0	30.6	25.6	28.3	30.2	29.9	28.4
1990	28.7	30.4	29.7	29.4	29.4	31.1	30.4	29.7	28.6	24.5	25.2	26.2	28.6
1991	28.5	27.7	28.7	28.9	28.9	30.4	29.5	29.0	28.7	28.3	26.0	26.0	28.4
1992	27.4	27.9	29.0	29.6	29.6	29.9	28.9	29.1	28.5	27.5	28.3	28.0	28.6
1993	27.8	29.7	30.2	27.8	27.8	29.8	30.7	25.5	28.1	27.0	27.2	27.4	28.2
1994	29.3	29.9	31.4	28.9	28.9	28.7	27.3	28.9	26.6	26.8	28.3	28.1	28.6
1995	27.7	27.6	30.0	29.4	29.4	27.4	28.9	30.3	25.7	26.1	28.7	27.4	28.2
1996	27.3	29.7	29.9	30.3	30.3	29.8	29.9	23.9	26.8	28.0	26.0	27.3	28.3
1997	27.8	29.8	29.6	30.8	30.8	26.4	23.8	23.6	25.0	25.4	26.2	26.8	27.1
1998	27.8	29.1	31.6	28.3	28.3	26.2	24.5	27.6	25.6	26.2	27.0	27.4	27.5
1999	28.2	28.6	28.5	27.4	27.4	28.1	26.8	24.5	27.2	26.9	27.0	27.2	27.3
2000	27.2	29.1	30.4	30.4	30.4	25.3	24.4	24.4	24.8	26.8	26.6	27.5	27.3
2001	27.0	28.2	29.4	26.6	26.6	30.2	25.6	24.1	24.7	27.5	27.7	27.4	27.1
2002	27.1	29.0	29.3	28.6	28.6	28.0	25.8	25.7	25.6	26.5	27.2	26.7	27.4
2003	28.6	30.0	30.8	30.9	30.9	28.2	27.2	27.2	25.2	26.7	27.4	28.1	28.4
2004	27.7	30.5	31.1	30.8	30.8	29.4	28.1	24.9	27.3	27.0	27.5	28.1	28.6
2005	28.8	27.2	28.6	28.8	28.8	27.6	26.7	25.5	27.2	26.9	28.0	28.1	27.7
2006	28.3	28.1	29.6	28.5	28.5	25.7	23.2	28.9	25.8	25.9	26.9	27.3	27.2
2007	28.0	28.2	30.1	28.3	28.3	28.6	29.0	26.8	27.9	27.0	26.4	26.2	27.9
2008	27.3	26.4	26.5	28.2	28.2	28.7	28.6	29.5	26.7	25.6	25.9	27.7	27.4
2009	27.0	26.5	27.8	28.7	28.7	26.9	25.5	25.3	26.8	27.4	26.8	27.4	27.1
2011	26.6	27.6	30.1	26.4	26.4	27.5	26.0	25.3	26.8	27.4	26.8	28.1	27.1
2012	26.4	26.5	26.5	26.4	27.4	29.6	29.2	25.7	23.2	27.9	27.0	27.3	26.9
Average	27.6	28.2	28.8	28.5	28.5	27.0	25.6	25.4	25.8	26.7	27.0	27.3	27.2

Mean Minimum Temperature (ºC) For Command area													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1964	4.9	5.7	5.2	9.1	8.8	9.7	11.9	12.0	8.5	6.6	2.1	7.1	7.6
1965	4.1	7.6	6.6	8.4	6.3	7.5	8.5	7.8	5.2	4.7	3.2	4.0	6.2
1966	5.4	6.7	9.3	10.7	11.3	9.6	10.6	11.2	9.2	6.7	5.5	3.4	8.3
1967	2.3	7.3	6.9	10.6	10.7	10.9	12.4	11.3	10.2	7.5	8.0	5.5	8.6
1968	4.7	10.7	11.6	9.8	11.8	11.4	11.9	10.0	9.5	6.0	6.2	5.5	9.1
1969	8.9	9.6	11.3	11.5	10.4	10.9	12.4	11.4	9.2	5.4	4.8	3.9	9.1
1970	9.7	0.3	7.1	8.2	7.7	11.3	12.1	11.8	10.6	4.3	2.5	2.6	7.3
1971	5.1	5.3	6.1	7.1	3.1	7.0	6.7	6.2	5.7	3.9	3.4	0.4	5.0
1972	2.2	2.5	4.3	7.5	7.6	5.5	7.2	6.5	5.3	0.4	1.8	1.0	4.3
1973	2.4	4.1	6.8	3.6	6.7	6.8	7.5	8.1	6.8	2.9	-0.6	0.3	4.6
1974	0.1	4.0	5.7	7.3	6.8	5.5	5.7	5.1	5.1	-0.3	-2.5	-1.2	3.4
1975	0.0	4.2	5.3	6.4	5.8	6.7	6.1	6.7	5.3	1.7	-1.5	-0.9	3.8
1976	2.0	4.4	5.1	5.9	6.4	5.2	6.3	5.6	4.8	3.1	2.8	1.7	4.4
1977	5.4	9.1	9.7	8.9	11.1	6.0	6.6	6.7	4.6	-1.2	0.1	-1.8	5.4
1978	1.7	8.0	10.2	8.2	10.5	10.8	13.4	11.8	7.9	2.8	3.4	7.2	8.0
1979	9.8	8.4	10.7	11.4	11.1	12.3	12.6	11.7	9.2	8.8	4.9	7.8	9.9
1980	7.0	6.1	11.7	9.5	10.6	11.9	11.6	9.6	9.1	5.4	6.5	4.0	8.6
1981	6.7	10.3	8.9	10.8	11.1	11.1	12.5	11.5	11.2	7.4	4.5	7.2	9.4
1982	7.4	8.6	11.7	12.2	12.2	10.3	11.0	12.3	9.3	7.4	9.0	3.8	9.6
1983	6.2	3.6	7.3	7.9	9.3	11.1	11.7	10.0	11.1	9.6	6.6	6.2	8.4
1984	4.5	0.9	4.2	4.8	4.9	8.9	9.6	10.9	9.5	5.1	7.3	-2.3	5.7
1985	6.3	9.6	9.9	11.1	11.0	5.8	10.6	10.3	10.4	7.4	0.6	5.7	8.2
1986	0.5	7.4	11.0	10.1	9.9	11.6	11.3	5.3	9.3	6.9	4.8	3.1	7.6
1987	5.1	10.8	9.1	10.5	11.1	6.5	5.2	10.6	3.0	3.1	5.1	4.6	7.1
1988	8.8	7.8	7.7	7.8	6.7	10.9	11.3	6.7	10.1	8.9	4.6	6.0	8.1
1989	8.0	10.8	8.3	9.8	9.2	8.7	5.9	11.3	7.4	4.9	1.4	2.4	7.3
1990	3.4	6.2	10.2	10.9	10.1	11.7	12.2	10.9	10.5	5.9	1.8	2.4	8.0
1991	4.4	10.4	9.6	8.3	9.9	11.5	11.4	10.5	8.3	3.4	4.1	4.1	8.0
1992	8.5	8.5	8.7	8.3	9.7	11.0	10.0	9.4	8.4	3.2	3.7	3.6	7.7
1993	5.6	7.8	10.7	10.7	10.5	10.6	10.0	10.0	8.1	6.0	2.6	5.6	8.2
1994	6.6	10.1	10.6	13.0	12.7	10.8	11.3	12.3	9.9	6.1	7.9	8.6	10.0

Mean Minimum Temperature (ºC) For Command area													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1995	5.6	9.4	11.7	11.1	10.3	10.9	11.8	10.0	9.1	5.9	6.6	4.6	8.9
1996	10.1	5.4	10.9	10.9	10.0	10.8	10.8	10.5	6.6	5.3	7.8	7.4	8.9
1997	6.8	11.0	11.1	11.6	13.7	10.6	10.9	12.3	6.5	7.7	9.3	3.8	9.6
1998	10.2	7.0	10.5	11.7	12.0	12.5	13.5	11.8	11.5	10.9	5.5	6.2	10.3
1999	6.8	6.1	10.6	11.2	11.6	12.6	13.3	10.7	9.8	9.9	3.4	5.2	9.3
2000	5.7	10.0	11.2	9.4	12.5	10.2	10.6	12.4	7.8	7.4	4.3	7.2	9.1
2001	7.8	8.8	13.0	12.9	12.6	11.4	12.5	12.0	8.8	9.2	6.6	9.6	10.4
2002	8.9	8.5	10.7	10.2	9.9	11.5	12.7	6.5	12.1	8.2	7.0	1.8	9.0
2003	10.2	3.8	6.9	8.1	8.6	8.2	7.8	8.3	6.0	2.4	1.6	2.9	6.2
2004	5.2	4.1	9.1	12.0	11.1	7.4	8.2	7.8	8.4	6.0	2.3	-0.4	6.8
2005	3.5	5.1	9.4	10.8	9.2	9.9	9.4	7.3	7.0	1.7	0.6	5.0	6.6
2006	2.0	7.3	7.8	9.6	8.7	8.1	7.4	8.8	6.9	5.4	4.9	1.9	6.6
2007	6.9	7.9	7.5	8.0	10.4	7.2	9.1	9.6	7.5	3.6	3.2	5.3	7.2
2008	5.4	9.7	10.7	8.7	8.1	8.9	7.3	11.0	7.9	6.4	5.2	8.1	8.1
2009	6.3	3.6	7.3	9.9	10.3	10.2	10.1	10.7	7.9	5.0	4.3	2.8	7.4
2010	6.5	5.6	7.6	9.6	10.8	10.3	10.8	11.1	9.8	4.2	5.6		8.4
2011	5.4	7.7	10.1	7.3	6.5	11.2	10.7						8.4
2012	5.6					11.5	11.0						9.4
Average	5.7	7.1	9.0	9.4	9.6	9.6	10.1	9.7	8.2	5.4	4.1	3.9	7.7

Mean Maximum Temperature (ºC) at Reservoir site													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1964	23.3	23.8	23.5	23.7	23.7	23.0	21.3	21.3	22.1	21.6	21.5	22.7	22.6
1965	23.1	24.8	25.6	25.2	25.2	21.7	21.0	20.9	21.8	22.4	22.8	22.8	23.1
1966	23.0	23.1	24.8	24.3	24.3	22.5	18.9	20.2	20.9	21.6	21.4	23.8	22.4
1967	22.6	22.7	23.1	24.6	24.6	22.1	20.8	20.7	21.7	23.4	24.3	22.5	22.8
1968	24.4	24.9	23.6	25.1	25.1	23.0	21.2	21.4	22.1	23.1	24.2	24.6	23.6
1969	24.1	24.6	24.8	24.7	24.7	23.4	20.8	19.3	20.3	22.3	22.4	25.3	23.1
1970	22.6	23.7	24.1	23.4	23.4	20.2	20.2	19.9	21.4	22.5	21.8	22.4	22.1
1971	23.9	25.6	26.6	26.0	26.0	23.0	20.8	20.4	21.5	23.4	24.1	22.0	23.6
1972	24.2	23.2	23.0	23.8	23.8	22.5	20.7	20.8	20.9	22.8	23.6	23.7	22.7
1973	23.4	23.9	25.4	24.6	24.6	21.2	20.7	20.9	20.9	23.3	21.6	23.1	22.8
1974	23.8	24.9	25.0	23.6	23.6	21.2	20.2	19.3	20.2	22.2	22.7	23.3	22.5
1975	23.8	22.1	23.2	23.2	23.2	21.4	19.4	20.0	20.9	22.9	21.5	22.2	22.0
1976	23.4	24.3	23.6	24.2	24.2	21.9	20.5	20.9	22.6	24.0	22.7	23.1	23.0
1977	23.7	23.3	23.9	25.1	25.1	22.2	21.0	21.3	22.5	22.6	24.1	23.7	23.2
1978	21.2	23.4	23.3	23.1	23.1	22.1	21.2	21.4	23.7	23.5	23.4	22.4	22.7
1979	23.6	24.3	22.9	24.5	24.5	22.1	20.9	22.8	23.1	23.6	23.8	22.7	23.2

1980	24.2	24.9	27.1	26.3	26.3	24.6	22.4	22.3	22.9	24.5	25.4	24.8	24.6
1981	24.6	24.5	24.3	24.8	24.8	23.3	21.5	20.3	22.9	23.5	22.1	23.2	23.3
1982	24.2	24.8	24.2	25.6	25.6	23.5	22.2	21.8	20.9	21.3	23.4	23.3	23.4
1983	23.8	24.3	25.3	23.7	23.7	23.1	21.2	20.6	21.0	22.9	23.4	23.0	23.0
1984	24.3	24.0	23.9	23.3	23.3	21.8	20.1	20.6	21.2	23.0	23.6	24.1	22.8
1985	24.0	25.1	23.7	23.6	23.6	22.8	21.4	21.2	22.7	22.6	23.5	23.7	23.2
1986	24.5	23.6	25.7	25.8	25.8	22.4	21.8	20.1	22.9	23.9	24.3	24.4	23.8
1987	24.5	24.7	24.4	23.1	23.1	22.8	19.7	22.7	21.6	23.3	25.4	25.4	23.4
1988	25.6	23.0	24.2	24.6	24.6	23.0	23.1	20.4	23.8	25.1	25.1	24.0	23.9
1989	23.6	26.2	26.1	25.2	25.2	22.6	20.8	26.5	22.1	24.5	26.1	25.9	24.6
1990	24.8	26.3	25.7	25.4	25.4	26.9	26.3	25.7	24.7	21.2	21.8	22.6	24.7
1991	24.7	24.0	24.8	25.0	25.0	26.3	25.5	25.1	24.8	24.4	22.5	22.5	24.5
1992	23.7	24.2	25.1	25.6	25.6	25.9	25.0	25.2	24.7	23.8	24.4	24.2	24.8
1993	24.1	25.7	26.2	24.0	24.0	25.8	26.6	22.1	24.3	23.3	23.5	23.7	24.4
1994	25.4	25.9	27.1	25.0	25.0	24.8	23.6	25.0	23.0	23.2	24.5	24.3	24.7
1995	24.0	23.9	25.9	25.5	25.5	23.7	25.0	26.2	22.2	22.5	24.8	23.7	24.4
1996	23.6	25.7	25.9	26.2	26.2	25.8	25.9	20.6	23.2	24.3	22.5	23.6	24.5

Mean Maximum Temperature (ºC) at Reservoir site													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997	24.0	25.7	25.6	26.6	26.6	22.9	20.6	20.4	21.6	21.9	22.6	23.2	23.5
1998	24.1	25.2	27.3	24.5	24.5	22.6	21.2	23.9	22.2	22.6	23.4	23.7	23.8
1999	24.4	24.7	24.6	23.7	23.7	24.3	23.2	21.2	23.5	23.3	23.4	23.5	23.6
2000	23.6	25.1	26.3	26.3	26.3	21.9	21.1	21.1	21.5	23.2	23.0	23.8	23.6
2001	23.4	24.4	25.4	23.0	23.0	26.1	22.1	20.9	21.3	23.8	24.0	23.7	23.4
2002	23.5	25.1	25.3	24.8	24.8	24.2	22.3	22.2	22.2	22.9	23.6	23.1	23.7
2003	24.8	26.0	26.6	26.8	26.8	24.4	23.6	23.5	21.8	23.1	23.7	24.3	24.6
2004	24.0	26.4	26.9	26.7	26.7	25.5	24.3	21.6	23.6	23.3	23.8	24.3	24.7
2005	24.9	23.5	24.8	24.9	24.9	23.8	23.1	22.1	23.5	23.3	24.2	24.3	23.9
2006	24.5	24.3	25.6	24.6	24.6	22.2	20.1	25.0	22.3	22.4	23.3	23.6	23.5
2007	24.3	24.4	26.0	24.5	24.5	24.7	25.1	23.2	24.1	23.3	22.8	22.7	24.1
2008	23.6	22.8	22.9	24.4	24.4	24.8	24.7	25.5	23.1	22.1	22.4	24.0	23.7
2009	23.3	22.9	24.1	24.9	24.9	23.3	22.0	21.9	23.1	23.7	23.2	23.7	23.4
2011	23.0	23.9	26.0	22.9	22.9	23.8	22.5	21.9	23.1	23.7	23.2	24.3	23.4
2012	22.8	22.9	22.9	22.9	23.7	25.6	25.3	22.2	20.1	24.1	23.3	23.6	23.3
Average	23.7	24.3	24.8	24.5	24.2	23.2	22.0	21.9	22.3	23.0	23.3	23.4	23.5

Mean Minimum Temperature (ºC) For Reservoir site													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1964	3.6	6.5	5.7	7.3	5.4	6.5	7.3	6.8	4.5	4.1	2.8	3.4	5.3
1965	4.7	5.8	8.0	9.3	9.8	8.3	9.2	9.7	7.9	5.8	4.7	2.9	7.2
1966	2.0	6.3	5.9	9.2	9.2	9.4	10.7	9.8	8.8	6.5	6.9	4.8	7.5
1967	4.1	9.3	10.0	8.4	10.2	9.9	10.3	8.6	8.2	5.2	5.3	4.8	7.9
1968	7.7	8.3	9.7	9.9	9.0	9.4	10.7	9.8	8.0	4.6	4.1	3.4	7.9
1969	8.4	0.3	6.1	7.1	6.7	9.8	10.5	10.2	9.1	3.7	2.1	2.3	6.4
1970	4.4	4.6	5.3	6.1	2.7	6.0	5.8	5.4	4.9	3.4	2.9	0.3	4.3
1971	1.9	2.1	3.8	6.5	6.6	4.7	6.2	5.7	4.6	0.4	1.6	0.8	3.7
1972	2.1	3.5	5.9	3.1	5.8	5.9	6.5	7.0	5.8	2.5	-0.5	0.3	4.0
1973	0.1	3.5	5.0	6.3	5.9	4.8	5.0	4.4	4.4	-0.3	-2.1	-1.0	3.0
1974	0.0	3.7	4.6	5.5	5.0	5.8	5.3	5.8	4.6	1.5	-1.3	-0.8	3.3
1975	1.7	3.8	4.5	5.1	5.6	4.5	5.5	4.8	4.2	2.7	2.4	1.4	3.8
1976	4.7	7.9	8.4	7.7	9.6	5.2	5.7	5.8	4.0	-1.1	0.1	-1.6	4.7
1977	1.5	6.9	8.9	7.1	9.1	9.3	11.6	10.2	6.8	2.4	3.0	6.2	6.9
1978	8.5	7.3	9.2	9.9	9.6	10.6	10.9	10.1	7.9	7.6	4.3	6.8	8.6
1979	6.0	5.3	10.1	8.2	9.1	10.3	10.1	8.3	7.8	4.7	5.6	3.4	7.4
1980	5.8	8.9	7.7	9.4	9.6	9.6	10.8	9.9	9.7	6.4	3.9	6.2	8.2
1981	6.4	7.5	10.1	10.5	10.5	8.9	9.5	10.7	8.0	6.4	7.8	3.3	8.3
1982	5.3	3.1	6.3	6.8	8.1	9.6	10.1	8.6	9.6	8.3	5.7	5.4	7.2
1983	3.9	0.8	3.6	4.2	4.2	7.7	8.3	9.5	8.2	4.4	6.3	-2.0	4.9
1984	5.4	8.3	8.5	9.6	9.5	5.0	9.1	8.9	9.0	6.4	0.5	4.9	7.1
1985	0.4	6.4	9.5	8.7	8.6	10.0	9.7	4.6	8.1	6.0	4.2	2.7	6.6
1986	4.5	9.3	7.9	9.1	9.6	5.6	4.5	9.2	2.6	2.7	4.4	4.0	6.1
1987	7.6	6.8	6.7	6.8	5.8	9.4	9.8	5.8	8.7	7.7	4.0	5.2	7.0
1988	6.9	9.3	7.2	8.4	8.0	7.5	5.1	9.8	6.4	4.3	1.2	2.1	6.3
1989	2.9	5.3	8.9	9.4	8.8	10.1	10.6	9.5	9.1	5.1	1.5	2.1	6.9
1990	3.8	9.0	8.3	7.1	8.5	9.9	9.8	9.0	7.1	3.0	3.5	3.6	6.9
1991	7.4	7.4	7.5	7.1	8.4	9.5	8.6	8.1	7.2	2.8	3.2	3.1	6.7
1992	4.9	6.8	9.3	9.2	9.1	9.1	8.7	8.7	7.0	5.2	2.2	4.8	7.1
1993	5.7	8.7	9.2	11.2	11.0	9.3	9.8	10.7	8.5	5.3	6.8	7.5	8.6

Mean Minimum Temperature (ºC) For Reservoir site													
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1994	4.9	8.1	10.1	9.6	8.9	9.4	10.2	8.6	7.8	5.1	5.7	4.0	7.7
1995	8.7	4.7	9.4	9.4	8.6	9.4	9.3	9.1	5.7	4.6	6.7	6.4	7.7
1996	5.8	9.5	9.6	10.0	11.8	9.1	9.5	10.6	5.6	6.7	8.0	3.3	8.3
1997	8.9	6.1	9.1	10.1	10.4	10.8	11.7	10.2	10.0	9.4	4.7	5.3	8.9
1998	5.9	5.2	9.2	9.7	10.0	10.9	11.5	9.3	8.5	8.5	3.0	4.5	8.0
1999	4.9	8.7	9.7	8.1	10.8	8.9	9.2	10.7	6.8	6.4	3.7	6.2	7.8
2000	6.7	7.6	11.3	11.1	10.9	9.9	10.8	10.3	7.6	7.9	5.7	8.3	9.0
2001	7.7	7.3	9.3	8.8	8.6	9.9	10.9	5.6	10.5	7.1	6.0	1.5	7.8
2002	8.8	3.3	6.0	7.0	7.4	7.1	6.7	7.2	5.2	2.1	1.3	2.5	5.4
2003	4.5	3.6	7.9	10.4	9.6	6.4	7.1	6.7	7.3	5.2	2.0	-0.4	5.9
2004	3.0	4.4	8.1	9.3	7.9	8.5	8.1	6.3	6.0	1.5	0.5	4.4	5.7
2005	1.7	6.3	6.7	8.3	7.5	7.0	6.4	7.6	6.0	4.7	4.3	1.7	5.7
2006	6.0	6.8	6.5	6.9	9.0	6.2	7.9	8.3	6.5	3.1	2.7	4.6	6.2
2007	4.7	8.4	9.3	7.5	7.0	7.7	6.3	9.5	6.9	5.5	4.5	7.0	7.0
2008	5.5	3.1	6.4	8.6	8.9	8.8	8.8	9.3	6.8	4.4	3.7	2.4	6.4
2009	5.6	4.8	6.6	8.3	9.4	8.9	9.4	9.6	8.5	3.7	4.8	0.0	6.6
2011	4.7	6.6	8.7	6.3	5.7	9.7	9.3	0.0	0.0	0.0	0.0	0.0	4.2
2012	4.9	0.0	0.0	0.0	0.0	10.0	9.5	0.0	0.0	0.0	0.0	0.0	2.0
Average	4.9	6.0	7.6	8.0	8.2	8.3	8.7	8.0	6.8	4.4	3.4	3.2	6.5

Mean monthly Wind speed at 2masl (m^3/sec) at Ambo Station													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1974								0.6	0.6	0.6	0.8	0.9	
1975	1.0	1.3	1.2	1.4	1.2	0.9	0.8	0.6	0.7		0.9	1.0	1.0
1976	1.0				0.9	0.4	0.3	0.2	0.1	0.1	0.2	0.6	0.4
1977	0.4	0.4	0.5	0.6	0.5	0.3	0.2	0.2	0.1	0.2	0.2	0.3	0.3
1978	0.4	0.6	0.4	0.5	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
1979	0.3	0.3	0.4	0.7	0.7	0.5	0.4	0.2	0.2	0.2	0.2	0.2	0.4
1980		0.4	0.5	0.5	0.4	0.3	0.2	0.3	0.3	0.3	0.4	0.3	0.4
1981	0.8	1.1	1.2	1.2	1.2	1.0	0.7	0.7	0.6	0.7	0.9		0.9
1982	0.9	1.1	1.2	1.1									
1983				1.1	1.0	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.9
1984		1.0	1.3	1.3	1.2	1.0	0.9	0.9	0.9	0.8	1.0	1.0	1.0
1985	1.0	1.4	1.3	1.3	1.0	0.9	0.8	0.7	0.7	0.8	0.9		1.0
1986	0.9	1.2	1.2	1.1	1.2	0.9		0.8	0.7	0.8	0.9		1.0
1987				1.0	0.9	0.8		0.8	0.9	1.0	1.0	1.0	0.9
1988													
1989	1.0	1.0	1.2	1.0	1.0	0.9	0.8	0.8	0.7	0.8	0.7	0.9	0.9
1990	0.9	0.9	1.0	1.0	1.1	0.9	0.8	0.7	0.7	0.7	0.8	0.6	0.8
1991	1.0	1.0	1.0					0.7	0.7	0.7	0.8	0.8	0.8
1992	0.8	1.0	0.9	0.9	0.9	0.8	0.6	0.5	0.6	0.6	0.6	0.7	0.7
1993	0.8	0.8	0.9	0.8	0.6	0.6	0.5	0.4	0.4	0.4	0.4		0.6
1994		0.7	0.7	0.8	0.5	0.5	0.4		0.4	0.5			0.6
1995	0.6												0.6
1997							0.9	0.8	1.0	1.8	2.0	2.3	1.5

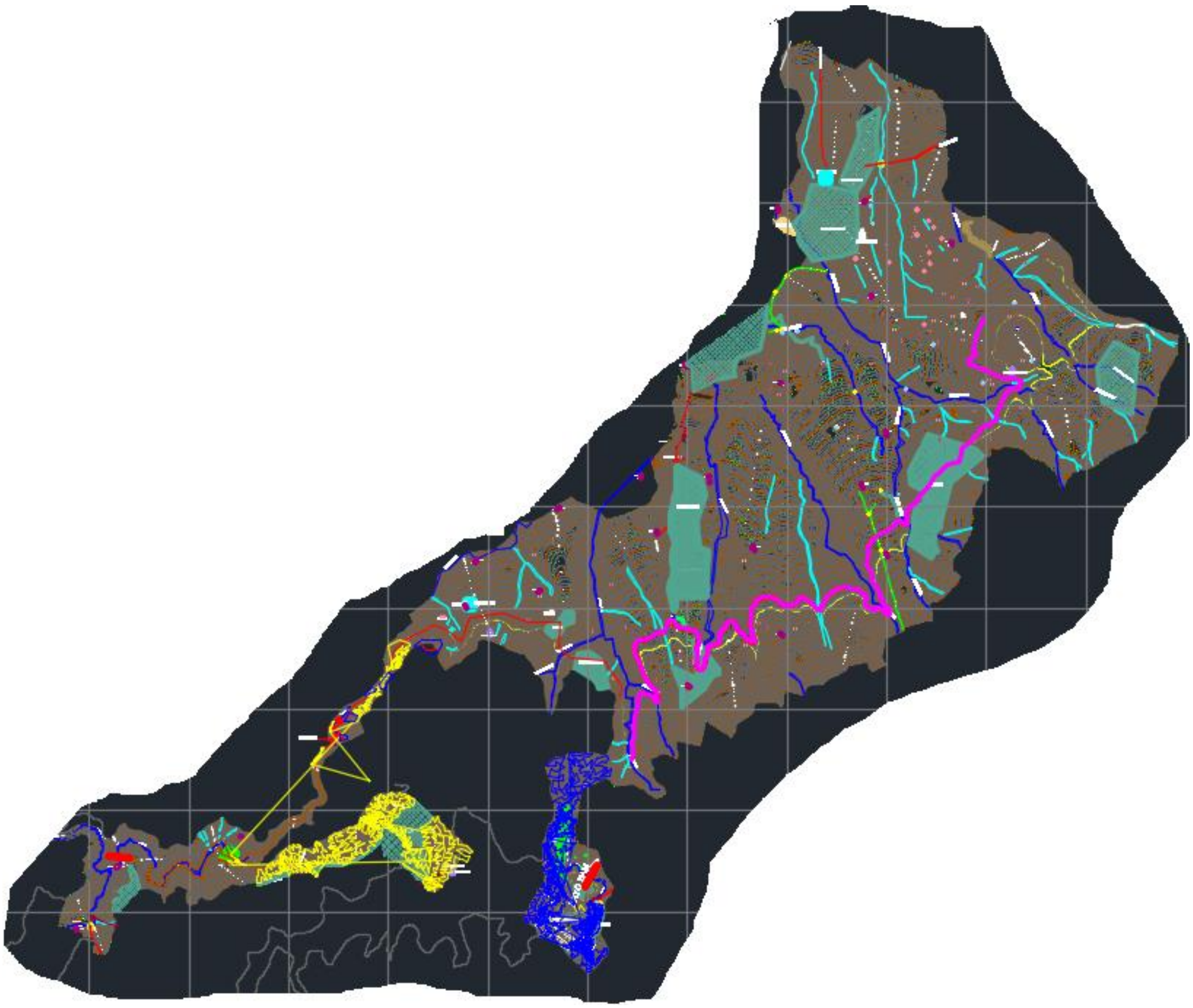
Mean monthly Wind speed at 2masl (m^3/sec) at Ambo Station													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1998	2.2	1.8	2.2	1.9							1.6	2.0	2.0
1999	2.1	2.7	2.3	2.2	1.7	1.3	1.0	0.9	0.9	1.1	2.1	2.3	1.7
2000	2.7	2.8	2.7	2.0	1.6								2.4
2001	1.9	2.2	1.8	2.1	1.5	1.1		0.7	1.0	1.3	1.9	2.2	1.6
2002	2.0	2.2	1.4	2.1	1.4	1.1	0.9	0.8	1.1	2.5	2.1	2.2	1.7
2003	2.1	2.3	2.3	2.3	2.0	1.8	1.3	0.9	0.9	1.8	2.3	2.4	1.9
2004	1.9	2.6	2.4	1.8	1.5	1.2	1.0	0.9	0.9	1.7	2.0	2.5	1.7
2005	2.1	2.7	2.0	2.0	1.7	1.1	0.8	0.8	0.9	1.3	1.6	2.2	1.6
Mean	1.3	1.4	1.3	1.3	1.1	0.8	0.7	0.6	0.7	0.9	1.1	1.3	1.0
Maximum	2.7	2.8	2.7	2.3	2.0	1.8	1.3	0.9	1.1	2.5	2.3	2.5	2.1
Minimum	0.3	0.3	0.4	0.5	0.4	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.3

Mean monthly Relative humidity (%) at Ambo Station													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1988										44	44	47	
1989	53	53	50	58	51	68	82	82	77	61	52	62	62
1990	38	63	56	52	53	77	79	80	78	52	48	46	60
1991	48	51	55	51		70	78	82	69	57	58	54	61
1992	58	70	53	55	59	75	80	82	73	62	53	56	65
1993	56	52			64	76	80	81	77	72	51	48	66
1994	42	56	53	46			79	81	77	56	54	45	59
1995	42	42	44	59									
1997								55	52	48	46	43	
1998	57	53	57	50							70	44	
1999	18	31	34	26		66	79	79	76	71	56	51	53
2001	49	41	58	51	58	73		78	73	58	50	46	58
2002	55	44	56	49	45	69	74	76	71	56	47	52	58
2003	47	39	50	50	44	60	63	72	78	54	47	47	54
2004	51	43	36	62	60	74	79	83	80				63
2005	51	43	36	62	60	74	79	83	80	59	47	37	59
Mean	48	49	49	52	55	71	77	78	74	59	52	49	59
Minimum	18	31	34	26	44	60	63	55	52	44	44	37	42
Maximum	58	70	58	62	64	77	82	83	80	72	70	62	70

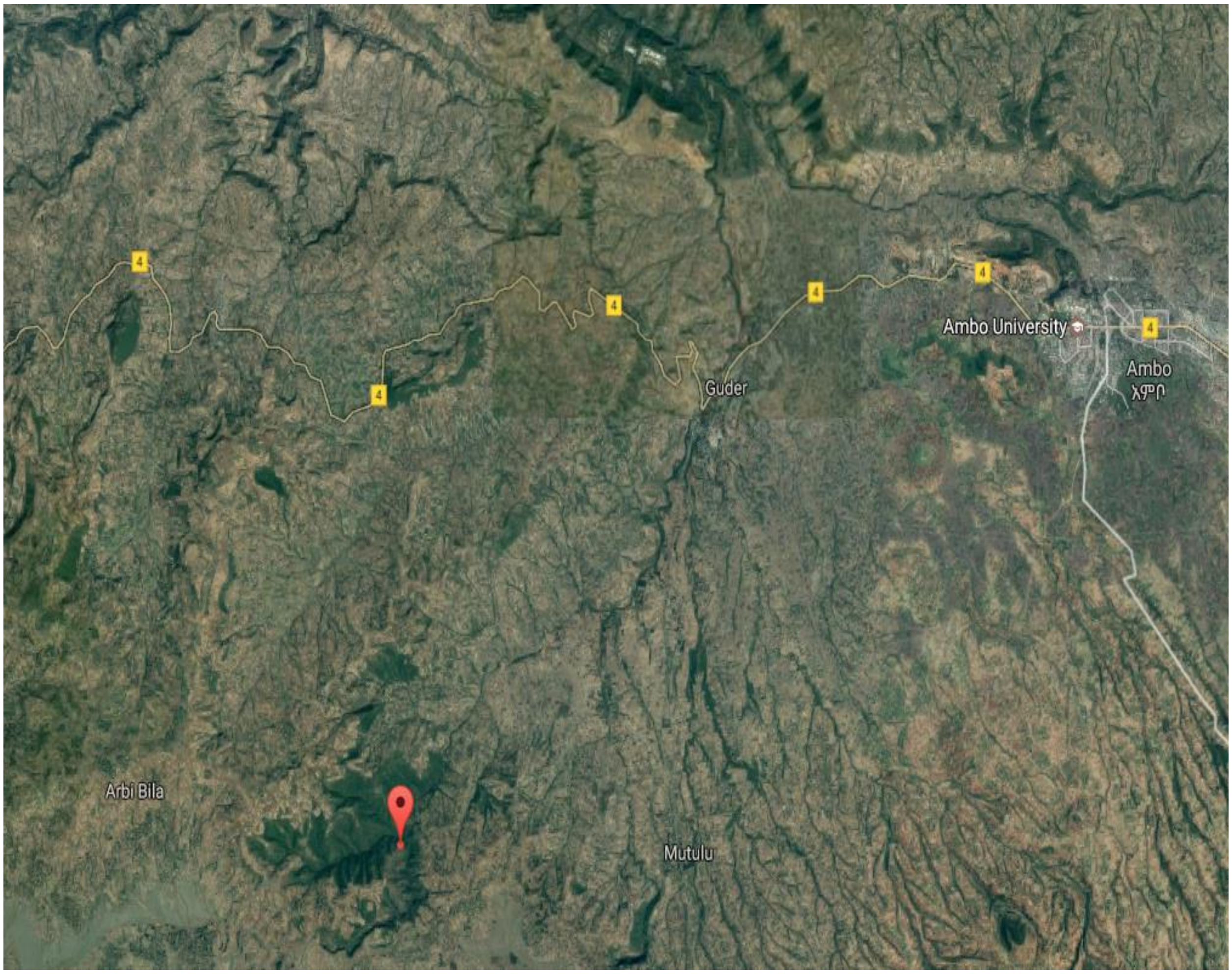
Mean monthly Sunshine hours (hrs.) at Ambo Station													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985										9.0	10.0	7.5	
1986	9.1	6.3	8.0	6.1	7.8	4.2	4.5	4.5	6.0	9.2	9.9	9.1	7.1
1987		5.5											
1988	8.8	7.0	7.1	6.9	7.1		1.7	4.2	5.1	8.1	8.4		6.4
1989		9.1	5.9	5.6	9.9	6.0	3.4	4.1		8.1		7.4	6.6
1990	9.4	5.4	7.5	6.6	7.5	6.6	7.5	6.8	3.4	4.0	4.8	9.3	6.6
2002	8.0	8.0	7.0	8.6			5.3	3.3	6.2	8.5			6.9
2003	9.2	9.0	8.3	7.4	9.1	5.1	2.7	3.3	4.0	9.6	9.6	9.3	7.2
2004	8.3	8.8	7.0	6.0	7.9	2.7	3.0	2.9	3.8	8.2	9.3	8.8	6.4
2005	8.1	9.4	8.1	6.4	5.8	5.7	3.7	4.5	4.4	9.1	9.7	10.6	7.1
Mean	8.7	7.6	7.4	6.7	7.9	5.1	4.0	4.2	4.7	8.2	8.8	8.9	6.8

Mean monthly Pitch evaporation (mm.) at Ambo Station													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1983										79.4	89.6	118.8	287.8
1986	282.6	205.7	241.2	167.5	187.8	78.1	52.9	34.7			185.0	243.7	1679.2
1987	221.6	134.8	144.6		127.0	60.0	39.4	37.9	80.8	150.3	175.7	203.2	1375.3
1988	193.4	155.8	257.4	165.3	161.5	15.5	22.8	30.8	46.7	57.7			1106.9
1989			8.3	192.7				18.8	48.4		76.2	92.4	436.8
1990	121.6	62.3	101.5		108.1	63.2	35.4	35.4	38.5	101.4	120.5		787.9
1991	75.2	59.3	69.6	105.3									309.4
1993	79.0	66.0	75.0	55.3	52.6	30.4	29.2	27.8	24.7	41.6	66.5	82.4	630.5
1999								40.8					
2000		337.5	360.8	183.6	161.2								
2001	207.0	245.8	177.8	239.0	156.5	80.1		52.4	85.6	152.8	218.6	235.3	1850.9
2002	201.3	226.4	190.1	246.9	211.8	86.2	50.2	38.1	101.0	250.9	272.0	221.2	2096.1
2003	248.3	291.9	267.4	218.8	299.4	117.6	56.8	53.8	61.8	210.6	244.0	246.5	2316.9
2004	203.7	272.0	250.8	108.1	234.5	97.9	60.2	53.7	69.4	185.7	235.6	225.4	1997.0
2005	222.0	338.9	242.4	252.3	108.8	99.8	59.1	50.7	21.1	132.5	217.7		1745.3
Mean	186.9	199.7	183.6	175.9	164.5	72.9	45.1	39.6	57.8	136.3	172.9	185.4	1620.5
Maximum	282.6	338.9	360.8	252.3	299.4	117.6	60.2	53.8	101.0	250.9	272.0	246.5	219.7
Minimum	75.2	59.3	8.3	55.3	52.6	15.5	22.8	18.8	21.1	41.6	66.5	82.4	43.3

AutoCAD Image of the Guder River Basin



Goggle Satellite Image of Bello Dam Site



Map of Bello Catchment

Projects that were considered for the study Before Selection of Bello Catchment

River	Location	Catchment Area	Head	Designed flow	Proposed installed Power
Tsatsadu	Alavanyo-Abehensi, Volta Region	40 km²	43 m	0,5 m³/s	320 kW
Nuboi	Afegame, Volta Region	30 km²	250 m		300 kW
Chemoga Yeda I	Debre Markos	364 km²	33 m	5.59 m³/s	4257 MW
Kasese	Mubuku I		200 m	3.7 m³/s	5 MW
South Mara	Mara		180 m		2.2 MW
Teski	Dangila	-	337 m	1.8 m³/s	4.8 MW
Upper Guder	Guder town	290 km²	260 m	6.25 m³/s	14.5 MW

Process of Project Selection Based on Available Data Types

	Tsatsadu Falls	**Wli Falls**	**Chemoga Yeda I**	**Mubuku I**	**South Mara**	**Teski**	**Upper Guder**
Hydrology							
River gauge flows as monthly time series data	✓	✓	✓	✓		✓	✓
Diversions	✓	✓	✓	✓		✓	✓
Instream or downstream (i.e. out of the basin study area) flow requirements	✓	✓	✓	✓		✓	✓
If using runoff model, precipitation and temperature time series data	✓	✓		✓		✓	✓
Reservoirs							
Inflow (if not on a river)			✓		✓		✓
Initial and total storage capacity			✓		✓		✓
Volume-elevation curve (to calculate evaporation or for hydropower)					✓		✓
Monthly evaporation rate							✓
Levels of reservoir storage (inactive zone, buffer zone, conservation zone, flood control zone)			✓		✓		✓
Hydropower: Max and min. turbine flows, tailwater elevation, efficiency, etc.	✓	✓	✓	✓	✓	✓	✓
Demand data (municipal, domestic, industrial, irrigation, livestock, etc.)							
Drivers (e.g., population, irrigated area, etc.) and projections of those drivers for scenarios	✓	✓	✓	✓		✓	✓
Withdrawal, either total or per activity (e.g., per person, per hectare)							
Consumption (% of withdrawal not returned) and routing of any return flow							
Monthly variation							
Loss and reuse							
Demand-side management policies, either current or possible future policies						✓	

Present Water Allocation System in the Catchment

	Volume Allocation	**Economic Allocation**	**Explicit Prioritization**
Power Generation ~Based on Plan~	1	2	3
Irrigation	2	1	1
Water Supply	3	3	2

Expected Future Water Allocation in The Bello Catchment

	Volume Allocation	**Economic Allocation**	**Explicit Prioritization**
Power Generation	1	1	1
Irrigation	2	3	2
Water Supply	3	2	1