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SMALL-SCALE HYDROPOWER POTENTIAL ASSESSMENT IN KOGA WATERSH

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Small-Scale Hydropower Potential Assessment in Koga Watershed

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A thesis submitted to the school of Research and Graduate Studies of Bahir DarInstitute of Technology, BDU in partial fulfillment of the requirements for the degree of MSc.degree in the Hydraulic Engineering in the Civil and Water Resource Engineering.

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DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the University and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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To my mother

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ABSTRACT

Ethiopia is abundantly endowed with water resources which by large can produce high hydropower. However, electricity shortage is one of the biggest problems the country is currently facing. Development of the small-scale hydropower with sub basins is vital in order to provide access to electricity for rural areas. In order to help address this problem, assessment and identification of potential sites for hydropower energy is needed. It is therefore necessary to locate the potential sites this renewable, alternate and non-polluting source of energy. Small hydropower projects (SHP) are emerging as solution for sustainable, eco-friendly, long term and cost- effective water or renewable energy resource for future.Therefore, the objective of this study was to assess and evaluates the potential hydro power locations in Koga watershed by using Multi criteria Decision Analysis.The Koga River Basin is located at 11° 22' 35.7243"N latitude and 37° 02' 7.0250" E longitude covers 280 km^2 watershed area which lies to the north of the Wezem Mountains.Different constraints of spatial data layers have been used. GIS based parametric flow duration curve method and Multi Criteria Decision Analysis was carried out in hydropower potential locations for small scale hydropower in Koga watershed, the input data was compiled and analyzed using GIS data layers, including topographic characteristics, discharge and precipitation data.Eleven potential sites were selected and ranked by setting different prioritization parameters. The minimum installed power in this watershed was set 11.74kW and the maximum installed power is 43.58kW. Generally, Koga Watershed hasa total installed power of 241.82kW and estimated to generate potential energy of 2118246.601kW or 2.12GWh annually.These results can be used to select the best areas for setting up hydropower plants in the Koga watershed. Moreover, this hydropower potential assessment can be used by planners and developers for future development of small scale hydropower by the regions.

Key Words: Koga, MCDA, SH.

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Abbreviations and acronyms

ABA	Abay Basin Authority
BoWIED	Bureau of Water, Irrigation and Energy Development
DEM	Digital Elevation Model
DSW_1	sub watershed 1 for drainage area weighted method
DSW_2	sub watershed 2 for drainage area weighted method
DSW_3	sub watershed 3 for drainage area weighted method
DSW_4	sub watershed 4 for drainage area weighted method
FDC	Flow Duration Curve
GIS	Geographic Information System
HP	Hydropower
IDW	Inverse Distance Weighted
Kw	Kilo watt
Kwh	Kilo watt hour
Gw	Giga Watt
KWS_{us}	Koga watershed up stream
KWS	Koga watershed
MADM	Multi Attribute Decision making
MCDA	Multi Criteria Decision Analysis
MODM	multi objective decision making
NMA	National meteorological agency
P	Annual precipitation
Q_{ave}	Mean annual streamflow
Raccu	Rain accumulation
Res	Reservoir
RSW_1	Sub watershed 1 to be regressed
RSW_2	Sub watershed 2 to be regressed
RSW_3	Sub watershed 3 to be regressed
RSW_4	Sub watershed 4 to be regressed

SHP	Small hydropower
SLP_{ave}	Average slope of the watershed
SSR	Sequential stream flow routing
UTM	Universal Transverse Mercator
WGS	World Geodetic System
HSR	Hydropower Status Report
PA	Power Africa
USDE	United States Department of Energy
JICA	Japan International cooperation Agency
WSHDR	World Small Hydropower Development Report

CHAPTER ONE

INTRODUCTION

1.1. General

Hydropower or water power (from Greek: ύδωρ, "water") is power derived from the energy of falling water or fast running water, which may be harnessed for useful purposes. Since ancient times, hydropower from many kinds of watermills has been used as a renewable energy source for irrigation and the operation of various mechanical devices(Elin and David, 2006).In the late 19th century, hydropower became a source for generating electricity. Crag side in Northumberland was the first house powered by hydroelectricity in 1878 and the first commercial hydroelectric power plant was built at Niagara Falls in 1879. In 1881, street lamps in the city of Niagara Falls were powered by hydropower.Since the early 20th century, the term has been used almost exclusively in conjunction with the modern development of hydroelectric power. International institutions such as the World Bank view hydropower as a means for economic development without adding substantial amounts of carbon to the atmosphere(Nikolaisen,2015).

Ethiopia is known for its huge water resources. It is known as the Water Tower of Africa as the result of the abundant water resources in the country.Developing this abundant resource holds the key to fulfill the country's economy growing energy and water demand in various sectors such as agriculture, transportation, industries and service.The population of the country increases with a growth rate of 2.3 per cent, has led to a staggering 14 per cent increase in energy demand. The country is making significant efforts to satisfy demand, maintain growth and supply a population where currently only 25 per cent have power connectivity(Dagmawi, 2015).

In terms of satisfying the growing energy demand the country clearly stated its vision in the Growth and Transformation Plan and Climate Resilient Green Economy strategy.The government published the GTP-II for 2016-20, with the objective of reaching total installed capacity over 17,208 MW. Hydropower is set to make up about 90 percent of the power supply (HSR,2017).

According to the Ethiopian Electric Power Cooperation, hydropower is the main source of power generating about 86 % of the electricity in the country. The country has enormous additional potential for extensive hydropower development. The national water resources are estimated to have the potential to generate as much as 30,000 MW of power from economically feasible hydropower projects (PA, 2016).

Ethiopia, as mentioned above is a country with a large population that is increasing in Africa and the distribution of the grid power supply in the country is very limited; 70 % of the country is out of electricity reach particularly in the rural areas where the majority of the population lives (IEA, 2014). Even in areas where there is grid coverage there are frequent blackouts and power shortages including the capital Addis Ababa, which is not only the country's political and economic capital but also the political capital of Africa. This has huge negative impact on the country's economy which is growing at a very fast rate. Studies indicate that the national demand will outstrip the supply capacity of the installed hydropower capacity in a few years, aside from impending demand for power export to neighboring countries which the country sees as a source of foreign currency (MoWIE, 2011).

Over half of the population is located geographically close to the electricity grid, but actual interconnection rates are just 25%. In 2015, the per-capita consumption ofelectricity in Ethiopia remains less than 100 kWh per year is farbelow the world average of 2,200 kWh.The national energy balance isdominated by a heavy reliance on traditional biomass energy sources such aswood fuels, crop residues, and animal dung it accounts for 89% of total domestic energy consumption (Lin and Herscowitz, 2016).

Energy is considered to be one of the key factors in economic development Sustainable energy resources are of vital importance and the energy resources, which are continuously available for long durations and which have no detrimental socialeffects, are compulsory for sustainable development. The fact that fossil originatedenergy resources are both exhaustible and have detrimental effects to environmenthas made inevitable to focus on alternative resources. The alternative energy resources,including hydropower, have some important advantages, such as being sustainable, renewable, environmentally friendly and clean resources. The inherent technical, economic and environmental benefits of hydroelectric power make it an important contributor to the future world energy mix, particularly in the developing countries (Murat, 2015).

So, assessing the potential sites of the River Basin is really important to indicate the total available power that the basin have and to compare to other known sites. Hydropower is emphasized as Ethiopia’s renewable energy sources. Ethiopia’s small hydro power potential is found to be an important energy source.

Small scale hydro or micro-hydro power has been increasingly used as an alternative energy source, especially in remote areas where other power sources are not viable. Small scale hydropower systems can be installed in small rivers or streams with little environmental effect on things such as fish migration. Most small-scale hydro power systems make no use of a dam or major water diversion, but rather use water wheels with little environmental impact (Jan and Torsten,2011).

1.2.**Statement of the problem**

The available water resources in Ethiopia have abundant hydro potentialwhich can be harnessed for the development of the country, but there is a lack of reliableand accurate information about the hydro potential in Ethiopia. The fundamental informationregarding the magnitude and distribution of the potential in the country helps in planning,formulating policies and strategies for the development of hydropower(Abtew and Melsew,2008).The need for energy is directly related to increments and life standards of the population, and currently the population of Ethiopia is rising at alarming rate. But the energy supplied from Ethiopian electric power corporation (EEPCo) is much lower than the population average total demand of energy. Relatively many ofthe towns and cities in the country are provided with electric power from theinterconnected grid system and other alternatives but almost all ruralareas and some small towns depend on energy from wood, fuel, dung and the like forvarious purposes such as cooking, warming and illumination(Mubarek, 2016).

This dependence on biomass is leading to drastic damage on the environment. The use of fuel wood as a source of energy should be reduced and replacedby environmental friendly source of energy, hydropower. But much of the Ethiopia's smallhydropower potential remains untapped. So, first step toremedying the situation is through dissemination ofreliable data that can inform policy development andenergy planning, as well as guide investors in entering renewable energy markets where this study is intended to do by identifying the potential sites of hydropower.

1.3.General objectives

The general objective of the study is to assess and evaluate small-scale hydropower potential in Koga river basin using GIS and MCDA.The specific Objectives of the study includes

1. Evaluating the flow rate of each points in the watershed using GIS techniques.
2. Evaluation and ranking of possible potential site for hydropower development in the Koga watershed by using MCDA.

1.4.Research questions

To achieve the aforementioned objectives, this paper should analyze the following research questions:

1. What is the actual state of small-scale hydropower potential in Koga watershed?

1.5.Significance of the study

At the end of this study, water resource engineers and decision makers are able to access for the information of low flow and its variability of the Basin that will be used for the design and planning of new Small-Scale Hydropower projects, but the main purpose of this paper is to exploit the hydropower potential of the basin with suitable site location that will be an input for further investigation and to alarm related organizations and private sectors to focus on it.

1.6.**Scope of the study**

This study does not deal with detail and deep investigation of hydropower development. It is limited to assessment of thepotential,the basin has so that the door is opened for further study and detail investigation and project implementation.

CHAPTER TWO

LITRATURE REVIEW

2.1. General

Hydropower engineering refers to the technology involved in converting the pressure energy and kinetic energy of water into more easily used electric energy. The prime mover in the case of hydropower is a water wheel or hydraulic turbine which transforms the energy of the water into mechanical energy. Until the mid-1970s, the pattern of hydro development was to develop bigger and bigger units because smaller hydro plants were not competitive with fossil fuel power plants (Warnick et al, 1984.

From the beginning of electricity production hydropower has been, and still is today, the first renewable source used to generate electricity. Nowadays hydropower electricity in the European Union -both large and small scale - represents according to the White Paper, 13% of the total electricity generated, so reducing the CO2 emissions by more than 67 million tons a year. But whereas the conventional hydro requires the flooding of large areas of land, with consequent serious environmental and social costs, the properly designed small hydro schemes (less than 10 MW installed capacity) are easily integrated into local ecosystems.Small hydro is the largest contributor of electricity from renewable energy sources, both at European and world level (Penche, 1988).

2.2. Advantages of hydropower

Hydro power is considered to be number one among other renewable energies.One of the reasons is its capability of storage, which is not possible for solar and wind, as they are intermittent sources of energy production and other advantages are listed below: -

- The technology is natural, reliable and offer flexible operations.
- Running costs are very low as compared to thermal or nuclear power stations.
- Hydraulic turbines can be switched on and off in a matter of minutes and gives very high efficiency over considerable range.

- This fresh water storage protects aquifers from depletion and reduces the possibility of droughts or floods.
- Hydropower is a clean source of electricity because it does not generate any toxic waste products, reduces air pollutions and contributes to the slowdown of global warming.
- Hydropower facilities bring electricity, roads, industry, commerce and employment to rural areas, developing the regional economy and increasing the quality of life.
- Hydropower provides national energy security which is a key issue for developing countries. Water used from rivers is a domestic resource that is not subject to fluctuations in fuel prices(Dody, 2015).

Even though the potential of hydro power described above makes this technology seems to be perfect and promising, it does not mean this technology has no drawbacks. Some of these are: -

- Hydropower can only be used in areas where there is sufficient supply of water.
- Dams containing huge amounts of water have the risk of failure which may cause catastrophic results such as flooding.
- The construction of a dam may have serious impact on the surrounding areas by changing the downstream environment, affecting both plant and animal life and creating problems such as relocation of people or historical artifact.

Generally, hydropower is the most preferable source of energy especially in developing country(Dody, 2015).

2.2.1. Importance of Small-Scale Hydropower

As an electricity generation technology, Small-Scale Hydropower is a very efficient energy technology because electricity is generated directly from the shaft power. Small-Scale Hydropower system for power supply is a well matured technology as the case with solar photovoltaic and wind energy systems (Kaunda et al.,2012).

2.3. **Contribution to rural electrification**

More than two billion people in the world, mostly in developing countries, are still living without benefit of electricity. For these people, access to electricity, even if limited in capacity, should improve the quality of life dramatically as a heat and light source. The daily life would be enriched,and the level of medical equipment and services as well as the safety of stored vaccines would beupgraded. In spite of an obvious need for the electrification in these regions, the majority cannotenjoy electricity because they live in localities which are away from the national power grid. Highconstruction costs for the extension of transmission lines from the grid make the governments indeveloping countries unable to respond to the needs of the local people(PA,2016).

Small scale hydropower can become an optimal distributed power source for the electrification ofremote regions. Costs associated with the construction and operation of the plants and distributionlines can be reduced by having local organizations take responsibility for the small-scale hydropower projects.And also, improvement of livelihood and empowerment of the local people can be achieved by making use of hydropower which is stable energy and regional resource(USDE, 2006).

2.4. **Global environmental issues**

Hydropower is a renewable energy which offers excellent advantages against the negative factors of environmental contaminants such as carbon dioxide (CO_2) and other fuel gases. With the increasing use of energy in recent years, the combustion of fossil fuels has resulted in an increasing volume of carbon dioxide causing urgent global warming and other environmental problems. The increase has also resulted in acid rain caused by gaseous pollutant (So_2& NO_2) emissions into the atmosphere. In developing countries, wood and charcoal fuels are the major energy resources, resulting in deforestation, soil erosion and ever-advancing desertification. Under these circumstances, the development of non-fossil energy sources like hydropower is growing in demand(Ian, 2010).

2.5. Use of local people and technology

Training local people properly so that they can manage the power plants themselves is a huge advantage. Through more than 100 years of practical application, hydropower generation technology is already well- established. Transfer of the appropriate technologies to the engineers indeveloping countries enables the production of safe, reliable electric energy, since small scale hydropower does not need such an advanced technology as large-scale hydropower and can utilizetraditional technology such as irrigation facilities(JICA, 2011).

2.6. Stable electricity rate

Energy generated by small scale hydropower plants is domestic and renewable, and the plants incur no fuel costs. In recent years global, economic development tends to increase prices for fuels suchas oil and coal. Major forms of power are reliant on fuels and their operating costs rise significantly year after year. However, once a hydropower plant is completed, it will provide stable low-priced power for a long period, and be unaffected by any changes in fuel prices(Kaunda et al.,2012).

2.7. Environmental impacts of small-scale hydropower

The impacts of small-scale hydropowerschemes are likely to be small and localized,providing best practice and effective site planning are used. Nevertheless, small-scale hydropower stillhas an impact on the environment whether large or small. The factors that harm ariver habitat with large hydropower projects are also present with small projects:interrupted water flows, barriers to animal movement, water loss from evaporation,involuntary population displacement and loss of biodiversity from the sacrificedportion of river are some examples. The most obvious and difficult impacts tomitigate are those on fish and the river morphology with all its consequences in theflow, sedimentation, continuity, water quality(Reshmi, 2016).

In Koga river basin, there is one existing earthen dam used for Irrigation but implementing a small-scale Hydropower will not have negative impacts on this dam. Because in this paper Run-off-River schemes will be found out and therefore the water flows directly in to the main river without decreasing the amount of flow.

2.8.Global Status of hydropower development

According to HSR, (2017)worldwide hydropower development increases with 31.5 GW new capacity installed in 2016. This figure includes 6.4 GW ofpumped storage – nearly double the previous year – while there is a further 20 GW of pumped storage under construction globally. This is indicative ofhydropower's increasingly important rolein providing flexible support to renewableenergy systems, as countries around the world take steps to meet the carbonreduction goals of the Paris Agreement.

In a world facing complex water and energy challenges and rapid population growth, the multiple benefits that hydropower can offer are needed more today than ever before. Furthermore, a large proportion of the world's untapped hydropower resources are located in regions where new development has the greatest potential to positively affect people's lives. However, many barriers to progress in developing countries remain, in particular at the preparation phase of projects where it is crucial to ensure they are built in a sustainable way and in the right place(HSR, 2017).

Since 2004, there has been a resurgence in hydropower development, particularly in emerging markets and less developed countries. Significant new development is concentrated in the markets of Asia (particularly China), Latin America and Africa. In these regions, hydropower offers an opportunity to supply electricity to under-served populations and a growing industrial base, while at the same time providing a range of complementary benefits associated with multi-purpose projects (WE, 2016).

Total hydropower generation for the year of 2016 was estimated at 4,102 TWh, the greatest ever contribution from a renewable source. An estimated 31.5 GW of hydropower capacity was put into operation, including pumped storage, bringing the world's total installed capacityto 1,246 GW.China once again led the market for new development, adding 11.7 GW of new capacity, including 3.7 GW of pumped storage (HSR, 2017).

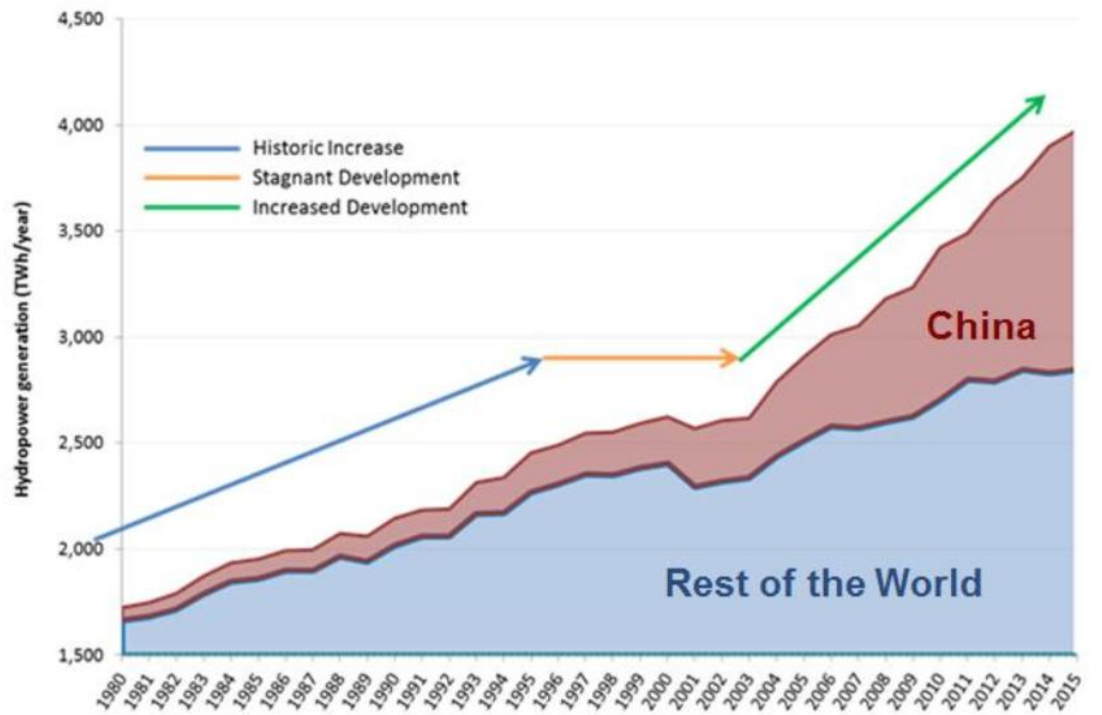

Figure 1: Global total hydropower generation since 1980. (World Energy, 2016)

2.9.**The Ethiopian energy sector**

In the past decade, Ethiopia's economyhas been one of the fastest-growing inthe world, averaging an 11 per centincrease in GDP each year. Record GDPgrowth, coupled with a populationgrowth rate of 2.3 percent, has led to astaggering 14 percent increase inenergy demand. The country is makingsignificant efforts to satisfy demand,maintain growth and supply apopulation where currently only 25 percent have power connectivity(HSR, 2017).

The untapped hydropower potential in the country amounts to around 30,000 MW. Hydropower currently accounts for over 80 percent of the electricity produced in

Ethiopia. The landlocked country is set to become a regional leader in the power supply business, exporting electricity to countries across the Eastern Africa Power Pool (EAPP) and beyond (PA, 2015).According to (HSR, 2017), Ethiopia is the first country in Africa and the forth in the world in 2016 new installed capacity following China, Brazil, and Ecuador with 11740, 6365, and 1987 MW respectively by producing 1502 MW. Generally, Ethiopia has 4054 MW total installed capacity and targets to have 22,000 MW total installed capacity by 2030.

The Ethiopian Electric Power Corporation (EEPCo) was named in 1997- after serving previouslyin the name of the Ethiopian Electric Light and Power Authority, which was established in 1956.EEPCo is a government owned utility responsible for the generation, transmission, distributionand sales service of electric energy throughout Ethiopia. TheEEPCo has two electricity supply systems: The Inter -Connected System (ICS) and the Self-Contained System(SCS). The main energy source of ICS is hydropowerplants and for the SCS the main sources are minihydropower schemes and diesel power generatorsallocated in various areas across the country as shown in figure 2-2 (EEPCo, introduction to Ethiopian Electric Power Corporation)

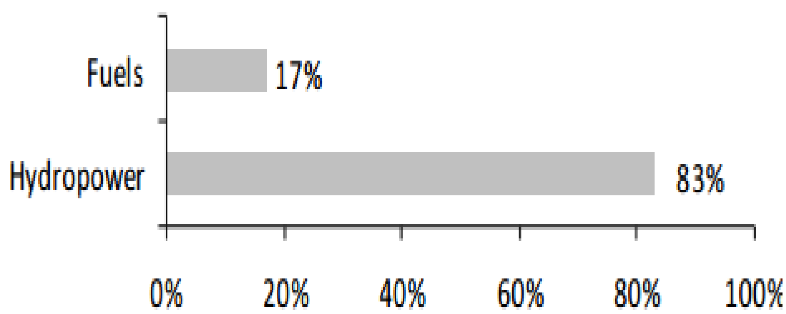

Figure 2: Electricity generation in Ethiopia

Ethiopia is also rapidly expanding itstransmission and distribution network in order to light up the country. Existing cross-border interconnections include 100 MW to Sudan and 50 MW to Djibouti, while the 1,000 km Eastern Electricity Highway Project (500 kV) will be capableof exporting 2,000 MW to Kenya uponcompletion in 2018. The country hasambitions of becoming the ‘energy hub’within the Eastern Africa Power

Pool(HSR, 2017). So, assessing and constructing small-Scale hydropower is important for small towns and rural areas to light and cook using electricity.

2.9.1. Rural electrification in Ethiopia

The current energy regime in Ethiopia, one that is heavily reliant on the burning of biomass, has had major implications for the environment. The use of traditional fuels as the main source of energy by rural households, which comprise the vast majority of Ethiopia's population, is especially an area of concern. Deforestation, land degradation, decreases in agricultural productivity, and increased greenhouse gas emissions have resulted from these patterns of unsustainable fuel consumption, and are further exacerbated by Ethiopia's growing population's increased energy demands (Jillian, 2011).

The rural Electrification fund(REF) was established in 2003 by proclamation No. 317/2003, which is an institution responsible to provide loan and technical services for rural electrification projects to be carried out by private operators, cooperatives and local communities and more specifically for those projects operating on renewable energy sources; and to encourage the utilization of electricity for production and social welfare purposes in rural areas. "rural electrification project" means a single activity of designing, constructing, generating, transmitting, and performing other related activities to achieve the distribution of electricity in rural off-grid areas (Nardos, 2011).

Findings suggest that Ethiopia has an abundance of potential renewable energy sources that, if pursued, could significantly alter the nature of Ethiopia's energy sector and cause a shift away from the combustion of biomass and towards a future of country wide electrification. Efficient cook stove technologies are available to increase energy efficiency immediately while Ethiopia is still reliant on biomass, with Uganda providing an example of a country successfully reducing fuel wood consumption through improved cook stove use. In the short- to medium-term, off-grid small-scale hydropower can increase rural access to electricity, further reducing demand for traditional biomass fuels(Jillian, 2011).

2.9.2. Small-scale hydropower in Ethiopia

According to Abtew and Melsew, (2008), Small scale hydropower is estimated to be 10% of the total hydropower potential of the country. However, in terms of technical feasibility, the potential could be reduced by more than half to about 5% due to inaccessibility, and proximity to grid and service centers.The available potential of small scale hydropower in the country has hardly been exploited so far due to government focus on large scale hydropower development to meet the energy demand of the country. As feasibility study, the government identified around 299 hydropower potential sites within eleven river basins with a total potential of 7877 MW including both large and small hydropower.The potential for small scale hydropower lies in western and southwestern Ethiopia, where annual rainfall ranges from 300 mm to over 900 mm especially in Omo Gibe basin and Abay basin.The Abay river basin is the largest basin in terms of hydropower potential site estimated about 79000 Gwh/yr. which cover about 49% of all river basins(Abtew and Melsew,2008).

In the past majority of small scale hydropower schemes in the country were abandoned due to the encroachment of the national grid with cheaper and more reliable electricity. Ethiopia has a potential for SSHP of 1500MW but has only 6MW installed capacity(WSHDR, 2016).Currently only one small and two mini hydropower (MHP) schemes are functional under EEPCOs Self Contained System (SCS), namely, Sor (5 Mw), Yadot (350 kW), and Dembi (800 kW), with a cumulative installed capacity of 6.15 MW. Moreover, another four new small hydropower schemes (Gobecho I = 7 kW, Gobecho II = 30 kW, Hagara Sodicha = 55 kW, and Ererte = 33 kW) have been installed in the southern part of Ethiopia in Sidama zone with the help of the German Cooperation Organization (GIZ) as pilot project in 2011 (Meder,2011).

2.10. **Plant classification of hydropower**

The hydropowerplant is classified broadly into diff erent classes based on head, hydraulic characteristics, and installed capacity.

2.10.1. Classification based on plant capacity

There is no international consensus on the definition of categorizing hydropower regarding to installed capacity because of different development policies in different countries. However, classifications vary from country to country asthere is currently no internationally agreed standard. Ethiopiauses a classification of hydropower systems which diff ersfrom other countries (Meder,2011).as shown in Table 2-1.

Table 2-1: Hydropower Classification in Ethiopia

No.	Terminology	Capacity
1	Large	>30 MW
2	Medium	10–30 MW
3	Small	1–10 MW
4	Mini	501–1000 kW
5	Micro	11–500 kW

6	Pico	≤10 kW

2.10.2. Classification based on hydraulic characteristics

Based on hydraulic characteristics hydropower plants can be grouped in to four classes of run-of-river schemes, Storage schemes, Pumped-Storage schemes, and Tidal power development schemes.The large majority of small hydro plants are «run-of-river» schemes, meaningsimply that the turbine generates when the water is available and provided bythe river. When the river dries up and the flow falls below some predeterminedamount, the generation ceases. This means, of course, that small independentschemes may not always be able to supply energy, unless they are so sized thatthere is always enough water **(**Penche, 1988).

Water is supplied from large storage reservoir that have been developed by constructing dams across rivers. Generally, the excess flow of the river during rainy seasons would be stored in the reservoir to be released gradually during periods of lean flow. Naturally, the assured flow for hydropower generation is more certain for the storage schemes than the run-of-river schemes. (Reshmi, 2016)

2.10.3. Classification based on head

The figure may vary depending on the country standard but according toDereje(2005), as cited in Ferede (2015), generally classified aspresented in table 2-2

Table 2-2: classification of hydropower based on head.

No.	Types of plants	Head range (m)
1	Low head plants	15
2	Medium head plants	15-50
3	High head plants	50-250
4	Very high head plants	>250

2.11. Flow estimation for ungagged sites

In order to determine the amount of water which is available at individual sites, oneneeds to know or to be able to estimate water flows. Several places on rivers havebeen considered to use, store, or divert water resources. On the other hand, only in limitedplaces, there are sites where gages are used to record hydrological data. At gaged locations,monitoring equipment records data for flow rate or stage along with the time of measurement. There are several available methods for distributing flows from gaged to ungagged sites,ranging from the very simple to the complex and laborious. On the simple side, the most widely used method is the distribution of flow in proportion to drainage area. In this case, thestream flow per unit area of watershed is assumed constant, and the naturalized flow at theungagged site is calculated as the naturalized flow at the gaged site multiplied by the ratio ofungagged to gaged areas (Najib, 1994).

On the other extreme, there are generalized computer models ofwatershed hydrology that are able to compute sequences of daily or monthly stream flows fora given precipitation unit. Some of the most widely used methods are as follows:

1. Proportional relationships of discharge to change in hydrologic parameters.
2. Modified curve number method developed by Natural Resource Conservation Service
3. Regression equations fitted between gaged and ungagged locations

4. Hydrologic simulation, e.g. HEC-HMS, SWAT

The first two methods are used frequently especially in the beginning stages of water resources studies. In the first method, the extending of flow rate to the ungagged location isbased on drainage area and rainfall. In this method, the proportion of river flow to the unitarea of watershed is considered constant. The advantage of hydrologic simulation is theaccuracy of its predictions. Their major disadvantage is that they require considerable expertise, time, effort and its weakness to determine each point discharge for the whole watershed to be used effectively. (Dayyani et al., 2003).

2.12. **Flow duration curve**

The flow-duration curve is a cumulative frequency curvethat shows the percent of time during which specified discharges wereequaled or exceeded in a given period.The flow-duration curve is the integral of the frequency diagram.Perhaps a simpler concept of the flow-duration curve is that it isanother means of representing streamflow data combining in one curve the flow characteristics of a stream throughout the ranges ofdischarge. Although the flow-duration curve does not show thechronological sequence of flows, it is useful for many studies (Viola et al., 2011).

To prepare a flow-duration curve, the daily, weekly, or monthlyflows during a given period are arranged according to magnitude,and the percent of time during which the flow equaled or exceededthe specified values is computed. The curve, drawn to average theplotted points of specified discharges versus the percent of time during which they were equaled or exceeded, thus represents an averagefor the period considered rather than the distribution of flow withina single year.

There are two principal methods used to construct flow-duration curves. These includes

1. Calendar-year method and
2. Total-period method.

In the calendar-year method, the discharges for one year are rankedaccording to magnitude (order number 1, 2, 3 * * *). This process repeated for each year of record. The discharges for each ordernumber are averaged. A block diagram is plotted with the abscissain time units and the ordinate in discharge units. If a day is thetime unit, the first item plotted is the average of the annual maximumdays for the period of record. A percent-of-time scale can be constructed for the abscissa, if desired. The calendar-year method giveslower values for the high discharges and higher values for the lowdischarges than the more accurate total-period method(Searcy,1969).

In the total-period method, all discharges are placed in classes according to their magnitude. The totals are cumulated, beginningwith the highest class, and the percentage of the totaled time is computed for each class. The data are then plotted with the discharge as the ordinate and the time in percent of total period as the abscissa.All complete years of record can be used to prepare a flow-durationcurve; records for partial years should be excluded. The years forwhich records are complete need not be consecutive, but the recordsused should be for years in which physical conditions in the basin,such as artificial storage, diversions, or other manmade influences,were essentially the same(Searcy,1969).

FDC can be developed using average stream flow data. Hydropower design and hydro potential calculation require streamflow data which can be obtained from the flow duration curve.The shape of FDC issignificant in evaluating the stream and basin characteristics. The slope of the curve atupper end shows the type of flood regime the basin is likely to have, whereas the slope ofthe lower end of the curve indicates the ability of basin to sustain low flows during dry seasons(Dashora et al, 2014).

2.12.1. Regionalization ofFDC

To overcome the problem of inappropriate flow data, regionalization of flow duration curve is a useful tool. Researchers in recent years have developed various FDC estimation techniques for ungauged sites. These methods can be divided into different approaches: with physiographic parametersand withoutphysiographicparameters(Dashora et al, 2014).

Physiographic parameters include rainfall-runoff relation and basin characteristics such as area and slope of catchment. These parameters of gauged site are transferred to ungauged site for estimation of flow. Similarity of geographical conditions of both gauged and ungauged sites can be the basis for applicability. For applying flow estimation without physiographical parameters only discharge data need to transform in to mathematical model using dimensionless flow techniques. These methods are applicable in the absence of information about geographical condition, remotely located sites or in sufficient data length(Dashora et al, 2014).

2.13. Multiple regression analysis

Commonly the hydrologist knows, from first principles, from experience, or from analysis of regression residentials, that improved explanation of the variation in dependent variable may be achieved by simultaneously considering the effects of more than one explanatory variable, in such cases, multiple linear regression should be used rather than simple linear regression, which is the relationship between two variables.

The multiple linear regression model takes the form:

$$Y = \beta_0+\beta_1 x_1 + \beta_2 x_2 + \beta_k x_k + \epsilon \quad 2\text{-}1$$

where y is observation of the response (or dependent variable), x is observation of the explanatory variable,$\beta_0$is intercept,$\beta_1$isslope, ϵ israndom error of residual, andK is number of explanatory variables.

A common type multiple linear regression model in hydrology is the sream flow basin characterstics model. Some stream flow statistic (such as the mean flow or the 10 year flood) is estimated as a function of drainage basin area , average basin altitude, percentage of basin forested. A similar approach is the basin yeald basin characterstics model in which, fore example, basin dissolved solids yield is estimated as a function of average rainfall, percentage of basin area underlain by carbonate rocks, and basin population.(David, 1998).

It is assumed that for any set of fixed values of X_I, X_2,. . . , X, thatfall within the rangeof the data, the linear equation (2-1) provides an acceptable approximation of the true relationship betweenY and the X’s (Y is approximatelya linear function of theX’s, and E measures the discrepancy in that approximation). In particular,ϵ contains no systematic information for determining Y that is notalready captured by theX's(Shewhart and Wilks, 2006).

The interpretation of the regression coefficients in a multiple regression equationis a source of common confusion. The simple regression equation represents a line, while the multiple regression equation represents a plane (in cases of two predictors) or a hyperplane (in cases of more than two predictors).In multipleregression, the coefficientβ_0, called the constant coeficient, is the value of Y when X1 = X2 = . . . = X, = 0, as in simple regression. The regression coefficient β_j, is also called the partial regression coeficient because Pj represents the contribution of Xj to the response variable Y after it hasbeen adjusted for the other predictor variablesj = 1,2,. . . ,p, has several interpretations. It may be interpreted as the changeinY corresponding to a unit change in X_j when all other predictor variables areheld constant. Magnitude of the change is not dependenton the values at whichthe other predictor variables are fixed.In practice, however, the predictor variablesmay be inherently related, and holding some of them constant while varying theothers may not be possible(Shewhart and Wilks, 2006).

2.14. Geographic information system (GIS)

Geographic information systems (GIS) a tool designed for spatial analysis which providesfunctionality to capture, store, query, analyze, display and output geographic information. As such they have biginfluence in spatial decision-making process. Recent development in field of decision making leads to dramaticimprovements in the capabilities of GIS in location analysis. These developments are reviewed through analysis of attribute data especially procedures for Multi-Criteria and Multi-Objective location analysis in GIS. Specialemphasis is given to the problems of incorporating subjective influence in the context of decision making; theexpression of uncertainty in establishing the relationship between evidence and the decision to be made; proceduresfor the aggregation of evidence in the presence of varying degrees of trade-off between criteria; and procedures forconflict resolution and conflict avoidance in cases of multiple objective decision problems(Eastman,1998).

The GIS-based analysis can be divided into the digital terrain analysis and the hydrological modeling.

2.14.1. Digital terrain analysis

The objective of the digital terrain analysis is to identify catchment boundaries and to model the topographic characteristics of the catchment as well as the resulting stream network. The GIS-based terrain analysis is subject to the presumption that the direct runoff of any given cell flows downhill in the direction of the greatest slope. To allow all cells of the input Digital Elevation Model (DEM)-data draining downhill, the elevation model is cleared of errors such as surface depressions, which would act as water sinks. To calculate the flow direction for each grid point, the deterministic 8 (D8) algorithm is applied. According to the flow direction of all cells, each grid point is assigned a value corresponding to the number of cumulated cells flowing to it. Cells with no inflow correspond to the pattern of ridges and form catchment boundaries (Jensonand Domigue (1988) as cited in Grett and Torsten, 2015).

One of the most important applications of GIS is thedisplay and analysis of data to support the process ofenvironmental decision-making. A decision can bedefined as a choice between alternatives, where thealternatives may be different actions, locations,objects, and the like. For example, one might need tochoose which is the best location for a hazardouswaste facility, or perhaps identify which areas will bebest suited for a new development(Nazli,2009).

2.15. **Selection of a hydroelectric power plant**

While selecting a suitable site, if a good system of natural storage lakes at high altitudes and withlarge catchment areas can be located; the plant will be comparatively economical. Anyhow the essentialcharacteristics of a good site are: large catchment areas, high average rainfall and a favorable place forconstructing the storage or reservoir. For this purpose, the geological, geographical and meteorologicalconditions of a site need careful investigation. The following factors should be given careful consideration while selecting a site for a hydro-electric power plant:

- Water availability
- Water Storage
- Head of Water
- Distance from Load Center
- Access to Site (Raja et al, 2006).

2.16. Multi criteria Decision analysis (MCDA)

Either individuals or a group of people faces with spatial decision making in everydaylife. Choosing a new development area, selecting a new residential area, or managingthe infrastructure system requires spatial organization. Most of the individual spatialdecisions are made by taking into account the heuristics or the past experiences.However, more reliable and analytical methods are needed for organizations to supportspatial decision making (Jankowski et al., 2001).

Broadly, decisions can be classified into twoextensive categories – policy decisions and resource allocation decisions. Resource allocation decisions,as the name suggests, are concerned with controlover the direct use of resources to achieve aparticular goal. Ultimately, policy decisions have asimilar aim. However, they do so by establishinglegislative instruments that are intended to influencethe resource allocation decisions of others. Thus, for example, a government body might reduce taxes onland allocated to a particular crop as an incentive toits introduction. This is clearly a policy decision; butit is the farmer who makes the decision aboutwhether to allocate land to that crop or not.

To be rational, decisions will be necessarily basedon one or more criteria – measurable attributes ofthe alternatives being considered, that can becombined and evaluated in the form of a decisionrule. In some circumstances, allocation decisions canbe made on the basis of a single criterion. However,more frequently, a variety of criteria is required. Forexample, the choice between a set of waste disposalsites might be based upon criteria such as proximityto access roads, distance from residential andprotected lands, current land use, and so on (Jiang &Eastman,2000).

The rationale of Multi Criteria Analysis (MCA) models is based evaluation of multiple criteria to find a solutionof a problem with multiple alternatives. These alternatives can be evaluated by theirperformance characteristics, in other words, decision criteria (Jankowski et al., 2001).Basically, MCDM enables the decision maker to evaluate a set of alternatives accordingto conflicting and incommensurate criteria. A criterion is a generic term which may beconstituted by both attributes and objectives. Therefore, MCDM can be classified intotwo groups: Multi-attribute decision making (MADM) and multi-objective decisionmaking (MODM) (Malczewski, 1999).

In the MADM approach, each alternative is evaluated with respect to various attributesand final choices are made among potential alternatives. On the other hand, MODM isbased on the decision maker ‘s objectives which can be a statement about the desiredstate of the system. Several different attributes might represent objectives. In otherwords, MODM problems deal with the objectives which require establishing specificrelationships between attributes of the alternatives (Malczewski, 1999).

Further classification depends on decisions under certainty and decisions underuncertainty. If decision makers have adequate knowledge about all the variables andparameters of the problem, the decision can be classified as decision under certaintywhich is also called deterministic decision-making. However, many real-world decisionsare very complex to be deterministic. Thus, decision associated with a problem involvingrandom and uncertain variables, and vague or incomplete data are considered asdecision under uncertainty. Two types of uncertainty may exist in a decision situation:uncertainty due to vague, incomplete or limited information or variability due torandomness. As a result, both MADM and MODM problems can be classified furtherinto probabilistic and fuzzy decision-making problems. Probability theory or statistics are used to solve problems involving random variables. On the other hand, fuzzy set theory tools are used to solve problems that involve vague and incomplete data.

Presence of incomplete information leads to results that may not be represented by crisp numbersbut rather with degrees. These types of problems are handled with fuzzy sets theory(Zadeh, 1965).

The determination of criterion scores depends greatly on the type of evaluation problem and the way the problems are treated. However, in general it can be said that an indicator must be based on the best available information. By indicator is meant the measuring rod by which the value of a choice possibly with respect to a criterion is determined. There are four different approaches:

- Direct quantitative determination of criterion scores
- Direct qualitative determination of criterion scores
- Indirect quantitative determination of criterion scores
- Indirect qualitative determination of criterion scores

The difference between Qualitative and quantitativeapproach is the measurement scale. In case of quantitative approach, the measurement scale is known, i.e. a quantity or item has been defined as a standard by which the magnitude of differences can be expressed but not for qualitative scale (the measurement scale is not known).Although significant numbers of decision rule approaches arepresented in the literature, there are limited applications of combined utilization of GISand MCDM. The weighted summation, ideal/reference point, and outranking methodsare the examples of such approaches which allow integration of MCDM and GIS(Malczewski, 2006).

One of the widely used decision rules is AHP which can be used in two different ways inGIS environment. In the first approach, weights are assigned to each attribute maplayer, and then weights are aggregated by using weighted additive combinationmethods. This method is more practical if large numbers of alternatives are involved(Eastman et al., 1993). In the second approach, the AHP principle is used to aggregatethe priority for all level of hierarchy structure including the level of representingalternatives. In this case, small number of alternatives is needed (Jankowski and Richard, 1994).

One of the most popular GIS-based MCDA approach is the weighted summationmethod. The main reason of its popularity is that the approach is easy to understandand apply within GIS environment, therefore, very appealing for decision makers. Thismethod has usually been employed together with Boolean operations. OWA approachprovides an extension and generalization of the Boolean operation and the weightedsummation procedures (Malczewski, 2006). In this study, together with -and- and -or-operators for aggregation of individual satisfaction degrees into an overall satisfactionvalue, the OWA operator is used as well.OWA is a general aggregator operator which includes three different types ofaggregation operators:

(i) -and- operator which refers to the intersection of fuzzy sets,
(ii) -or- operator which refers to the union of fuzzy sets; and
(iii) the averaging operator(Tabesh, 1992; Eastman et al., 1993).

Most commonly used aggregation operators are-and- and -or- operators and they are used to represent two extreme cases: ―Satisfaction of all the desired criteria‖ and ―Satisfaction of any of the desired criteria‖,respectively (Yager, 1988). However, in some cases, decision makers may want toperform an aggregation which lies in between these two extreme cases. For suchsituations, Yager (1988) proposed the OWA function which combines -and- and -or-operators and refers to it as the -or and- operator. The rationale of this application is toaggregate the attributes not by classical weighted average but by ordered position ofthe attributes.

2.17. **Previous study**

In Koga watershed, no research is done that deals with the potential of the watershed for hydropower. But some researchers try to exploit the potential of some watersheds using different methods.

Abebe, (2011) assessed the micro hydropower potential of selected Ethiopian rivers- a case study in the northwest part of the country. In the study,the discharge wastransformed only using drainage arearatio method for whole watershed and the head wasmeasured manually for the selected sites. Finally, three sites were selected and except one of the sites which was a hybrid system, the rest were taken to be a hydro-only system.

Keneni, (2007) assessed micro hydropower potential sites for rural electrification in some selected sites of Genale-dawa basin. The study estimates discharge using area ratio method, the head was estimated using topographic map and manually by GPS reading for sites that have less than 20m contour interval, and the sites were prioritized by setting some parametersand assigning the weighted value manually. The overall results of the study indicate that twenty-one potential sites were selected. Finally, the study recommended EEPCo can't cover the whole empire with interconnected system and self-contend system. Thus, dealing with small scale hydro such as micro hydropower is mandatory. Therefore, policies and strategies concerning rural electrification should be promoted.

Tulu, (2007) Assessed potential sites for micro to small hydro power potential in baro-akobo river basin. The discharge was transformed only using drainage area ratio method for whole watershed, the head the head was estimated using topographic map and manually by GPS reading for sites that have less than 20m contour interval, and the sites were prioritized by setting some parameters and assigning the weighted value manually. The study results a total of 23 potential hydropower sites with total potential capacity of 144MW. Finally, the study recommendsfurther assessment should be performed to know the exact potential of the basin. If all these sites could be known the Micro to small hydro power of the basin mightbe doubled or tripled.

In this thesis, the discharge transformation to ungauged sites is done using drainage area ratio method for ungauged sites within a range of (0.5–1.5) of the contributing drainage area for the gauging station and for ungauged sites not within that range, first runoff coefficient is found out using regression analysis by creating a relation between the discharge and basin characteristics (rainfall, average slope, and drainage area of the sub watershed) used for drainage area weighted method. Then equation from regression is applied for the Sub watersheds that are to be regressed. As result, discharge is calculated by multiplying the runoff coefficient to rainfall using Arc Map software. Here also the potential sites are prioritized using multi decision criteria analysis (MDCA).

CHAPTER THREE

MATERIALS AND METHODS

1.1 Description of the study area

The study will be conducted in Mecha district, Amhara National Regional State, Ethiopia. The Koga watershed lies in the Blue Nile basin and comprises the Koga watershed above its confluence with the Gilgel Abay. The Koga River Basin is located at 11° 22' 35.7243" N latitude and 37° 02' 7.0250" E longitude covers 280 km^2 watershed area which lies to the north of the Wezem Mountains. The Koga River flows south to northwest with a total length of over 64 km with minimum elevation of 1842m a.s.l and maximum elevation of 3089m a.s.l. The River terminates at its confluence with the Gilgel Abay just to the west of the town of Wettet Abay.

In this watershed, there is one Semi-Homogeneous Earthen dam, the Koga Irrigation Dam. This Damirrigates 7,000 ha, and it improves the formerly used rain fed agriculture by allowing two cropseasons which will increase the yield. Forestry, livestock, soil conservation, water use andsanitation on the 22,000-ha catchment area is also improved. It covers up to 1,750 ha reservoir area with a maximum elevation of 2020m. Selection of potential site on this watershed does not include the dam structure and its reservoir area up to 2020m (as mentioned below in section 4.5.2), that is the elevation of the dam surface. During the site visit on July 31, 2017, the elevation of the water surface was 2015.3 and based on the Koga Irrigation and Watershed Management Project office, till now the reservoir water surface does not reach 2020m but to be safe from any flooding I prefer to search potential sites by neglecting this area.

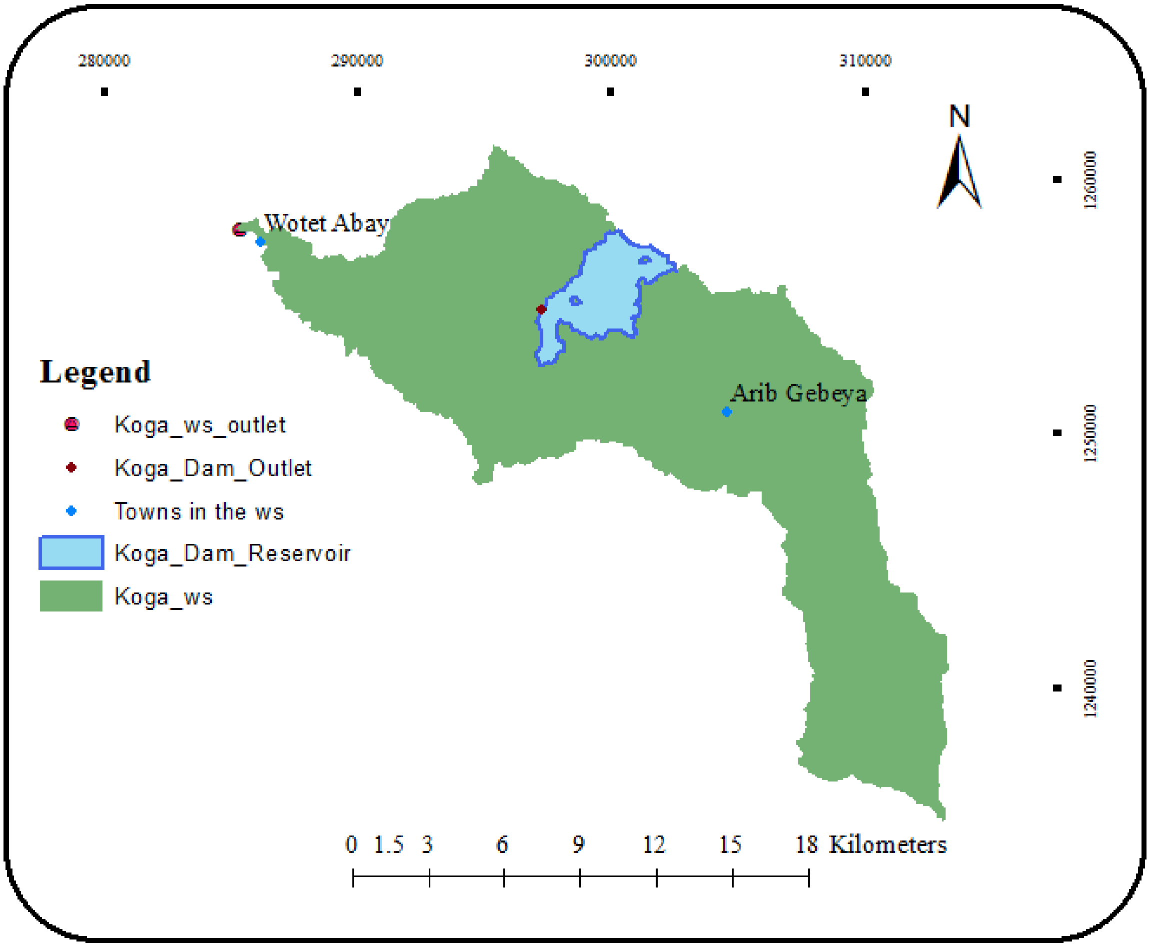

Figure 3-1: Koga dam in the watershed

3.2. Materials

In this research, the materials are necessary to guide the researcher to do easily and correctly. The materials used in this thesis are mentioned in table 3.1.

Table 3-1: Materials used for this study and the purpose

No.	Materials	Purpose	Source
1	Arc Map 10.2	To analyze spatial data	ArcMap Software
2	Rainfall data	An input for runoff estimation of the watershed	NMA BDMD*
3	Stream Discharge	Data used for calibrationto estimate the runoff coefficient of the catchment	ABA
4	DEM	to determine the geographical behavior of the watershed.	BOWIE
5	Spatial data	to know the characteristics of the basin	BOWIE

3.3.**Methodology**

3.3.1. General

In this section, methodology of the study is explained comprehensively forsmall-scale hydropower potentialassessment procedures. The flowchartof the proposed methodology is given in Figure 3-2.Stream flow, Digital Elevation Model (DEM) (30*30 m), land use/land cover and any other factors that can affect the assessment, iscollected from different organization and recognized websites.Then,filling in the missing data of stream flow and rainfallfor the gauged rivers and rain gauge stations around Koga watershed respectively is done.Develop Flow Duration Curve and take 35%, 70% and 90% dependable flow forhydropower calculation to the proposed sites.Using 30m DEM data, streamlines are generated and head can be calculatedusing statistical function (focal statistics) in GIS software.Calculate the potential of the proposed site for hydropower development. Some restrictions are set to screen out sites that satisfy these requirements and parameters are used to prioritize the potential sites using GIS based multi criteria decision analysis (MCDA) method.

Generally, the methodology to be used in the estimation of hydro potential consists of mainly two parts:

i. Estimation of discharge along the river system and
ii. Estimation of potential head drop. The details are discussed below:

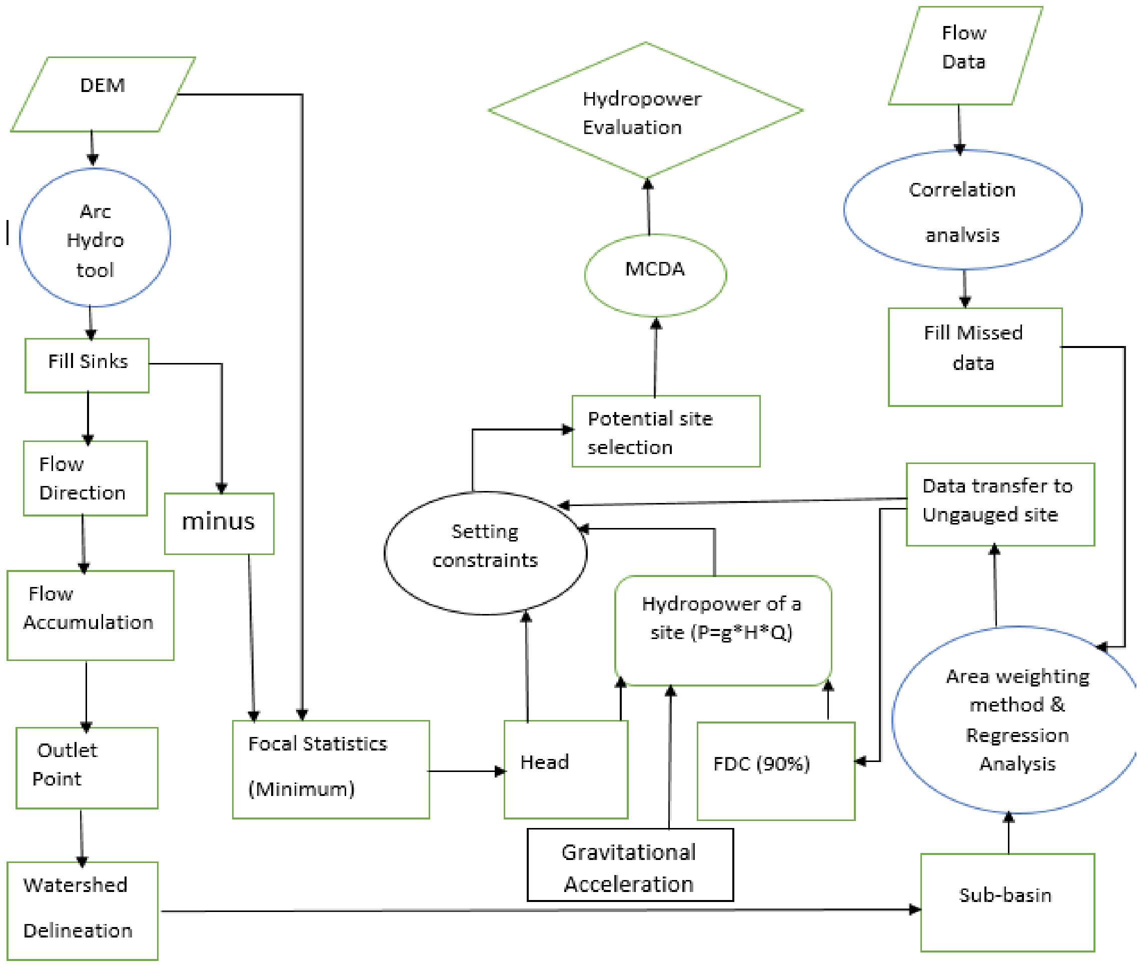

Figure3-2: General methodology flowchart

3.4.**Data collection and processing**

Assessment of the small-scale hydropowerrequires various geographic anddischarge data; the first step involves data collection and processing.Stream flow data, Rainfall data, Digital Elevation Model (DEM), land use/land covers shape file and road shape file are among the collected spatial data.

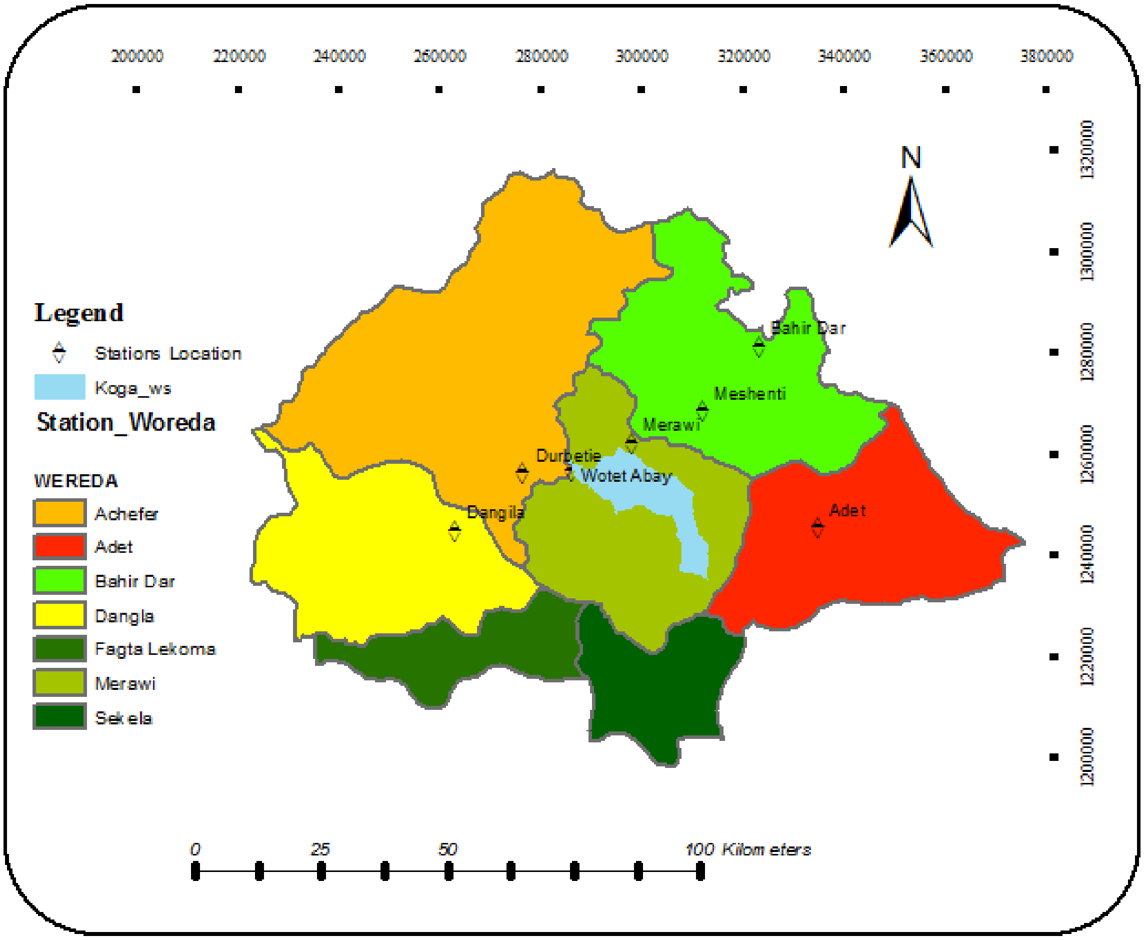

Figure 3-3: Locations of meteorological stations

In this study, the main purposes of these data were to use as an input to determine Rainfall Accumulation and then runoff for each cell by the help of GIS Software. In Ethiopia, the source of rawmetrological data is the National metrological service agency (NMSA). A request for Monthly rainfall data was made to the agency and available data were collected.

Table 3-2: Hydro meteorological data type and available periods

No.	Data Type	Period
1	Stations rainfall data	2001-2016
2	Koga stream discharge	1959-2003

3.4.1. Filling missed data

When undertaking an analysis of precipitation data from gauges where dailyobservations are made, it is often to find days when no observations arerecorded at one or more gauges. These missing days may be isolatedoccurrences or extended over long periods. In order to compute precipitationtotals and averages, one must estimate the missing values.Ordinarily, periods of recorded data at different location do not cover the same time span, and therefore, it is necessary to estimate missing values in order to obtain a complete set of data for analysis. Most of the rainfall recorded from the stations has missing data ranging from 9 to 35 %. Therefore, before using the data to runoff modeling missing data should be filled. In filling missed data there are different techniques to be applied, generallytwo, using station own time series data, &neighborhood station data (Peter et al., 2016).Several approaches were used to estimate the missing values. Station average,Normal ratio, Inverse Distance Weighting, and Regression methods arecommonly used andinverse distance method is best to fill the missing records(Silva et al., 2007)

For this study, the mean arithmetic technique of its own station is used for stations that have less than 10% missed value. But for stations greater than 10% missed value, the Distance power method was used. In Distance power method,the rainfall at a station is estimated as a weighted average of the observed rainfall at theneighboring stations. The weights are equal to the reciprocal of the distance or some power ofthe reciprocal of the distance of the estimator stations from the estimated stations. Let Di be thedistance of the estimator station from the estimated station. If the weights are an inverse squareof distance and was estimated by using equation 3-1.

$$P_A = \frac{\sum_{i=1}^{n} P_i/{D_i}^2}{\sum_{i=1}^{n} 1/{D_i}^2} \quad 3\text{-}1$$

Note that the weights go on reducing with distance and approach zero at large distances.Distance is computed with the help of the coordinates using equation 3-2

$$D_i^2 = [(X - X_i)^2 + (Y - Y_i)^2] \quad 3\text{-}2$$

where x and y are the coordinates of the station whose data is estimated and X_i and Y_i are the coordinates of stations whose data are used in estimation(Silva et.al., 2007).

According to Nardos(2011) if the correlation coefficients is in the range $0.6<R^2<1.0$, it indicates good correlation then linear regression equation can be used to fill the missing dataotherwise mean value should be used for filling the missing values.

3.4.2. Outlier test

An outlier is an observation that deviates significantly from the bulkof the data, which may be due to errors in data collection, or recording,or due to natural causes. The presence of outliers in the data causesdifficulties when fitting a distribution to the data. Low and high outliers are both possible and have different effects on the analysis. While low outliers are more common than high outliers in flood recordsfrom arid regions, tests should be made for both. The procedure depends on the station skew.If station skew is less than -0.4, check for low outliers first. If station skew is greater than+0.4, check for high outliers first. If the skew is between -0.4 and +0.4, a check for bothhigh and low outliers should be made simultaneously. If low outliers are identified, then theyare censored (for example, deleted from the flood record) and the moments recomputed.When high outliers are identified, the moments must be recomputed using the historic-peakadjustment; this requires historic flood information. If historic information is not available, then the high outlier must be retained in the record (Richard. H, 1998).

TheGrubbs and Beck (1972) test (G-B) was used to detect outliers. According to Borislava et al, (2014)G-Btest is best for outlier detections of hydrologic data. Inthis test, the quantities higher limit (X_H) and lower limit (X_L) are calculated by using Equations3-3 and 3-4.

$$X_H = \exp(\bar{X} + K_N S) \qquad 3\text{-}3$$

$$X_L = \exp(\bar{X} - K_N S) \qquad 3\text{-}4$$

where $\bar{X}$and S are the mean and standard deviation of the naturallogarithms of the sample, respectively, and K_N is the G-B statistic (equation 3-5) tabulated for various sample sizes and significance levels by Grubbsand Beck (1972). At the 10% significance level, the following approximation proposed by Pilon et al. (1985) is used, where N is the samplesize.

$$K_N = -3.62201 + 6.28446N^{1/4} - 2.49835N^{1/2} + 0.491436N^{3/4} - 0.037911N \qquad 3\text{-}5$$

Sample values greater than X_H are considered to be high outliers, whilethose less than X_L are considered to be low outliers.

3.4.3. Checking stationary and homogeneity

If the statistics of the sample (mean, variance,etc.) are not functions of the timing or thelength of the sample, then the time series issaid to be stationary.if a definite trend is discernible in the series, then it is a non-stationaryseries. Similarly, periodicity in a series means that it is non-stationary.

Homogeneity is an important issue to detect the variability of the data. In general,when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments(David R, 1998).

To detect the presence of Stationary or non – homogeneities Mann-Whitney test is used. First the flow data divides in to two groups in such a way that the number of records in the first group (p) is less than or equal to the second group (q).

In this test two samples of size p and q are compared. The combined data set of size N = p + q is ranked in increasing order. The Mann-Whitney (1947) (M-W) test considers the quantities V and W in Equations 3-6 and 3-7:

$$V = R - \frac{p(p+1)}{2} \quad 3\text{-}6$$

and

$$W = pq - V \quad 3\text{-}7$$

Where V - the number of times an item in sample p follows an item in sample q in the ranking,R - is the sum of the ranks of the elements of the first sample (p) in the combined series (size N)

The standardized test value,

$$\mu = (U - \bar{U})/[VAR\ U]^{1/2} \quad 3\text{-}8$$

$$[VAR\ U] = \left[\frac{pq}{N(N-1)}\right]\left[\frac{N^3-N}{12}\right] \quad 3\text{-}9$$

$$\bar{U} = pq/2 \quad 3\text{-}10$$

where N isnumber of total data (p+q),U issmaller value of V or W,Ū is the mean value of the number of the two samples, andVAR U is the variance of the number of the two samples.If the standardized test value (µ) isStudent's t value at a significance level of 5 percent (two-tailed). i.e. $t\{v,2.5\%\} < t_t < t\{v,97.5\%\}$it is Acceptable (David. R, 1998).

3.4.4. Trend test

Trend analysis is performed: to detect a slow continuous variation of meteorological conditions or along periodic variation of the climate and to observe the modification of catchment physiography especiallythrough human activity.This may be caused by long-term climatic changes or, in river flow, by gradual changes in acatchment's response to rainfall owing to land use changes. Sometimes, the presence of a trendcannot be readily identified. Any smooth trend that is discernible may be quantified and thensubtracted from the sample series.In this case Spearman`s Rank-correlation coefficient Method is used(Mojtaba et al., 2011).

To test for absence of trend to the given data first set assumptions of the Null and alternatehypothesis. The null hypothesis, Ho: Rsp= O (there is no trend), against the alternate hypothesis, H1: Rsp <>O (there is a trend), with the test statistic:

$$R_{sp} = 1 - \frac{6 \sum_{i=1}^{n} D_i^2}{n*(n^2-1)} \quad \text{3-11}$$

where n is the total number ofdata, D is difference, and i is the chronological order number. The difference between rankings iscomputed with:

$$Di = Kxi - Kyi \quad \text{3-12}$$

Where Kxi is the rank of the variable, x, which is the chronologicalorder number of the observations and Kyi is the chronological order number of an observation inthe original series.One can test the null hypothesis, Ho: Rsp= O(there is no trend), against the alternatehypothesis, H1: Rsp <> O (there is a trend),with the test statistic was estimated by using equation 3-13.

$$t_t = R_{sp} \left[\frac{n-2}{1-R_{sp}^2}\right] \quad \text{3-13}$$

where t_t has Student's t-distribution with v = n-2 degrees of freedom.

The null hypothesis is accepted if t_t is notcontained in the critical region. In otherwords, the time series has no trend if:$t\{v,2.5\%\} < t_t < t\{v,97.5\%\}$(Mojtaba et. al., 2011).

3.4.5. Consistency test

Hydrologic data generally consist of a sequence of observations of some phase of the hydrologic cycle made at a particular site. For most hydrologic purposes, a long record is preferred to a short one, the user should recognize that the longer the record the greater the chance that there has been a change in the physical conditions of the basin or in the methods of data collection. If these are appreciable, the composite record would represent only a nonexistent condition and not one that existed either before or after the change. Such a record is inconsistent(James and Clayton,1960).

Spatial consistency checks for rainfall data are carried out by relating the observations from surrounding stations for the same duration with the rainfall observed at the station. This is achieved by interpolating the rainfall at the station under question with rainfall data of neighboring stations. The station being considered is called the test station. The interpolated value is estimated by computing the weighted average of the rainfall observed at neighboring stations. Ideally, the stations selected as neighbors should be physically representative of the area in which the station under scrutiny is situated. The following criteria are used to select the neighboring stations:

a) The distance between the test and the neighboring station must be less than a specified maximum correlation distance;
b) Many neighboring stations should not be considered for interpolation; and
c) Reduce the spatial bias in selection, it is advisable to consider an equal number of stations in each quadrant.

The use of a double-mass curve by W.B. Langbehn is a convenient way to check the consistency of a record. Such a check is one of the first steps in the analysis of a long record, except when the scarcity of other old records makes it infeasible. A double-mass curve is a plot on arithmetic cross-section paper of the cumulative figures of one variable against the cumulative figures of another variable, or against the cumulative computed values of the same variable for a concurrent period of time. The accumulated total of the individual gauge was compared with the corresponding totals for a representative group of nearby gauges. If a decided change in the regime of the curve is observedit should be corrected. (James and Clayton, 1960; Subramanya, 1998).

3.5.DEM, land use/land cover &road shape files

The DEM is the important input to describe the topography of the watershed. The DEM used inthis study is of 30 meters resolution i.e. 30*30 m grid size.

The land use/land cover major soil types of Koga Watershed especially for the downstream section in which drainage area weighting method is applied for stream flow computations are Agriculture and Haplic Luvisols respectively and the upstream sections are the same for the parent and estimated watersheds.

Table 3-3a: Land use/land cover of Koga watershed

No.	Land use/land cover	Area (hectare)	Coverage (percent)
1	Agriculture	16363	66.87
2	Pastoral	187	26.98
3	Agro-pastoral	7265	0.79
4	Koga Dam Reservoir	1277	5.36

Table 3-3b:Major soil types of Koga watershed.

No.	Major soil types	Area (hectare)	Coverage (percent)
1	Haplic Luvisols	12555.38	52.72
2	Haplic Alisols	6646.45	27.91
3	Eutric Vertisols	2323.67	9.76
4	Haplic Nitisols	2289.92	9.61

The road shape file is also taken for the purpose of the selected potential hydropower sites prioritization. In evaluation section, the road accessibility is one parameter to weight the potential sites. To do so road map is necessary as a shape file in order to integrate with the potential sites using GIS software.

3.6.Estimating areal precipitation

Rain or stream gauges represent only point measurements. in practice however, hydrological analysis requires knowledge of the precipitation over an area. Several approaches have been devised for estimating areal precipitation from point measurements.The Arithmetic mean, the Thiessen polygon and the Isohyetal method are some the approaches. But these all methods estimate one representative average value for some area, for example watershed. So, to estimate rainfall value for each point cells Spatial Interpolation method, using GIS software, is the best method (Grett and Fay, 2015).

Spatial Interpolation is a process of estimating unknown geographic values on the basis of known values and it is possible to create realistic surfaces from a limited number of sample Points. The distance from the cell with unknown value to the sample cells contributes to its final value estimation. The unknown value of the cell is based on the values of the sample points as well as the cell's relative distance from those sample points. Sample size is to be decided by the user by Number or Search radius. There are some interpolation methods among them Inverse Distance Weighted (IDW) method is best.

IDW works best for dense, evenly spaced sample point sets and Sample points closer to the cell have a greater influence on the cell's estimated value than sample points that are further away. (Feizizadeh and Haslauer, 2014)

After areal precipitation was done rain accumulation would be the next process to change rain fall height (mm) to discharge collected from the upstream section. In order to do this Raster Calculator tool in GIS software was used using equation 3-14.

$$R_{accu} = AR * cell\ area/(365 * 24 * 60 * 60 * 1000) \quad \text{3-14}$$

Where R_{accu} is the rain accumulation without considering any losses (m^3/s), AR is areal rainfall (mm/ annual), cell area is calculated using square dimensions based on cell resolution (m^2),(365*24*60*60) is to change the value given annually to seconds and 1000 is used to balance the dimensions given in mm for areal rainfall.

3.7.**Estimating runoff**

The derivation of relationships between the rainfall over a catchment area and the resulting flow in a riveris a fundamental problem for the hydrologist. In most countries, there are usually plenty of rainfall records,but the more elaborate and expensive stream flow measurements, which are what the engineer needs for theassessment of water resources or of damaging flood peaks, are often limited and are rarely available for aspecific river under investigation. Evaluating river discharges from rainfall has stimulated the imagination and ingenuity of engineers for many years, and more recently has been the inspiration of many researchworkers.

To facilitate comparisons, it is usual to express values for rainfall and river discharge in similar terms. Theamount of precipitation (rain, snow, etc.) falling on a catchment area is normally expressed in millimeters(mm) depth, but may be converted into a flow rate, cubic meters per second (m^3/s) flowing on the catchment as described in the above section.Alternatively, the river discharge (flow rate), measured in cubic meters per month (m^3/month) for a comparable time period may be converted into the same unit, flow rate(m^3/s). The discharge, often termed runoff for the defined period of time, isthen easily compared with rainfall accumulation to compute runoff coefficient for each cell in the watershed.

3.7.1. Setting basin characteristics

Basin characteristics investigated as potential explanatory variables in the regional regression analyses were selected theoretical relationswith streamflow characteristics, and the ability to generatethe characteristics using GIS analyses and digital datasets.Basincharacteristics were manually measured or estimated usingtopographic maps, planimeters, overlaying transparentgridded cells on the maps, and raster maps using GIS(Peter et al., 2016;Emerson et al., 2005).The data for each candidate basin characteristic wereconverted into a digital grid or raster format and overlaid onthe basin boundaries for each gaging station using standardtools available in ArcMap. The data werethen summarized for each gaging station and its associatedbasin (Peter et al., 2016)

3.7.2. Stream flow characteristics

Streamflow characteristic estimates for ungauged sites thatare on the same stream as a gaging station can be determinedusing the drainage-area ratio method. The drainage-area ratiomethod requires the computed streamflow characteristic at thegaging station and the contributing drainage area of both theungauged site and the gaging station. A major assumption of thedrainage-area ratio method is that the streamflow characteristics of the ungauged site are similar to streamflow characteristics of the gaging station and the sites are located on the samestream contributing drainage basins were delineated for each gaging stationusing a combination of 30-meter digital elevation data(Peter et al., 2016;Emerson et al., 2005).

3.7.2.1. Stream flow estimation in ungauged catchments

Stream flow data are required to determine the Runoff coefficient. Since most of the micro hydropower stations are ungagged, Regression models and GIS interpolation methods were used to estimate the stream flow at different points, but to use these model's estimation, the watershed should be divided in to nine sub watersheds and each sub watershed is characterized with catchment area, mean annual rainfall accumulation and mean slope to create a relation between stream flow and basin characteristics based on the first four estimator sites where the discharge is derived using Drainage Area weighting method.

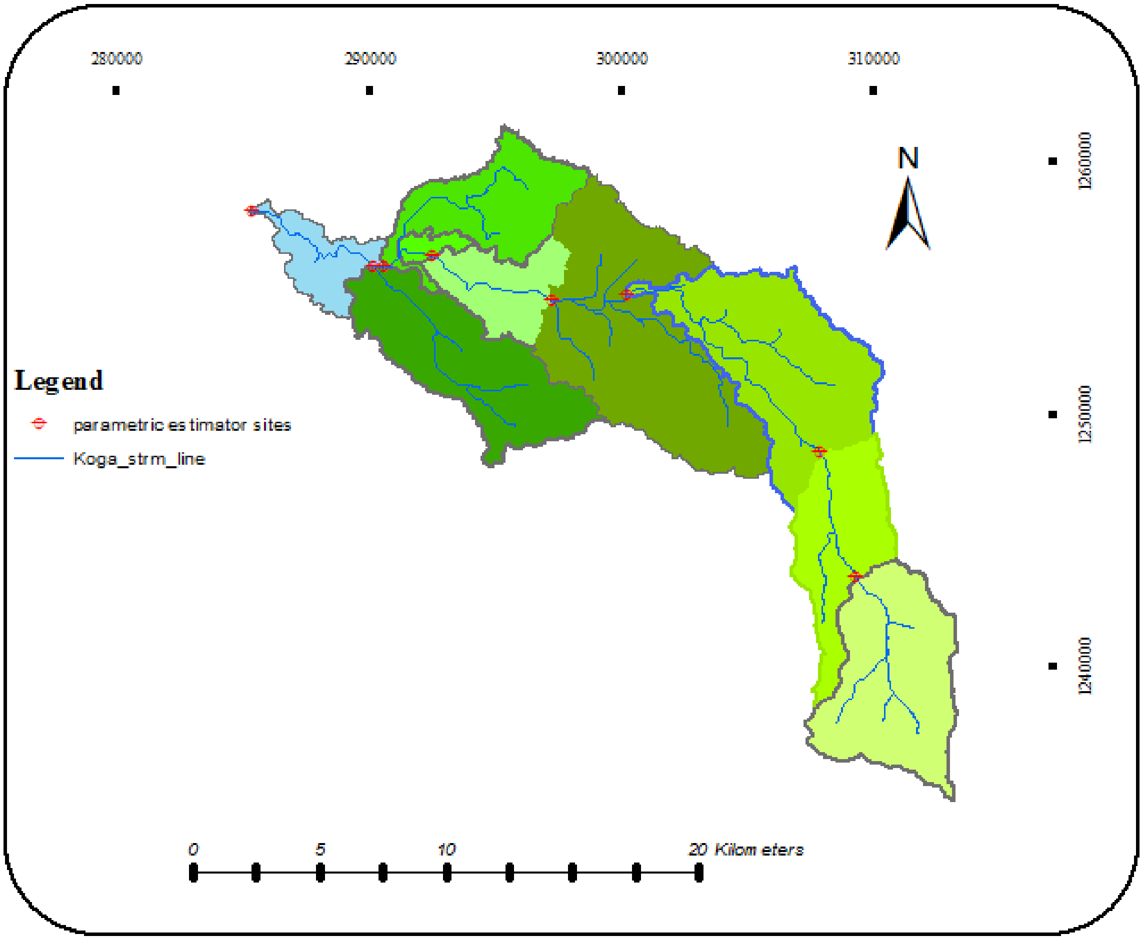

Figure 3-4: Koga sub watersheds for regression analysis

Streamflow characteristics and contributingdrainage area for the gaging station and the drainage area for the ungauged sites are used in the equation 3-15 to estimate streamflow characteristics at the ungauged site:

$$Q_{ungauged} = \frac{A_{ungauged}}{A_{gauged}} * Q_{guaged} \quad 3\text{-}15$$

Where$Q_{ungauged}$ is Flow at the ungagged location, Q_{gauged} is Flow at gaged station,$A_{ungauged}$is Drainage area of the ungauged location, andA_{gauged} is Drainage area at gauged station.

The drainage-area ratio method is limited to sites that arewithin a range of 0.5–1.5 Ag(the contributing drainage area for thegauging station). For sites that are outside ofthis range, the regression equation might providemore reliable estimates of Q. The regressioncoefficient for the drainage area adjustment was computed for each streamflow characteristic in each region usingmultiple regression methods.

Some points are selected within 30% of the contributing drainage area for thegauging station to create a relationship between basin characteristics and flow characteristics using regression Analysis, and then to estimate discharge for the contributing drainage area for theselected estimator ungauged sites that are outside ofthis range. Then after runoff coefficients are calculated for the estimator sites by dividing the discharge to the rain accumulation.

To estimate the runoff coefficients for each cell of the watershed, first a relation is created between rain accumulation and the runoff coefficients of the selected estimator sites using simple regression method. Then, the formula is applied to the rain accumulation raster map using raster calculator in Arc Map software.Finally, the runoff coefficient raster map is multiplied by the rain accumulation raster map to get stream flow of each points. (Nazli, 2009; Emerson et al., 2005).

3.7.2.2. Multiple Regression Analysis

Regression analysis is a conceptually simple method for investigating functional relationships among variables.The relationship is expressed in the form of an equation or a model connecting the response or dependent variable and one or more explanatory or predictor variables.

A regression equation containing only one predictor variable is called a simple regression equation. An equation containing more than one predictor variable is called a multiple regression equation.

The data consist of n observations on a dependent or response variable Y and p predictor or explanatory variables, X_1, X_2....X_p, the relationship between Y and X1, X_2, ----X_p is formulated as a linear model.(Note that the term linear (nonlinear)) here does not describe the relationship between Y and X_I, Xp, . . .,X,. It is related to the fact that the regression parameters enter the equation linearly (equation 3-16)

$$Y = \mathcal{B}_o + \mathcal{B}_1 X_l + \mathcal{B}_2 X_2 + \ldots + \mathcal{B}p Xp + \mathcal{E}, \quad 3\text{-}16$$

where $\mathcal{B}_0$, $\mathcal{B}_1$, $\mathcal{B}_2$, . . ., $\mathcal{B}_p$, are constants referred to as the regression coefficientsand$\mathcal{E}$is a random disturbanceor error.It is assumed that for any set of fixed values of X_1, X_2, . . ., X_p, that fall within the range of the data, the linear equation above provides an acceptable approximation of the true relationship between Y and the X's (Y is approximately a linear function of the X's, and $\mathcal{E}$ measures the discrepancy in that approximation). In particular, $\mathcal{E}$ contains no systematic information for determining Y that is not already captured by the X's(Sampritand Ali 2006).

3.8.Parametric flow duration curve analysis for ungauged sites

The flow duration curve provides us with a means of representing the variability of flowat a proposed hydropower site in a concise graphical fashion. Flow duration curves haveproven to be useful in evaluation of surface water resources for water supply studies,hydropower design and planning studies, low flow studies such as in streamflowrequirements and other studies where it is desirable to define the variability of the flowsin streams.Two methods are widely used for analysis of stream flow data as a primary estimation of power.Potential-flow-duration curve (FDC) and sequential stream flow routing (SSR). Theflowduration curve method is better method for all preliminary or screening studies. This method is also, the best choice for high-head, run-of-river projects where head is generally fixed or evenfor low-head projects where head varies with discharge. For multipurpose storage projects, theSSR method is more appropriate and also can be used for examining the feasibility of includingpower at new water conservation or floodcontrol projects. For peaking and pumped storageprojects, hourly SSR routing is required (Mohammed et al., 2003). As described in literature review part, FDC using total period method is preferred because it includes all recorded data and is the more accurate method.(Fabianand Jochen,2016).

In FDC calculation setting arrange is the first step. Next the values that occur between the given ranges are counted and then number of greater values are computed by subtracting the cumulative value from the total number of monthly data. percent greater (% of greater) is calculated by dividing number of greater value by total number of data 539 and multiplying by 100 to change it to percent(Naufal and Masahiko, 2016).

Over the past century, many methods have been developed to derive FDCs for sites where discharge measurements are inadequate or completely absent including the ratio of mean annual flows at ungauged and gauged sites. But Spatial Interpolation Algorithm by Hughes and Smakhtin, 1996 is best and it is developed to generate the flow time series that are timely coincident with the source site based on the following principles:

(1) Choose the object sites, the destination site and the source site in the same basin
(2) Decide the period of simulation
(3) Compute FDC and discharge at 17point time excess probability values (The discharge value at time excess probability of 0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9, 99.99 % at each site.
(4) Normalize the FDC computed at each site.
(5) Compute the regional FDC at the destination site by simple averaging of object sites
(6) Interpolate normalized daily flow value at the destination sites
(7) Multiply long term mean daily flow that is estimated by multiple linear regression.

In the Spatial Interpolation Algorithm, the monthly flow time series and flow duration curves are normalized so that the impacts of specific site's characteristics will be negligible. Hence, the flow time series values that computed at the ungauged site are also normalized, and the values must be multiplied by the long-term mean daily flow value to give the characteristics of the ungauged site. The long-term mean daily and monthly flow value can be computed as following (Smakhtin et al. 1997).

$$\ln Q_{mean} = -\alpha + ß \ln A + \gamma \ln MAP \qquad 3\text{-}17$$

Where, Q_{mean} is long-term mean daily or monthly flow (cfs), A is drainage area (sqmi), MAP is Mean Annual Precipitation (*in*).

The independent variables of multiple linear regressions are MAPand Drainage Basin Area. Once the value of independent variables (MAP, Drainage area)at each parametric Duration Curve estimator sites was determined; one equation was developed to validate relationships between the dependent and independent variables.If the estimated and gauged flow is nearly the same, the equations for FDC of the parametric estimator sites for key percentage flow were applied to the runoff map.

The drainage area of gauge station as well as the estimator sites was computed in the GIS Environment and MAP value of each site was computed considering of weighting factor of drainage area at each site.

3.9.**Potential head estimation**

Head is a vertical distance between two points (intakeand turbine). It can also be defined as the pressure created by elevation differencebetween intake and turbine. River head calculation is done using GISmethods. First, DEM data which contains elevation information was clipped with rivernetwork to generate riverbed topographic profile. Finally, potential head was calculated usingneighborhood analysis tool in ArcGIS. The analysis calculates elevation drop betweenneighborhood pixels with in 500m in riverbed topographic profile by using focal statistics(minimum) function.And then subtract the lowest elevation from filled sinks DEM using raster calculator(Garcia, 2016).

3.10. **Validating the head of potential sites using GPS material**

The potential head calculated by GIS using focal statistics need to be evaluatedto compare current measurement efforts with previous study results. The efficiency criteria are used to evaluate the observed and estimated head. The process of assessing the performance of a focal statistics using GIS requires evaluation to make estimates of the “closeness” of the simulated behavior of the GIS to observations made along the river.

In this section, the efficiency criteria used in this study are presented and evaluated.The coefficient of determination criterion and the Nash–Sutcliffe efficiency (NSE, defined by Nash and Sutcliffe, 1970) are the two criteria most widely used for evaluation of some models with observed data(Hoshin et al, 2009).

3.10.1. Coefficient of determination (R^2)

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

$$R^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2} * \sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right)^2 \quad \textit{3-18}$$

with O observed and P predicted values.

R^2can also be expressed as the squared ratio between the covariance and the multiplied standard deviations of the observed and predicted values. Therefore, it estimates the combined dispersion against the single dispersion of the observed and predicted series. The range of r^2 lies between 0 and 1 which describes how much of the observed dispersion is explained by the prediction.A value of zero means no correlation at all whereas a value of 1 means that the dispersion of the prediction is equal to that of the observation. The fact that only the dispersion is quantified is one of the major drawbacks of r^2 if it is considered alone. A model which systematically over- or under predicts all the time will still result in good r^2 values close to 1.0 even if all predictions were wrong(Krause et al, 2005).

3.10.2. Nash-Sutcliffe efficiency (E)

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

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad \textit{3-19}$$

The normalization of the variance of the observation series results in relatively higher values of E in catchments with higher dynamics and lower values of E in catchments with lower dynamics. To obtain comparable values of E in a catchment with lower dynamics the prediction has to be better than in a basin with high dynamics. The range of E lies between 1.0 (perfect fit) and $-\infty$. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model. The largest disadvantage of the Nash-Sutcliffe efficiency is the fact that the differences between the observed and predicted values are calculated as squared values. As a result, larger values in a time series are strongly overestimated whereas lower values are neglected. For the quantification of runoff predictions this leads to an overestimation of the model performance during peak flows and an underestimation during low flow conditions. Similar to r^2, the Nash-Sutcliffe is not very sensitive to systematic model over- or underprediction especially during low flow periods (Krause et al, 2005).

3.11. Hydropower potential estimation

Hydropower converts the potential energy of a mass of water, flowing in a stream with a certain fall to the turbine (termed the "head"), into electric energy at the lower end of the scheme, where the powerhouse is located. The power output from the scheme is proportional to the flow and to the head.

3.11.1. Theoretical hydropower estimation

The head values generated by the head algorithm were multiplied by the discharged values to compute for theoretical hydropower potential for each river segmentsin ArcGIS. Equation 3-20 wasused to calculate the theoretical power potential:

$$P = \eta * g * Q * h \quad 3\text{-}20$$

where P =hydropower potential (kw), η = Overall Efficiency[ ], g = gravitationalacceleration (9.81 m /s^2), Q =the flow rate of the stream (m^3/sec), andH =gross hydraulic head (m).For theoretical potential hydropower, turbine efficiency was assumed to be 100%and no hydraulic head loss was considered in the calculation.

In small scale hydropower development, there are two categories of development, the development incategory 1 is more interested in generating only what energy is needed and having thatenergy available for as much of the year as possible. The development is not interested inrecovering the maximum energy available from the stream. As a result, the system will bedesigned for the minimum stream flow of the year.The primary motivation of those in category 2 is to produce the maximum energy availablefrom the stream for the money invested. Category 2 developers are normally interested in flows between 20 to 35% exceedance.Category 1 is used in the case where the power required for the site is known, but in category 2we don't know the power demand but just interested to determine the maximum potential,which is the case for this research (USDE, 1983).

3.11.2. Technical hydropower estimation

According to physical and technical reasons hydropower plants aren't able to fully use the gross theoretical hydropower potential. The technical potential of hydropower describes the energy capacity that is actually useable when technical, infrastructural, ecological and other conditions are taken into consideration.

As noted earlier, the theoretical power calculations shown above represent a theoretical maximum, and the actual power output from the hydro system will be substantially less. In actual hydropower estimation pipeline losses, and small amounts of power will be lost through friction within the turbine, drive system, generator and transmission lines. For small-scale hydropower calculation, the overall efficiency of the system was taken as, $\eta = 0.8$ (Julius et al, 2016).

3.12. Selection of potential site for hydropower development

Thepotential a river has for producing power depends on the water flow rate and the headfor where the water can be made to fall.But in selection of potential small-scale hydropower site considering only the two sources is not enough so other source and environmental conditions may be considered. Generally, in potential site selection any factors that can affect the hydropower production should be investigated.

3.12.1. Setting constraints/factors of hydropower site selection

In selection of possible potential sites some constraints may be considered. This is because of producing sustainable power, cost optimization, and to be safe from already constructed plants and others that can affect and affected by constructing small-scale hydro power facilities. In this research work five constraints were considered to select potential small-scale hydropower sites in Koga watershed.

1. The mean annual flow at the proposed site should be greater than $0.1m^3/s$
2. The elevation drops or height difference (H) should be higher than 10 meters to ensure sufficient potential head.
3. The distance between each potential site should be less than 500m.
4. The hydropower produced should be greater than or equal to 10kw.
5. The site shouldn't lie within a zone of existing dam and its reservoir area.

By considering all constraints mentioned above the potential small-scale hydropower sites are selected. First changing the raster value of power and discharge to vector (polyline) was done. Then the two polylines are intersected using Arc Map 10.2 spatial analysis. The raster value of head is extracted by intersected polyline of power and discharge using Spatial Analysis Tool (extract by mask). Finally, the extracted head is multiplied by the raster value of power using Raster Calculator. As a result, sites that fulfilled the three criteria were selected (Sarapirom et al., 2011;Kusre et al, 2009).

3.13. **Multi criteria decision analysis (MCDA)**

Evaluating or making decision of smallhydropower project or any of its parameter is a complexanalysis as it is always unique and site specific. The use ofMCDA techniques canprovide a reliable methodology to rank alternatives in thepresence of different objectives and limitations. A review of various publishedliteratures such asHeracles et. al., 2006;and Ronald, 2011 on sustainable energy planning indicates greaterapplicability of MCDA methods in changed socioeconomic scenario.The methods have been very widelyused to take care of multiple, conflicting criteria to arriveat better solutions Increasing popularity and applicabilityof these methods beyond 1990 indicate a paradigm shift inrenewable energy planning, development and policyanalysis (Priyabrata et al,2015).

In evaluating the potential sites first, the parameters should be set and then the weight of each parameters should be determined.

3.13.1. Determine the weight of each factor

In this sub section, the measure of the relative importance of the factors to the given objective will be done. There are many measurement methods available, but only three widely used methods are mentioned for comparison.

a) Paired comparison

This method was based on the paired comparison matrix i.e.Analytical Hierarchy Process (AHP) developed by Saaty (1980) with the scale from 1 to 9. This scale represents Comparison importance between every two factorsas presented in table3-4:

Table 0-1: Analytical hierarchy process scale developed by Saaty

No.	Scale	Description
1	1	Equally important
2	3	Weakly more important
3	5	Strongly more important
4	7	Very strongly more important
5	9	Absolutely more important

The values 2, 4, 6 and 8 are a compromise judgement of importance between the above scale. This means that the paired comparison matrix can be filled in with the actual scale if one criteria is more important than the other and the reciprocal is taken for the inverserelations (Voogd 1982).

There are several methods for weight determination of each factor. Among them, a pairwise comparison method, (AHP), is the most widely used one. First of all, a matrix is constructed, where each criterion is compared with the other criteria, relative to its importance, on a scale from 1 to 9. Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the pairwise comparisons. If CR > 0.10, then some pairwise values need to be reconstructed, and the process is repeated until the desired value of CR < 0.10 is reached (Di, 2015).

3.13.2. Standardization

Even if the criterion scores have been determined on a ratio scale for all criteria, these scores are mutually incomparable since most of the measurement units will differ from each other. One criterion might be expressed, for instance, in kilo meter, whereas another criterion is measured in number. To make the various criterion scores comparable it is necessary to transform them into one common measurement unit, for example by taking care that for each criterion the scores will get a range from 0 to 1. This kind of transformation is called standardization. There are different kinds of standardization from them thefollowing method is best for pairwise comparison.

I. 0transformation of raw scores to scores with in a range from 0 to 1 for which holds that its interval-scale properties are further used.

   This type of standardization is especially appropriate in case a technique is used to performs a pairwise comparison(analytical hierarchy process) of the criterion scores. This kind of standardization can be written as:

$$\text{Standardized score } i = \frac{Raw\ score\ i - Minimum\ \ raw\ score}{Maximum\ \ raw\ score - Minimum\ \ raw\ score} \quad 3\text{-}21$$

   This kind of transformation means that the worst criterion score will always be given a standardized value of 0, whereas the best criterion score will always have a standardized value of 1.(Voogd, 1982).

   There are two types of criteria in standardization: benefit criteria and cost criteria which is a higher criterion score implies a better score and worst score respectively (Vicky and Michael, 2006).

$$directed\ standardized\ score \begin{cases} = \ standardized\ score \\ \quad (benefit\ criterion) \\ = 1 - standardized\ score \\ \quad (cost\ criterion) \end{cases}$$

CHPTER FOUR

RESULTS AND DISCUSSION

4.1. Data analysis

The quality and quantity of input data largely determines the performance of any hydrological works (Prabin, 2014).For this study, generally five basic data's which are the stream flow data, rainfall data, DEM, Land use/Land Cover & Shape files are used. The details ofresults are discussed in this chapter.

4.1.1. Stream flow data analysis

Stream flow data are required to determinethe Runoff coefficient. Since most of the micro hydropower stations are ungagged, Regression models and GIS interpolation methods are used to estimate the stream flow atdifferent points, but to use these model's estimation, the watershed should be divided in to nine sub watersheds and each sub watershed is characterized with catchment area, mean annual rainfall accumulation and mean slope to create a relation between stream flow and basin characteristics based on the first four estimator sites where the discharge is derived using Drainage Area weighting method.

Forty-four (44) years (1959-2003) monthly Koga river flow data weretaken from Abay Basin Authority. Among these monthly recorded data only 1.7% are missed. Therefore, to fill these missed data asimple Arithmetic average method from its data set was applied.

To maintain the hydrological data qualities, different data quality checking methods are applied as mentioned before. The end results of these analyses aredescribed as follows:

4.1.1.1. Detection of Outliers

In the first phase of koga stream flow data outlier test analysis, one higher outlier was detected. This value highly variates the mean value and from the mean value, and also this paper aims largely on low flow analysis, it is omitted. Then the other values are reanalyzed and results no outlier:

Table 4-1: Koga stream flow outlier test result

No.	Description	Value
1	G.B statistic, K_N	2.72
2	Standard deviation, s	0.12
3	Higher limit	9.68
4	Lower limit	2.14

As shown in the table 4-1, the higher limit is 9.68 which is greater than the maximum recorded value 9.21, and also the lower limit is 2.14 which is lower than the minimum recorded value 2.52. Therefore, the result indicates that koga stream flow data have not any outlier value.

4.1.1.2. Checking for Stationary and Homogeneity

To detect the presence of Stationary or non – homogeneities Mann-Whitneytest was used.As shown in appendix 7.3 $C_2$the absolute value of the standardized test value, μ= -0.975 is less than Student's t value at a significance level of 5 percent,$\mu_{0.25}$=1.96. As a result according to the Mann-Whitney test the data is homogenous and non stationary.

4.1.1.3. Trend Test

Table 4-2: Koga stream flow trend test result

No.	Description	Valuel	
1	Total Sum of difference between ranking, D_i^2	12898	
2	Spearman's rank correlation coefficient, Rsp	0.0911	
3	Degree of freedom, f=	42	
4	computed students t-distribution, t_t	0.5925	
5	t_t at 5% sign. Level from student, table for f = n-2	1.68	No Trend

As results presented in table 4-2, the value ofcomputed students t-distribution is not contained in the critical region of 5% significance level from student's level at n-2 degree of freedom then according to Spearman's rank correlation it indicates that the data has no trend.

4.1.2. Meteorological data analysis

4.1.2.1. Filling missed data results

Filling missed data is done using Arithmetic mean from its data set especially for Adet(daily), Bahir Dar(monthly), Dangila(daily), Durbetie(monthly), Merawi(monthly) and Wotet Abay(monthly) stations with a missed data of 1.32%, 0%, 0.7%, 9.03%, 6.25%, 8.93% respectively. But Meshenti station has 14.88% missed data so it is preferred to correct using Inverse Power Distance method from neighboring Stations based on available data. And data extension methods are applied for all stations except Bahir Dar using regression analysis of nearby three stations are made as presented in annex 6.

4.1.2.2. Outlier test:

No outlier is detected in all stations. Here the Wotet Abay station outlier test is shown, the results of other stations are listed in the appendix 7.3 C_1.

Table 4-3: Outlier test for Wotet Abay station

No.	Description	Value
1	G-B statistic, K_n	2.28
2	standard deviation of the natural logarithms,s;	0.05
3	Higher Limit;	2729.24
4	Lower Limit;	1008.72

As shown in the table 4-3, the higher limit is 2729.24which is greater than the maximum recorded value 2261.12, and also the lower limit is 1008.72.11which is lower than the minimum recorded value 1140.43. Therefore, the result indicates that Wotet Abayrainfalldata have not any outlier value

4.1.2.3. Stationary and homogeneity test result

To detect the presence of Stationary or non – homogeneities Mann-Whitney test is used. As shown in appendix 7.3 C_3 for example for Wotet Abay station, the absolute value of the standardized test value, μ= -0.37 is less than Student's t value at a significance level of 5 percent,$\mu_{0.25}$=1.96. As a result according to the Mann-Whitney test the Wotet Abay rainfall data is homogenous and non stationary.

4.1.2.4. Trend analysis

As results presented in table 4-4, the value ofcomputed students t-distribution is not contained in the critical region of 5% significance level from student's level at n-2 degree of freedom (|0.511|<1.68) then according to Spearman's rank correlation it indicates that the data has no trend. As shown below in table 4-4 for Wotet Abay station and for the other stations refer to appendix7.3 C_4, all stations pass the trend Test.

Table 4-4: Trend test of Wotet Abay station

No.	Description	Value	
1	Total Sum of difference between ranking, D_i^2	588	
2	Spearman's rank correlation coefficient, Rsp	0.135	
3	Degree of freedom, f=	14	
4	computed students t-distribution, t_t	0.511	
5	t_t at 5% sign. Level from student, table for f = n-2	1.68	No Trend

4.1.2.5. Consistency test

As shown in the figure 7 the cumulative value of Wotet Abay station (Y-axis) and average cumulative value of neighboring stations for Wotet Abay. i.e. Bahir Dar, Adet and Dangila stations, at the (X-axis), it indicates that these values are linearly correlated. As a result, according to W.B. Langbehn the stations are consistent. For the other stations refer to annex 7.3 C_5.

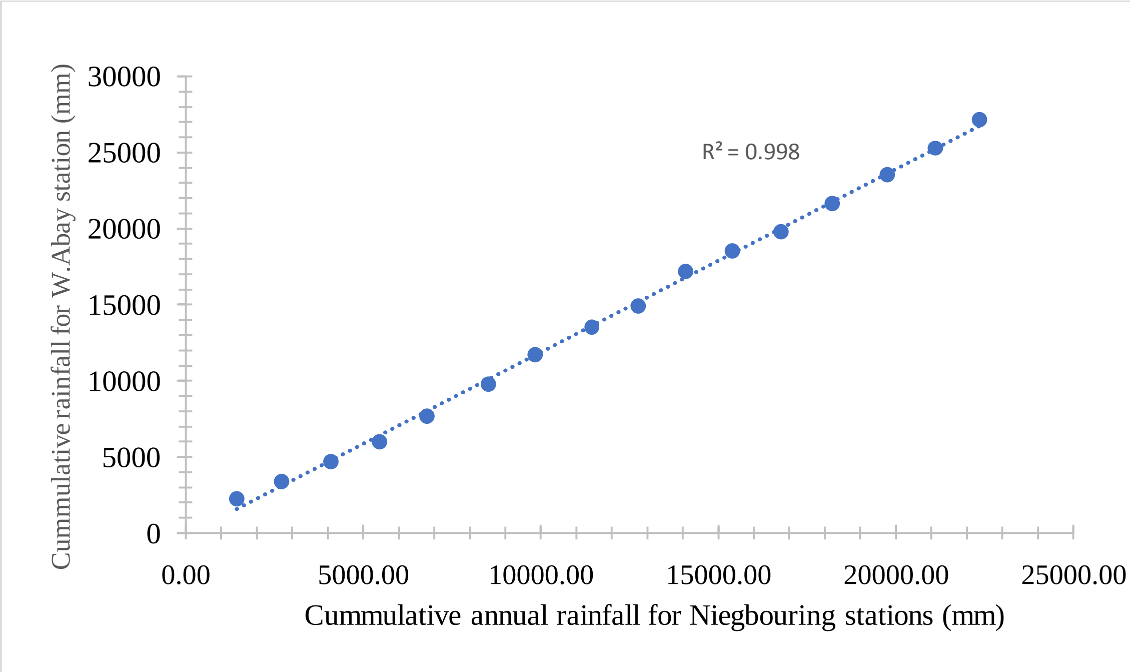

Figure 4-1: Consistency of Wotet Abay with Bahir Dar, Adet and Dangila as a neighboring Stations

4.2. Discharge Analysis

Discharge or volumetric flow is the rate of flow of water from any point along a stream per unit time. In this thesis, the discharge was calculated by analyzed precipitation with physical characteristics of the watershed and stream flow to estimate the runoff coefficientusing Arc Map 10.2 and discussed in detail as follows.

4.2.1. Areal precipitation

Areal Rainfall was done simplyusing IDW Interpolation by the help of GIS Software as shown below in the figure 8.

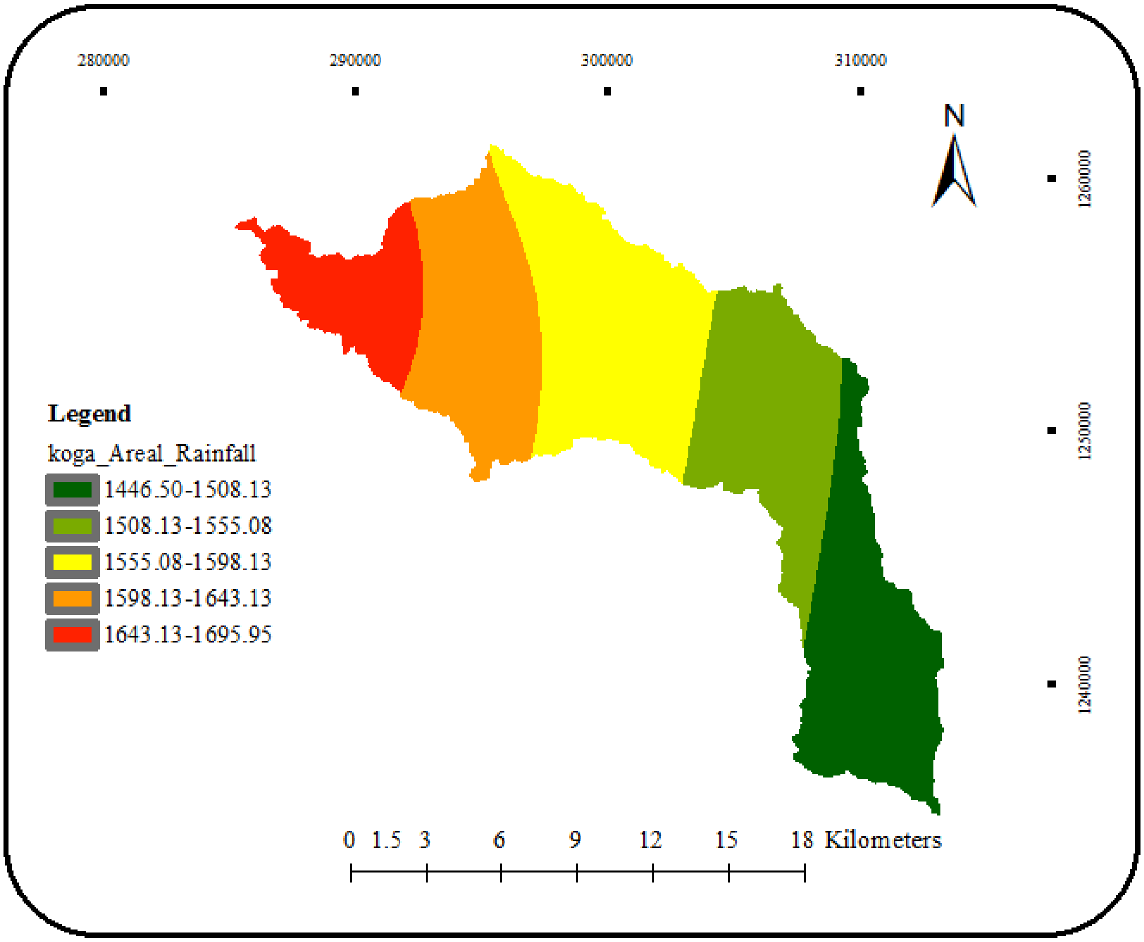

Figure 4-2: Areal Rainfall of Koga Watershed

As shown in the figure 4-2 the downstream section gained more rainfall than the upstream. At downstream the height of annual rain ranges 1598.13 up to 1695.95 mm but in case of upstream it gains less than 1555.08 and on the dam reservoir section the rain ranges from 1508.08 to 1598.13mm annually.

4.2.2. Rain accumulation

Accumulated rainfall calculated using equation (3-14) results accumulated rainfall in each cell.As shown in the figure 4-3 the maximum accumulation rainfall for d/s section is higher than u/s section even the precipitation is higher for d/s section this is because of the area of d/s section (82.65 km^2) is lower than the u/s section (191.86km^2).

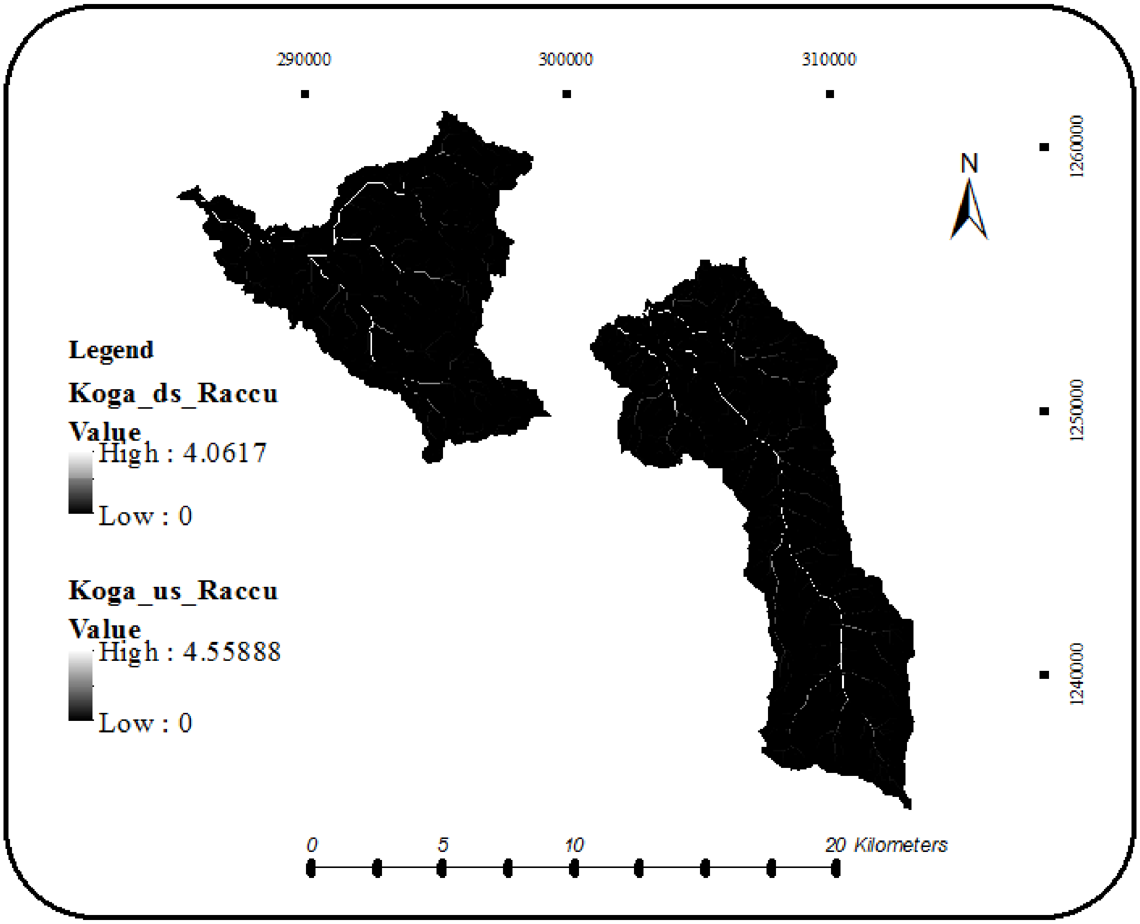

Figure 4-3: Rain accumulation of Koga watershed

4.2.3. Estimating runoff

To establish a rainfall-runoff relationship for a catchment, Runoff coefficients arerequired. To compute this coefficient Multiple Regression method was applied with total watershed, and each sub watersheds used for drainage area weighted method, stream characteristics and basin characteristics were used as an input to get the relationship between them and applied for the other sites which are not within 30% of the total watershed area. But for the above sub watersheds that lies within 30% of the stream flow watershed area, Drainage Area weighted method was used which was computed using the equation 3-15. Then the runoff coefficient for each sub watersheds used for drainage area weighted method was found out and regressed to get equation (4-1) & (4-2) for upstream and downstream respectively, and applied for the whole watershed cells using map algebra. Finally, runoff for each cell was calculated. Here separation of the watershed in to upstream and downstream is due to the existence of Koga Dam and its reservoir with no Spilled water in the watershed. The runoff for downstream section was similarly analyzed as upstream section.

$$R_{coff}=0.840462-0.03855*R_{accu} \quad 4\text{-}1$$

$$R_{coff}=2.436832-0.50972*R_{accu} \quad 4\text{-}2$$

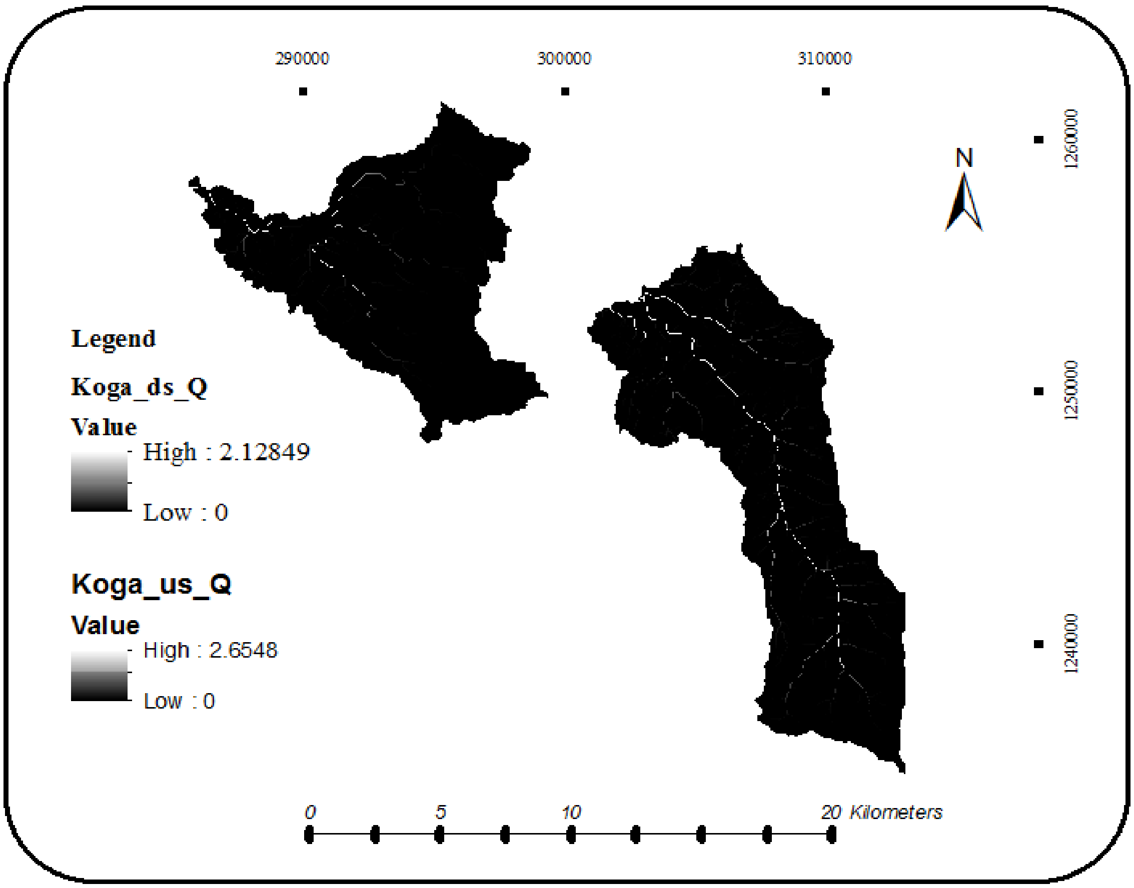

Figure 4-4: Stream flow of Koga watershed

As shown in the figure 10, like accumulated rainfall the discharge(Q) for the u/s section is higher than the downstream.

4.3. **Flow duration curve**

4.3.3. Computing Flow Duration curve at the Koga gauging Station.

The flow duration curve was computed at the outlet point by averaging FDCs of another 5 sites to validate the estimation done before for the parametric estimator sites. Figure (4-5) shows the comparison between the observed and computed FDC at the Koga outlet. As shown from the graph there is no significance difference between the observed and simulated FDCs. As a result, the simulated FDC were decided as the FDC of destination site.

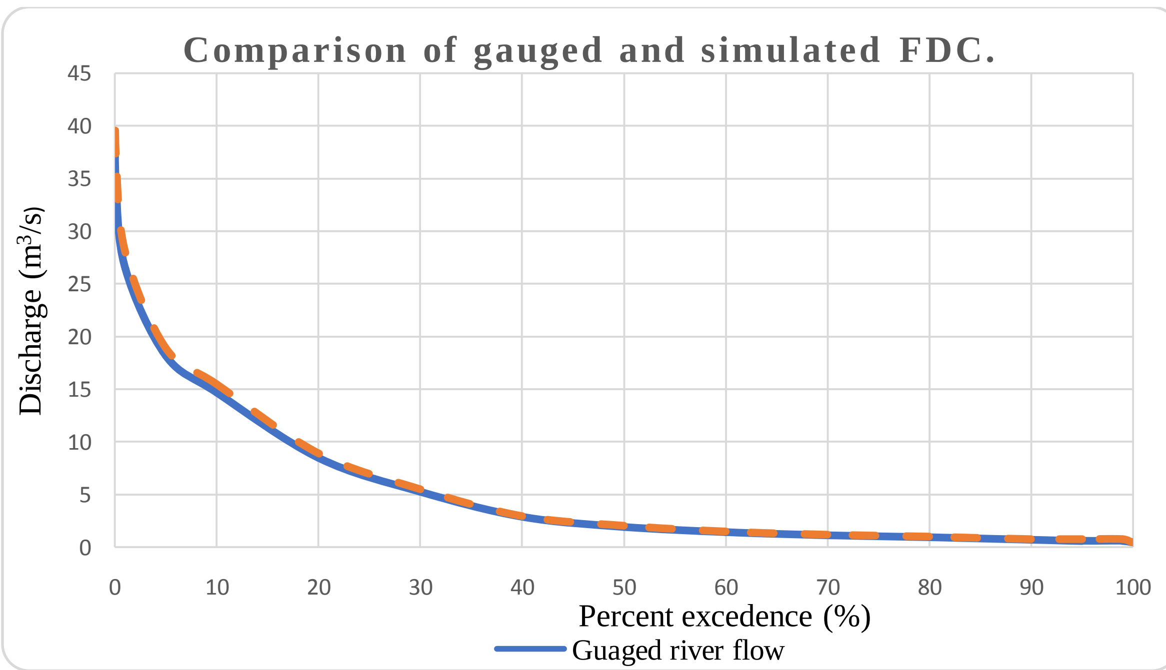

Figure 4-5: Comparison of gauged and simulated FDC for the Koga outlet point.

The key percent of exceedance of gauged and simulated flow for Koga watershed outlet point was analyzed using coefficient of determination and results a value of 0.9988. this indicates the simulation was very efficient. Therefore, transferring FDC of the parametric estimator sites for the destination sites using the equation developed from the key percent FDC of each site were efficient.

4.3.4. Development of equations for each key percent FDC for the parametric estimator sites

As shown in the figure (4-6) below the parametric duration curve, which represent the flow nature of the stream in the Koga Watershed was presented with the corresponding representative equation. Based on those equations the discharge pixel value of each and every cell in the Koga watershed was estimated.

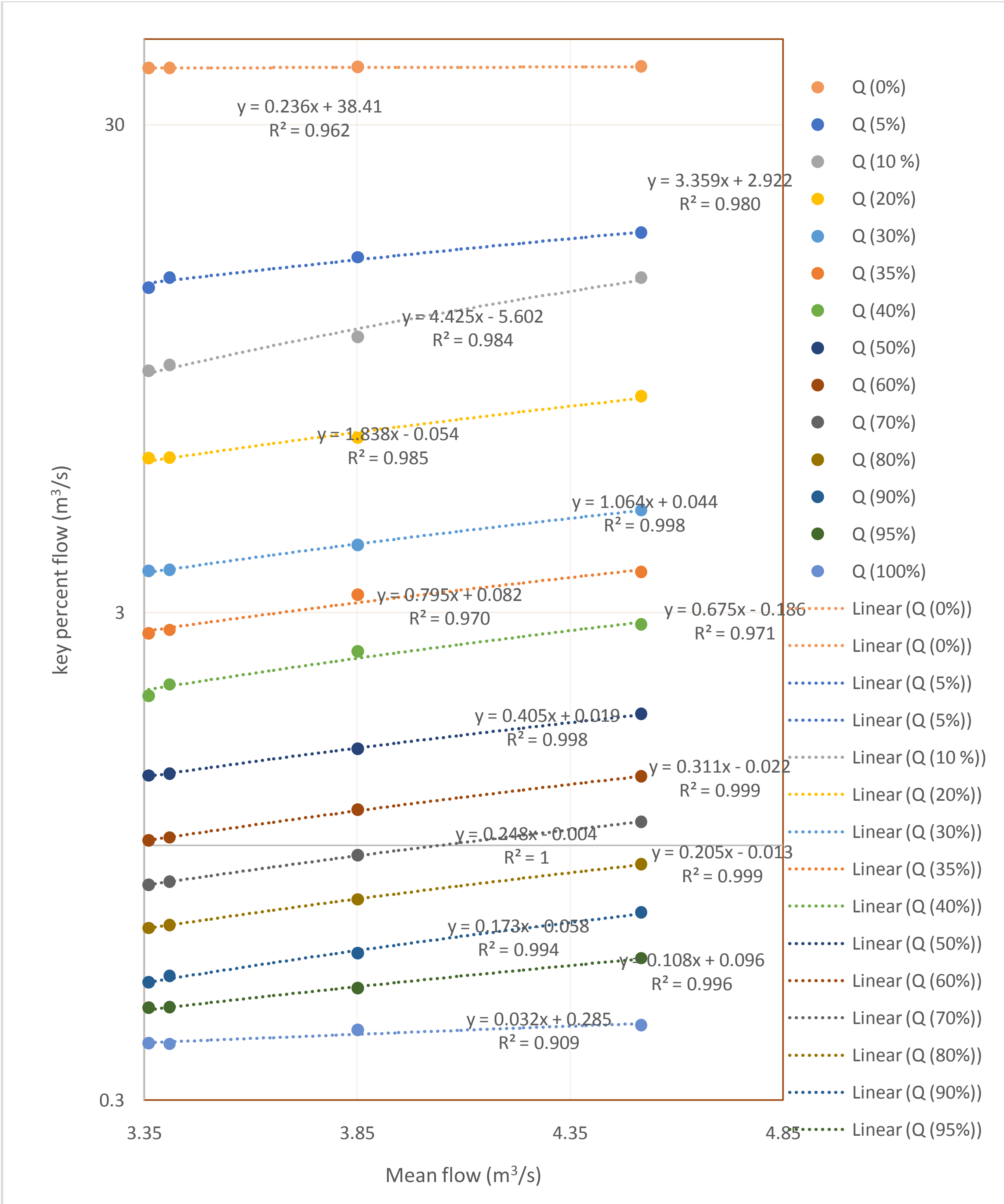

Figure 4-6: Parametric duration curve for the Koga watershed

For further accuracy of this method, the long term mean monthly flow of the koga outlet gauged point was calculated using equation 4-3 (Nwachukwu, 2005).

Q_{mean}=0.025(Q_0+Q_{100}) +0.05(Q_5+Q_{95}) +0.075(Q_{90}+Q_{10}) +0.1(Q_{20}+Q_{30}+ Q_{40}+Q_{50}+Q_{60}+Q_{70}+Q_{80})*4-3*

Q_{mean}=0.025(39.1 + 0.29) + 0.05 (19.26 +0.54) + 0.075 (16.08 + 0.76) + 0.1(8.16 + 4.38 + 2.20 + 1.55 + 1.04 + 0.90 + 0.79) = 5.14

The flow estimated by key percent, 5.14 was a bit greater than the mean monthly flow of the koga outlet gauged flow.

4.4.Potential head estimation

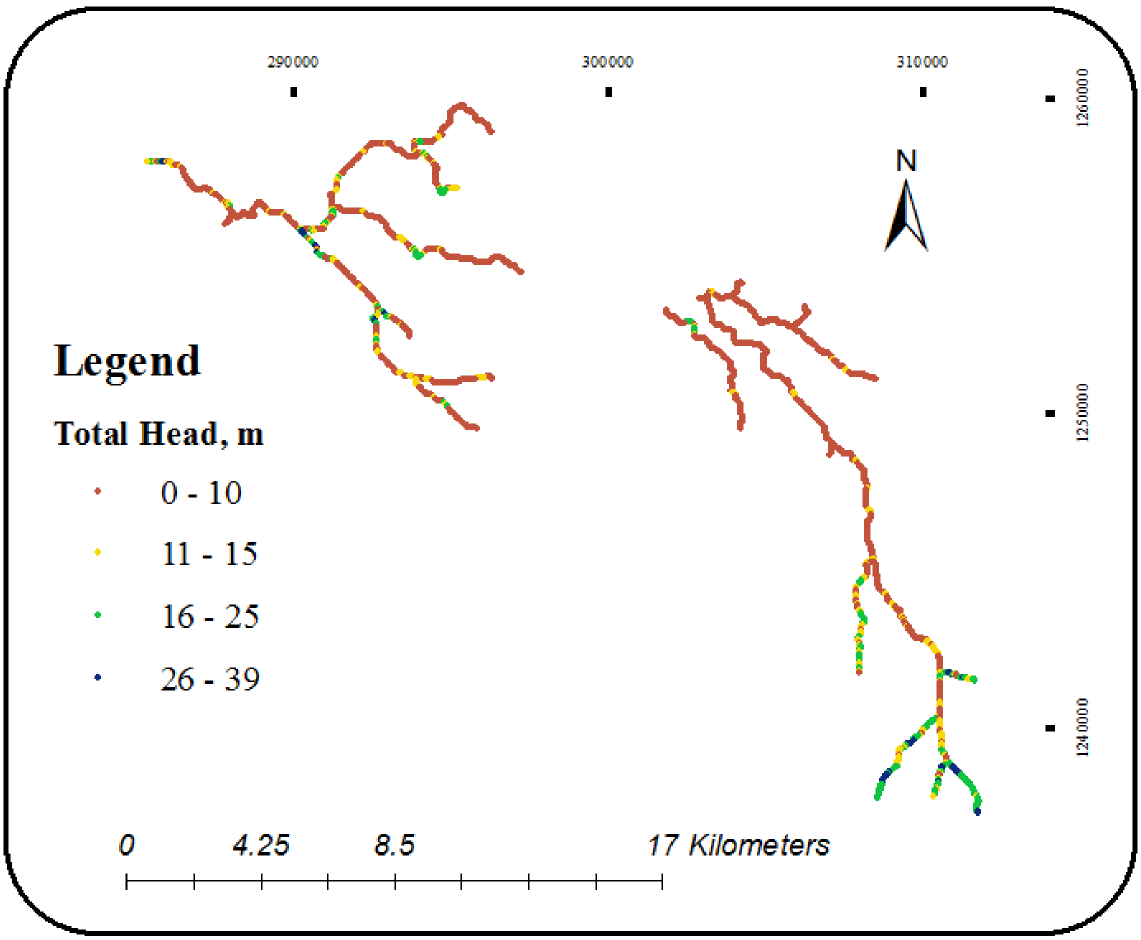

Figure 4-7: Head map of Koga stream line

As shown in the figure 4-7 the total head in the watershed goes up to 39 and 42m for d/s and u/s respectively. In the d/s part the head range 0-10 covers 71.35% from the total in number, 10-15m covers 17.06%, and 15-25 and 25-39 covers 9.61% and 1.98% respectively from the total head sites of downstream section. In this section, almost ¾ of the total were less than ten. So, these were not considered in the analysis. In case of u/s section 0-10, 10-15, 15-25 and 25-42m covers 65.79%, 15.86%, 14.93%, and 3.42% respectively. Totally the watershed has the head range of 0-10, 10-15, 15-25 and 25-42m with the coverage of 68.3%, 16.4%,12.53%, 39.52 and 2.77% respectively. It indicates that more than two-third of the extracted head were not used for power analysis and most of them were located in the upstream section.

4.5.Hydropower potential estimation

4.5.1. Estimation of available power

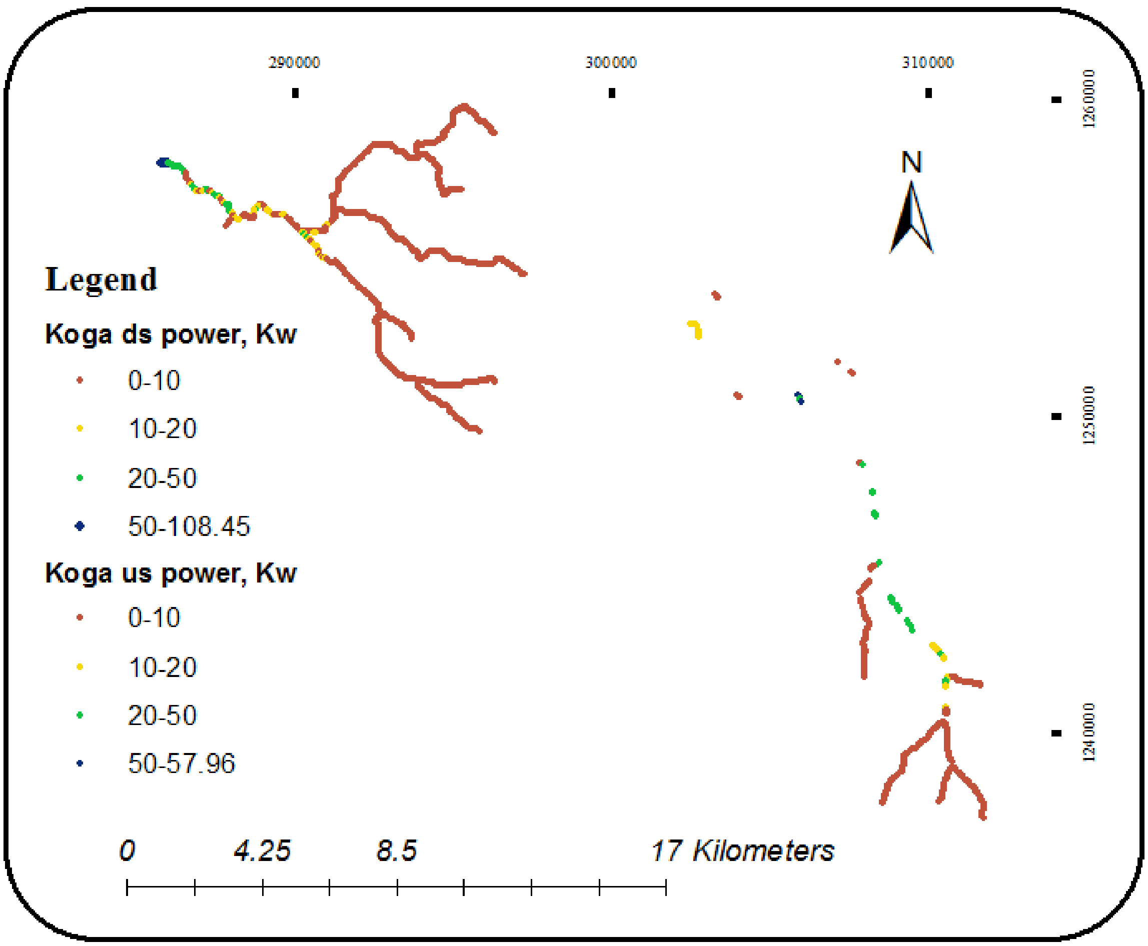

Figure 4-8: Power map of Koga stream line

As shown in the figure 4-8 there were too many sites which can generate a hydropower. In thiswatershed 86.39% were less than 10kw which were not part of this study and the range 10-20, 20-50and greater than and equal to 50kw sites cover 6.88%, 5.85% and 0.88% respectively. But even the sites which has greater than or equal to 10kw were not directly recorded as a potential site due to other factors as presented in the next section.

4.5.2. Constraints for potential site locations

In hydropower site selection some factors were considered to insure the sustainability of the selected site and to ignore or decrease the probability of false site selection due to the errors in the estimation process.As mentioned in section 3.12 five factors were selected and the result is discussed as follows:

1) **The mean annual flow**

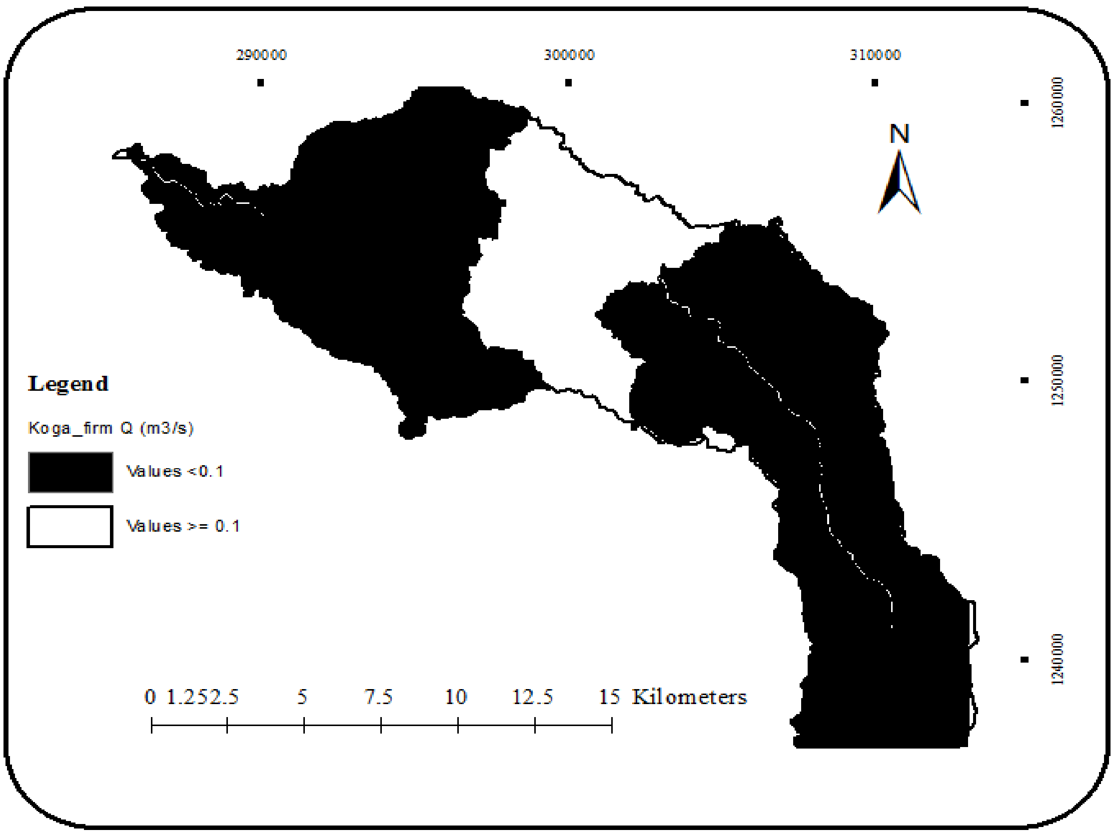

Figure 4-9: Map of firm discharge (90% dependable discharge) of Koga watershed

As shown in the figure 4-9 above, the sites that have a discharge value of greater than 0.1 m^3/s, marked white color in the map were considered as efficient in power calculation even though this was not the only factor for potential site selection.

2) **The elevation drops (H)**

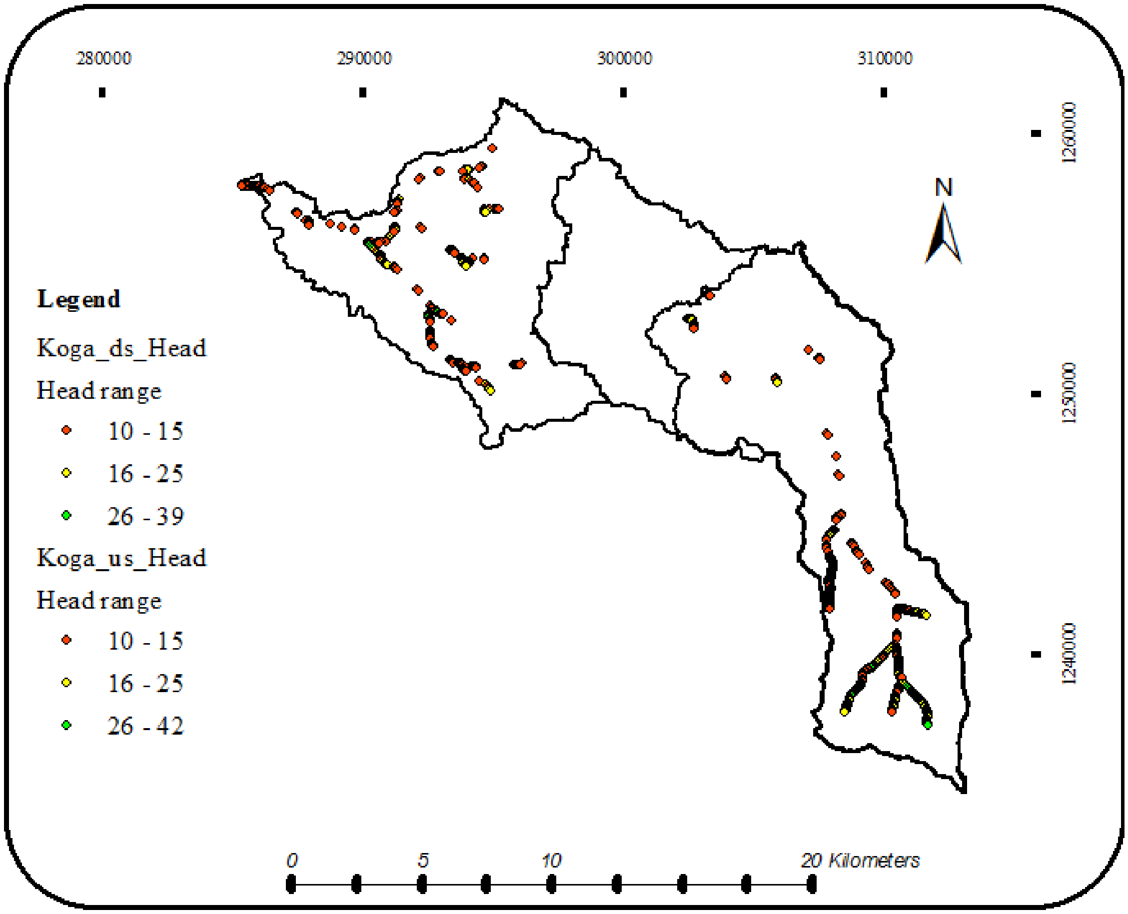

Figure 4-10: Map of head greater than 10m

As shown in the figure 15 the potential head goes up to 39 and 42m for d/s and u/s respectively. In the d/s part the head range 10-15m covers 59.54% and 16-25 and 26-39 covers 33.55% and 6.91% respectively from the total head sites of downstream section. In this section, more than a half part of the selected head sites were less than 15m. In case of u/s section 10-15, 16-25 and 26-42m covers 46.36, 43.64 and 10% respectively. Totally the head range 10-15, 16-25 and 26-42m covers 51.75, 39.52 and 8.74% respectively. It indicates that more than a half part of the selected potential head of Koga watershed were less than 15m and most of them were located in the downstream section.

3) The distance between each potential site

Whereas the distance between each potential site is fixed to be economical; especially in case of penstock length. Most literatures recommend 500m distance between two small scale hydropower plants is usually considered feasible (Kurse, 2009; Naufal andMasahiko, 2016; Khan andZaidi, 2015).The analysis was done using spatial analysis tool box with a function of neighborhood and focal statistics tool set in Arc Map 10.2 by setting 17 cell units of Hight and width as the cell size is 30 by 30m.(Kusre et al, 2009). Based on this only 11 sites were selected.

4) Estimated hydropower production

The small-scale hydropower to be produced should be greater than or equal to 10kw was set for this study. This is because since this paper focuses on the theoretically potential sites of Koga watershed that may be reduced by 50% to convert in to technically feasible sites. Therefore, to get at least 5kw power the theoretical potential power should be greater or equal to 10kw. Based on this the theoretically feasible sites on this watershed is shown below:

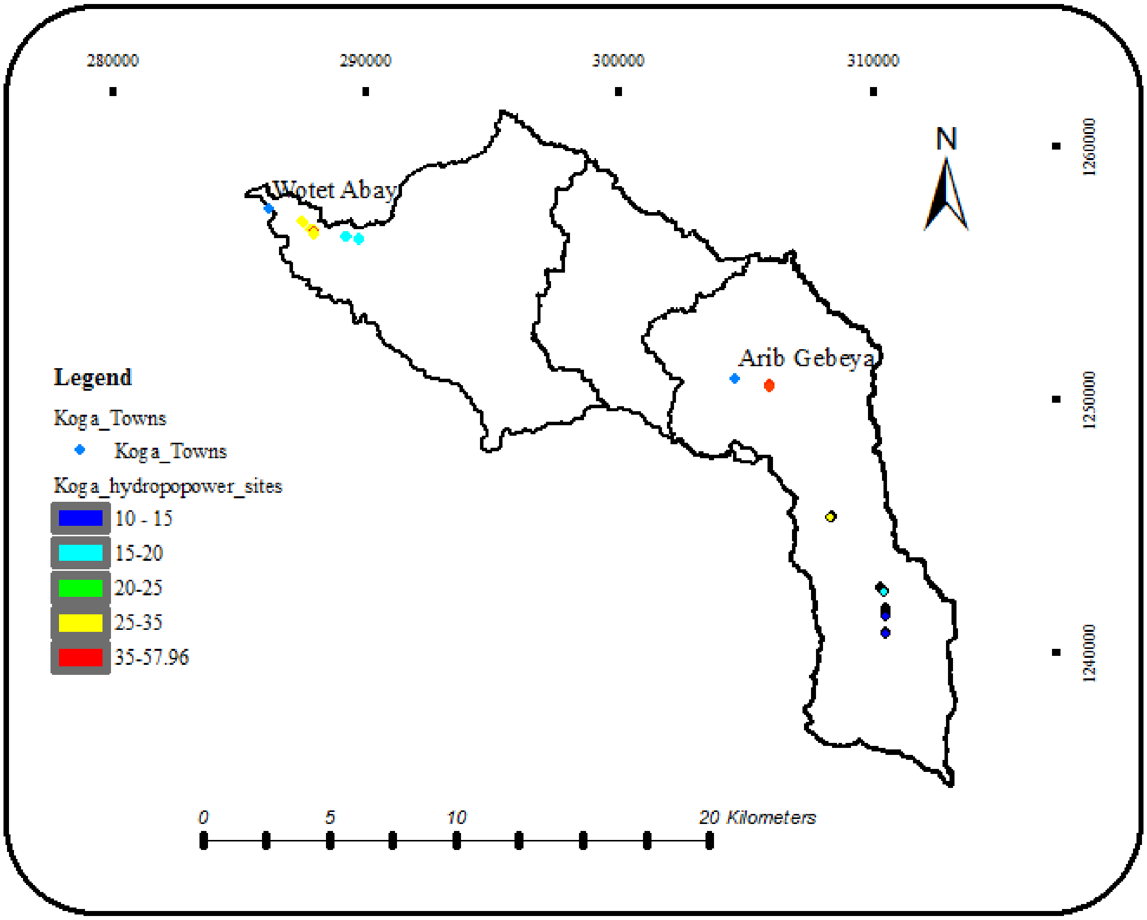

Figure 4-11:Map of hydropower sites greater than 10kw

As shown in the figure 4-11at the downstream section more potential sites especially that have a power of 25-35kw were near to Wotet Abay town. In case of upstream section,some potential sites that have a power of 35-57.96kw were near to Arib Gebeya rural town and the others are slightly far away from these small towns

5) Zone of existing dam and reservoir area.

As mentioned earlier in Introduction section, in Koga watershed there is one irrigation dam that prohibits installation of hydropower facilities and therefore taken as a constraint. As a result, potential site analysis omits its structure and its possible maximum reservoir surface elevation and the analysis is done by dividing the watershed in to two parts as shown below

- ✓ Upstream(u/s) section: a section located on the upstream section of the existing dam zone

- ✓ Downstream(d/s) section: a section located on the downstream section of the existing dam zone.

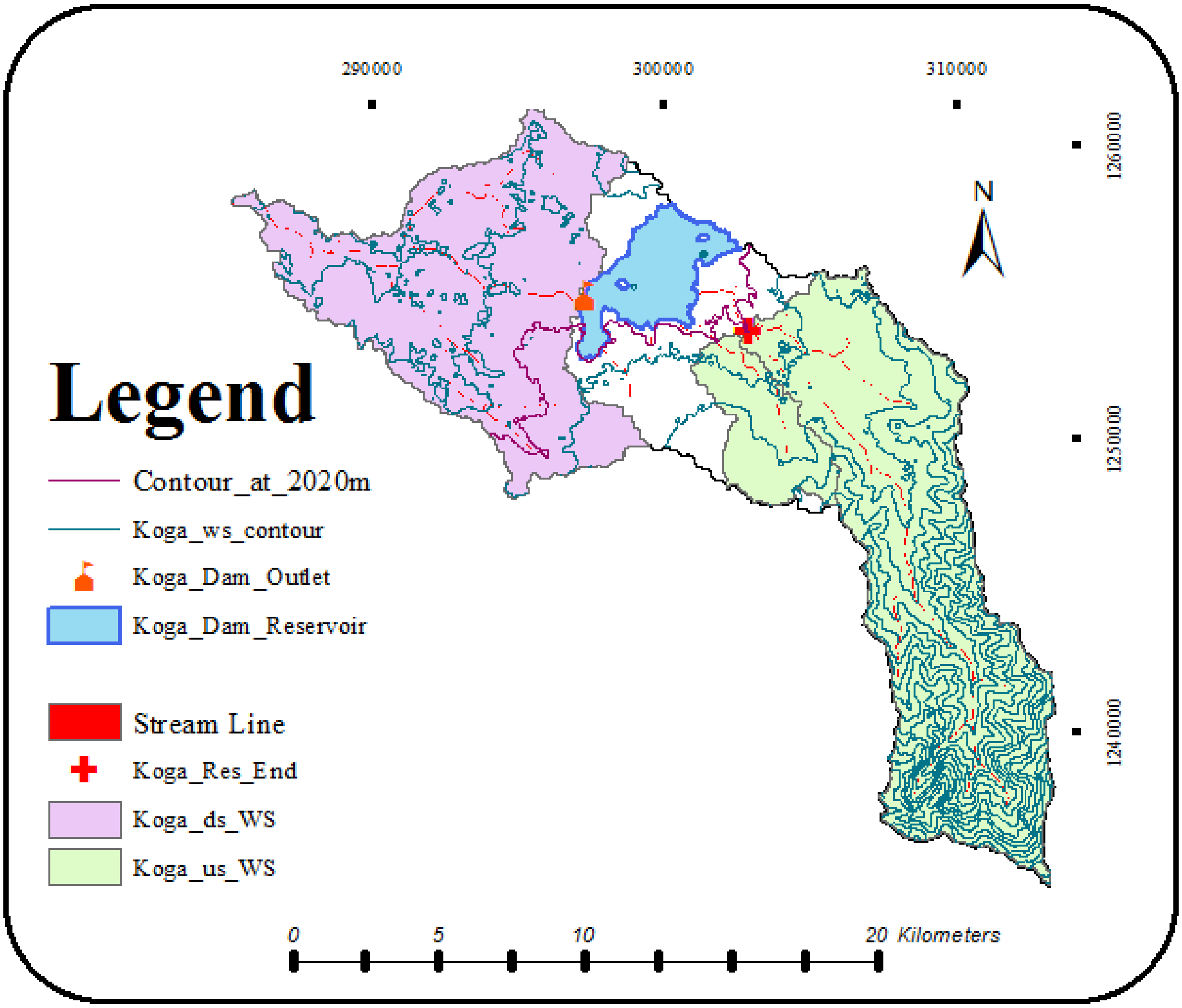

Figure 4-12: Map of constructed regulation structures and its reservoir surface area in Koga watershed.

4.6.MCDAanalysis result

This Section focuses on the very specific problemsof spatial resource allocation decisions in thecontext of multiple criteria – a process mostcommonly known as multi-criteria decision evaluation /MCDE/ (Voogd, 1982). Almost all of the case study examples in thischapter are based on an analysis of suitability for Small Scalehydropower development for the Koga Watershed.

4.6.1. Setting parameters result

Some parameters are taken as a milestone to prioritize the potential sites. These parameters are settled by reviewing different literatures that deals with small scale hydro powers and the data availability for this watershed. The parameters used in this study arediscussed below(Priyabrata et al., 2015; Keneni, 2007).

1) Firm Discharge

While it is difficult to judge the suitability for development based on the absolutevolume of firm discharge, a potential site with a relatively high level of firm discharge is more favorable site for a small-scale hydro plant designed to supply power throughout theyear. It is known that stream discharge increases dawn wards in to the downstream section because when we go in to the downstream section of a given stream, the area of watershed that contribute in to that stream will be increased. But that does not mean as we go to the downstream section the available power to be produced is increased due to the other parameters that does not linearly increased or decreased along the stream line.

As shown in the figure 4-13 stream flow increases to the downstream section and as the stream flow increases the standardized value goes to one (refer to next section).

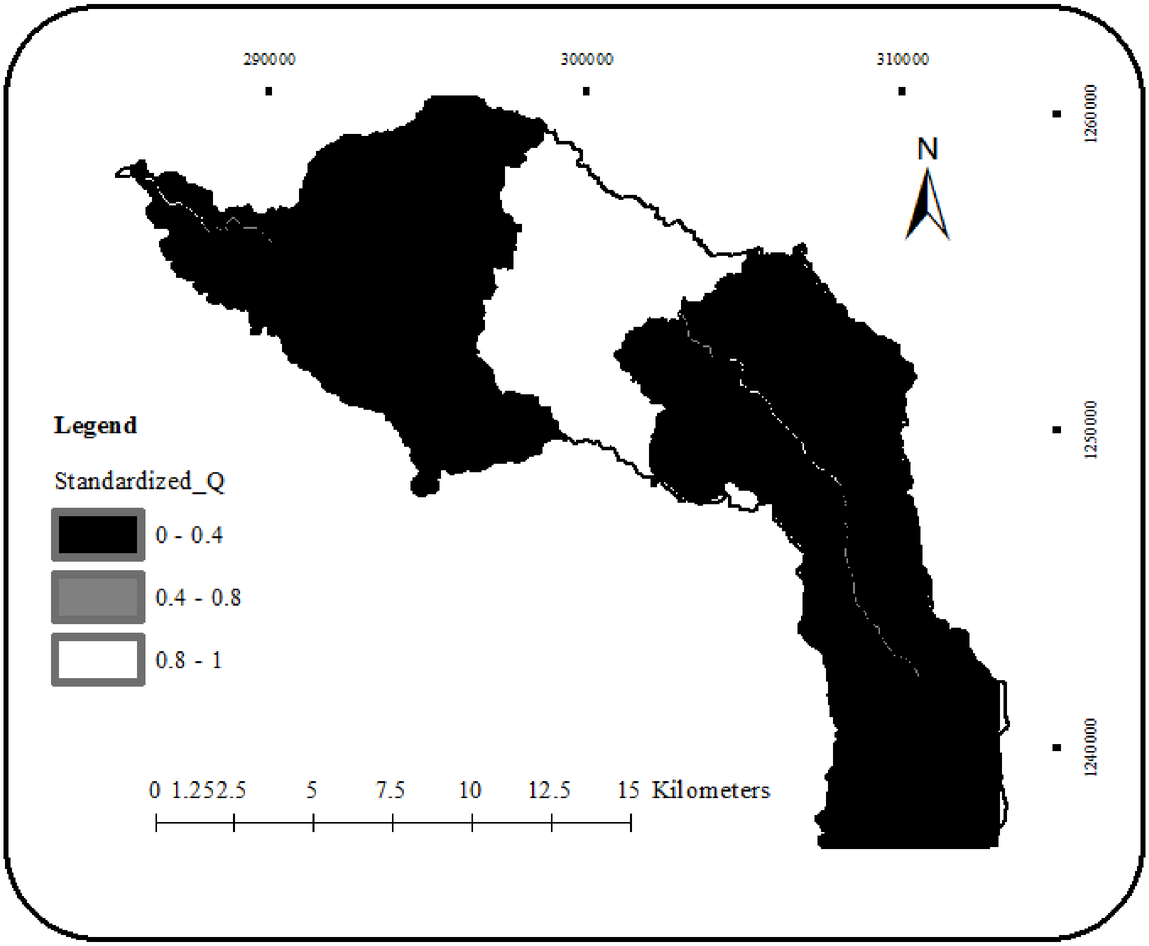

Figure 4-13: Constraint map of discharge

2) Head

Gross head is one of the physical characteristic of the site which is used to estimate the hydropower potential at the site. Sites which have a higher head are more favorable.The greatest fall over the shortest route is preferable when choosing a small-scale hydro site as a long penstock can be quite costly. More head is usually better, since power is the product of head and flow. Thus, less flow is required at a higher head to generate similar amounts of power. Also with a higher head, the turbine is able to run at a higher speed,resulting in a smaller turbine and generator for a given power output. However, pipe pressure ratings and pipe joint integrity require careful design at very high heads.

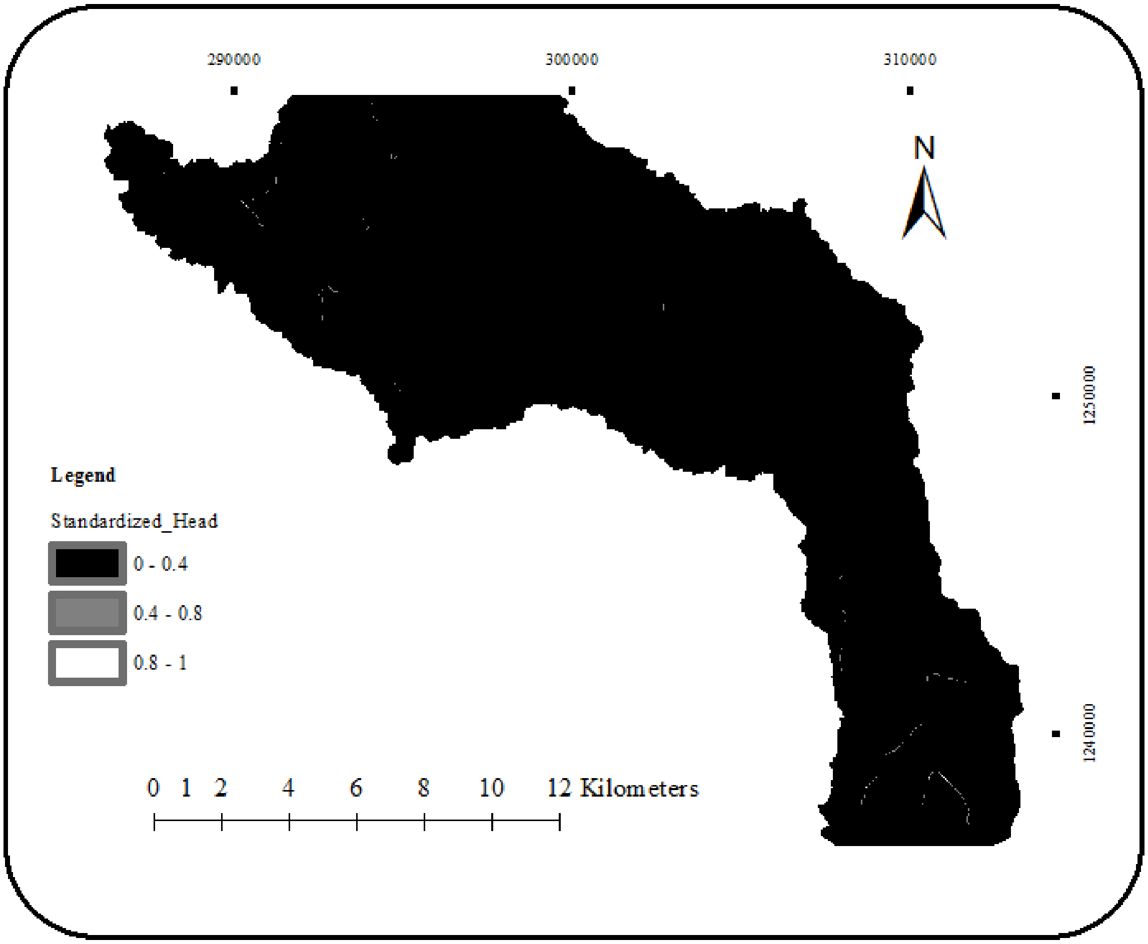

Figure 4-14: Constraint map of head

3) Stream Power

Even though the main target of this paper is selecting sites that has a good stream power, Sites that have more power may not be selected. Because the sites may not pass the restrictions discussed in the previous section. And also, sites that have more power may not be preferred from the sites that have less power due to the prioritization of the given parameters.

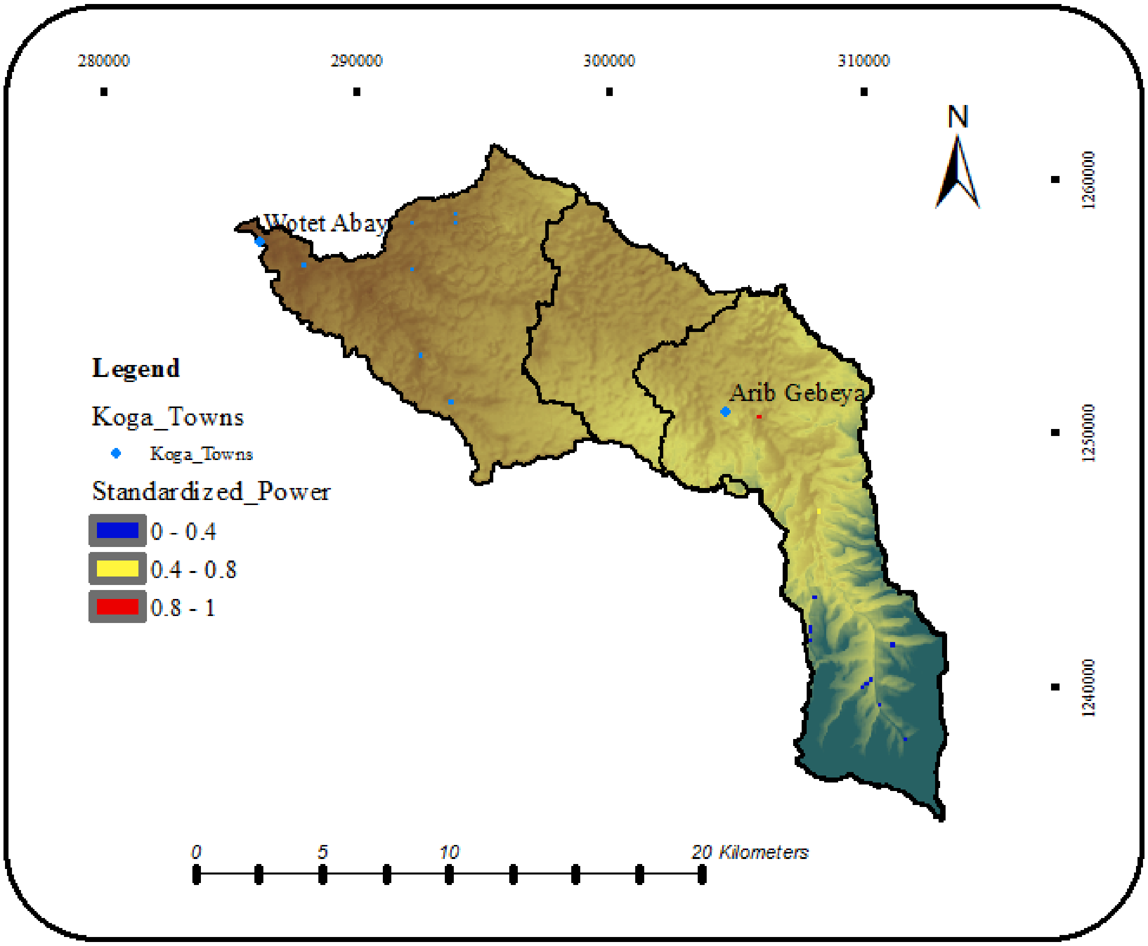

Figure 4-15: Constraint map of power

As shown in the figure 4-15 more potential sites were located at the downstream section and best potential sites are located near the rural towns.

4) Road Accessibility to the Site

Road access is one parameter in selecting preferred sites of small-scale hydropower. Because constructing roads, for the purpose of transportation for construction as well as monitoring and maintenances is costly, it may be much greater than the cost of constructing a hydropower facilities. A potential site that has lower distance from the road is preferred over a site that has more distance.

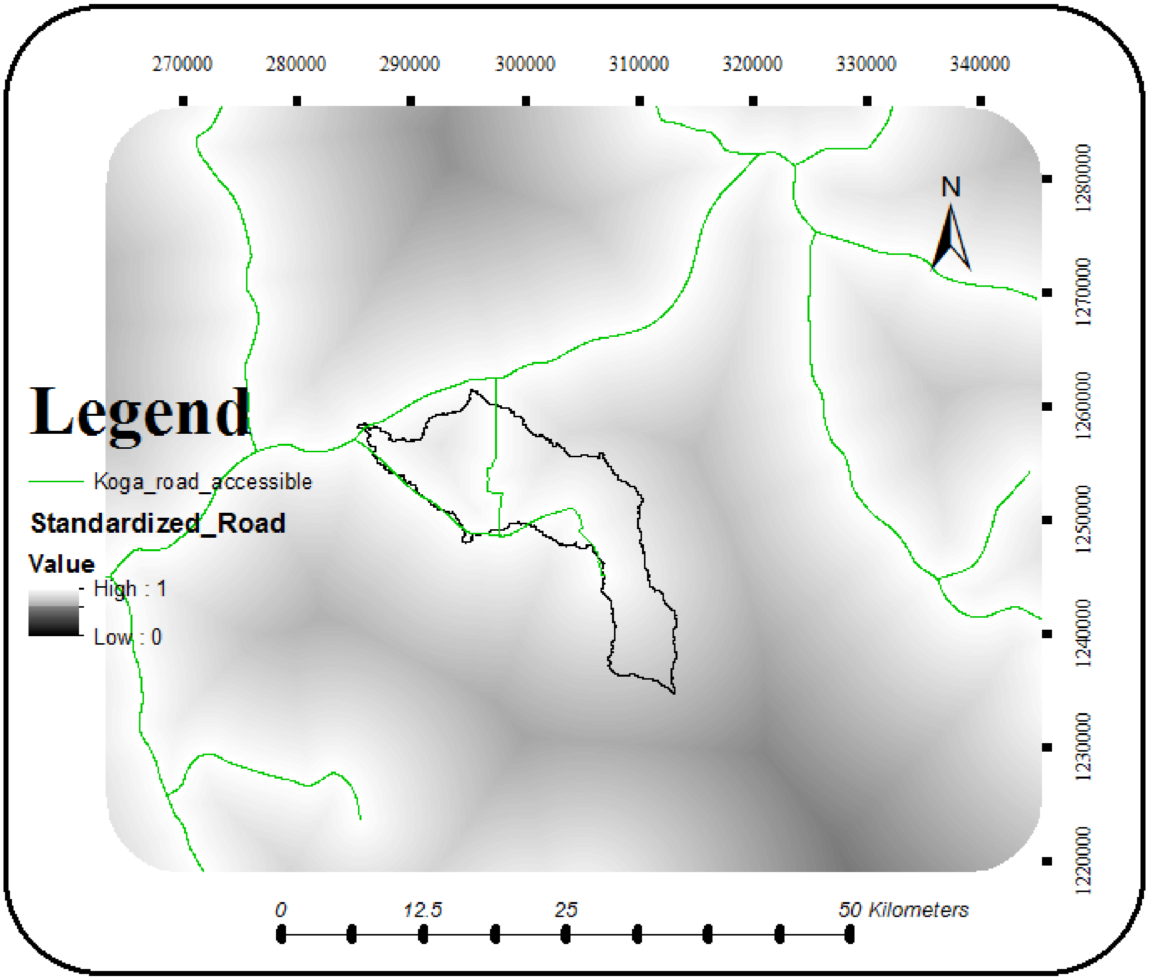

Figure 4-16: Constraint map of road accessibility

As shown in the figure 4-16 on the standardized map, sites near to the road have more value than and the sites are preferred to decrease transportation cost and time.

4.6.2. Determine the weight of each factor

In this sub section, the measure of the relative importance of the factors to the given objective is done. As mentioned in section 3.12, Analytical Hierarchy Process (AHP) is selected for analysis.

4.6.2.1. Constraint map preparation

Constraint maps are created to determine the criteria that are constraints to the hydropower power plant. It is done based on the standardization value described at section 3.12. It is a sort of Boolean map; each pixel has a unique value with 1 or 0.Pixels with value of 0 represent the areas are not possible to be the optimal sites. On theother hand, Pixels with the value of 1 means the areas that may be the optimal sites.

Here the third standardization method is selected as it is used for a pairwise comparison of the criterion scores and widely used.Fuzzy Membership Functions of GIS software are used to standardize the criterion scores as shown below for each constraint. Here the cost criterion is applied for road accessibility and benefit criterion is applied for the others.(Refer to section 4.5.2)

4.6.2.2. Complete the matrix

In paired comparison weighted method, the first step is completing the matrix where each criterion iscompared with the other criteria, relative to its importance, on a scale from 1 to 9 as shown below in table4-5.

Table 4-5: Completed matrix for the criterion

Factors	Power	Head	Discharge	Accessibility
Power	1	2	3	6
Head	1/2	1	2	5
Discharge	1/3	1/2	1	4
Accessibility	1/6	1/5	1/4	1
Sum	2	3.7	6.25	1/6

4.6.2.3. Normalization & weight determination

Normalization and weight determination is the next step of weighting factor.To normalize the values, divide the cell value by its column total of table 7 and then priority vector or weight is determined by averaging the value of the rows as shown below.

Table 4-6: Normalization and weight determination

Factors	Head	Discharge	power	Accessibility	Priority vector* or Weight
power	0.5	0.540541	0.48	0.375	0.4739
Head	0.25	0.27027	0.32	0.3125	0.2882
Discharge	0.166667	0.135135	0.16	0.25	0.1780
Accessibility	0.083333	0.054054	0.04	0.0625	0.0600

4.6.2.4. Calculate the consistency ratio (CR)

Finally, Consistency ratio is done. The matrix prepared above should be consistent to validate weight estimation.As mentioned in the methodology section of 3.10. If CR > 0.10, some pairwise values need to be reconsidered & the process isrepeated until the desired value of CR < 0.10 is reached. The consistency ratio should be checked using the formula below:

CR = Consistency index (CI)/Random Consistency Index (RI)

$CI = (\lambda_{max} - n)/n - 1$and $\lambda_{max}$is the principal eigen value; which is the summation of the products between each element of the priority vector and column totals, n is the number of factors, and RI is taken from appendix 7.6 F_2.

Table 4-7: Consistency ratio calculation

No.	**Description of factors**	λ_{max}
1	Power	0.94777
2	Head	1.066313
3	Discharge	1.11219
4	Accessibility	0.95955
5	Total λ_{max}	4.085823
6	CI	0.0286081
7	CR	0.031786

The principal eigen value, $\lambda_{max}$was calculated by multiplying the sum of the AHP scale after preparing a matrix (see appendix 7.6 F_2) and priority vector presented at appendix 7.6 $F_3$for each factor. According to Saaty (1980) if the consistency ratio is less than 0.1 the estimated AHP scales are accepted and the priority vector or weights will be taken. Therefore, as shown in table 4-8 since CR was less than 0.1 the weights were taken. After validating the matrix, the criteria are aggregated using weighted linear combination using by multiplying the value of each factor with the priority vector using raster calculator in Arc mapand the output was the rank of potential hydropower sites as shown inFigureand appendix 7.4 D_2.

4.6.3. Technical hydropower results

Here the actual hydropower was calculated using equation (3-20) by taking a value of 0.8 for overall efficiency as stated in section 3.11.2, and the resulted 12 sites potential is clearly presented in appendix 7.4 D_2.

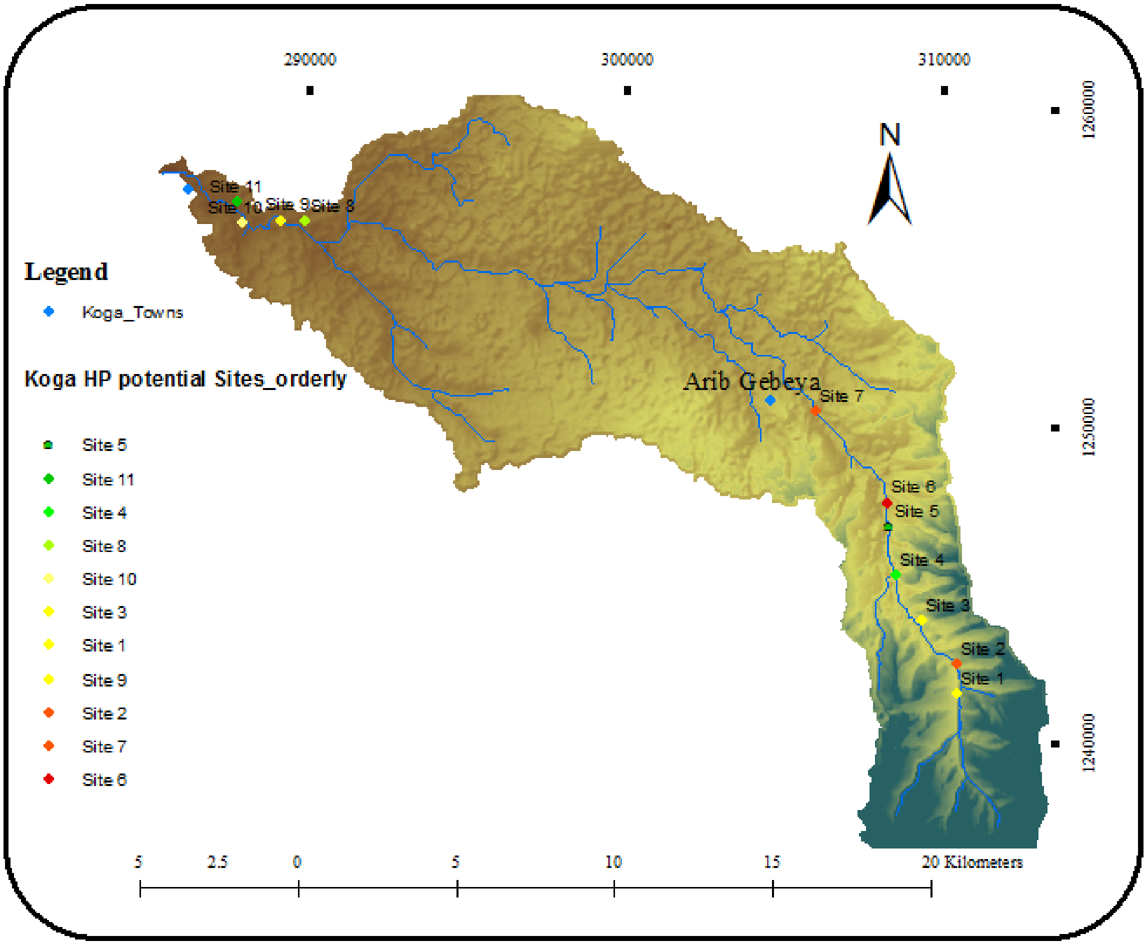

Figure 4-17: Map of small scale hydropower (HP) potential sites.

As shown in the figure 4-17 comparatively best and more potential sites were selected on the upstream section with a total installed capacity of 162.69kw whereas at the downstream section only four sites were selected with a total capacity of 79.12kw. from this only site 7, and 10 and 11 were near to the rural town Arib Gebeya and Wotet Abay respectively and the other sites were near to the rural villages. In this thesis as described in the earlier section, the power was calculated using 35%, 70% and 90% dependable discharge but for firm power 90% dependable flowwas used to serve for almost 11 months per year.The 35% and 70% dependable powerwere calculated for comparison for the developers to choose them as a hybrid system.The 70% dependable power increases by 22.72% from the 90% dependable power for each site. This shows that the 70% dependable power is almost two times the 90% dependable power but the design power is more than 4 times the 90% dependable power.At the appendix 7.4 D_2. the location of the sites, the weighted values aggregated from each constraint, the dependency power and rank of the site based on the weighted value are listed respectively.

4.7. Validation of the head of potential sites

The value of head computed by GIS and field measurement were compared using the two widely used efficiency criteria; coefficient of determination and Nash-Sutcliffe efficiency. The value of the coefficient of determination r^2, is 0.83 while the value of the Nash-Sutcliffe efficiency E is 0.73, The value of the Nash-Sutcliffe efficiency, E, was 0.73, a little lower than r^2 but still very high considering that all head values were predicted closest to the observed values; the value was presented in appendix 7.7 G.

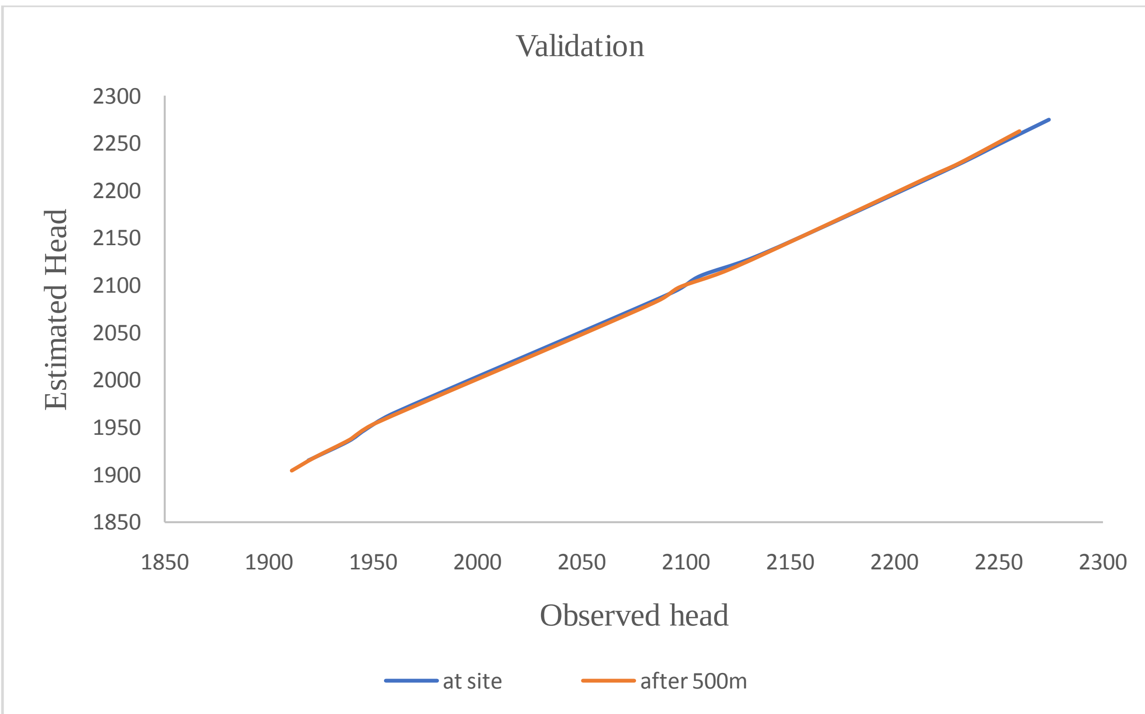

Figure 4-18: Comparing estimated and measured head.

CONCLUSION AND RECOMMENDATION

5.1.Conclusion

The study aimed at searching some potential sites for small-scale hydropower plants by defining intake locations based onpower capacity, stream discharge and thecomputation of head.

For this study, the Koga Watershed has a total of 11 potential sites when we can select the best suitablesites for hydropower development. For a minimum head of 10m and a maximum horizontal distance between thevirtual intake and virtual powerhouse of 500m that we used. The minimum installed power in this watershed was11.74kW and the maximuminstalled power was43.58kW. Koga watershedhas the average installed power of 21.98kW and can generate average potential energy of 192567.87kWh per year. OverallKoga Watershedinstalled power of 241.82kW and estimated to generate potential energy of2118246.601kW or 2.12GWh annually.

The results of the potential sites evaluated were validated by collecting the field data in the watershed. Where the collected GPS parameter in the locations of potential sites has provides a good result. The relation between the estimated and measured head was validated by the Nash Sutcliff and coefficient of determination coefficient criteria, and both were above 0.7. Above all the GIS based MCDA parameter of constraints used in this study could be used for choosing in other watersheds for rural electrification of the country.

This study can serve as the model approach for investigating the potential sites in the Blue Nile basin. Where these results can serve as for engagement of public and private sector investment. Which later can reduce the power shortage in towns and rural electrification.

In this investigation, the selected sites should also be acceptable socially by attributing additional suitability factors, such as cultural and historic values, fish presence value, and geologic value and economic feasibility.

5.2. Recommendation

Ethiopia has a substantial amount of water resources potential and yet a nationwhere vast hydro power resources are still untapped. Due to the use of traditional energy system, deterioration of the environment is increasing from time to time. In view of theeconomic and social development, the stabilization of sustainable energy supply to the rural and urban area throughout the nation will keep the environment safe & additionally promote themodernization of peoples living in rural areas. Therefore, to bring into effect the povertyreductions at national level and to speed up the economic development, the government has toinitiate study & further action on small-scale hydropower projects.

For further studies, by using different values for head and a maximum horizontal distance can be another basisfor estimation of power and identifying potential sites in the region and conduct site suitability analysis.

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APPENDIX

7.1. Appendix A: Sample data

A_1 Sample MonthlyFlow at Koga Gaging station

Station Number: 111003

Time-Series Type: Flow (Cumes)

Longitude: 284920.37E Latitude: 1258283.26N Elevation: 1989m

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1959	3.66616	2.76295	2.4796	1.61	1.62	2.48	30.3	59.66	38.16	20.69	9.89	5.71
1960	4.32	3.23	2.39	1.66	1.65	2.28	25.87	52.68	29.3	12.21	5.97	4.41
1961	3.18	2.65	2.15	1.88	1.38	2.36	31.87	44.12	33.17	17.67	13.36	10.46
1962	3.94	2.44	2.15	1.32	1.59	2.26	23.89	41.63	30.08	14.48	7.15	4.6
1963	3.23	2.16	1.99	1.83	2.59	3.22	24.27	44.67	27.5	10.88	13.63	7.12
1964	3.37	2.05	1.44	1.54	1.87	3.08	45.65	57.29	35.89	20.98	9.48	5.83
1965	4.32	3.32	3.23	2.73	1.98	2.81	13.7	32.14	17.14	16.43	11.44	6.77
1966	3.84	2.82	2.71	1.98	2.28	2.83	22.15	34.2	22.38	8.28	5.9	4.08
1967	3.02	2.4	2.53	1.96	1.79	4.07	32.35	51	33.59	17.27	7.68	5.51
1968	3.94	2.79	2.56	2.01	2.11	5.34	36.67	45.77	25.24	14.2	5.85	4.44
1969	3.61	2.66	2.74	2.02	2.06	3.45	37.19	68.35	33.86	10.3	6.16	4.96
1970	4.38	3.74	3.69	3.26	4.9	7.56	29.67	50.64	27.85	13.35	7.01	5.4
1971	4.37	3.26	3.12	2.7	2.86	5.2	24.08	55.89	27.7	11.68	9.26	5.73

1972	3.75	2.47	2.12	1.74	1.8	3.56	14.82	28.46	19.47	7.47	5.03	2.96
1973	2.45	1.94	1.91	1.75	2.19	3.14	18.06	52.62	23.33	11.9	5.17	3.74
1974	3.07	2.33	2.3	1.96	3.92	3.91	31.06	44.47	36.32	14.12	6.07	4.29
1975	3.53	3.4	2.8	2.29	2.36	5.03	53.38	95.01	73.44	31.28	10.27	9.74
1976	3.76	3.47	3.89	3.14	4.92	19.09	37.21	61.29	31.86	15.07	9.78	5.44
1977	3.46	2.92	2.81	2.13	1.97	4.29	25.71	33.11	22.25	26.03	6.75	4.76
1978	3.27	2	1.59	1.68	1.94	11.08	44.3	44.12	36.41	17.94	8.58	5.78
1979	3.51	2.39	2.31	1.99	2.61	4.16	19.1	39.45	28.84	16.23	5.7	3.09
1980	2.6	2.46	2.24	2.2	2.08	9.31	44.07	60	16.72	6	3.5	3
1981	2	1.8	1.6	1.5	1.4	12	45	70	36	12	5	2.5
1982	2	1.9	1.8	1.5	1.4	3	13	25	17	7	3.5	3
1983	2.53	2.01	1.99	1.42	1.47	4.75	7.47	30.56	15.47	10.02	5.36	3.61
1984	3.25	1.66	1.47	1.24	1.38	10.79	21.71	23.2	17.62	6.48	3.6	2.94
1985	2.53	1.64	1.36	1.17	1.74	4.87	16.41	28.63	17.12	9.88	6.12	3.99
1986	2.78	1.65	1.38	0.934	0.669	4.54	15.68	17.12	16.69	10.9	5.31	4.14
1987	3.25	2.57	3.47	1.76	4.36	11.22	16.28	19.33	14.1	10.96	6.63	4.83
1988	4.06	2.8	2.4	1.31	1.9	7.53	31.68	29.95	23.68	20.22	8.8	6.1
1989	4.818	3.204	3.041	2.462	2.882	9.674	23.753	28.438	17.318	10.68	5.897	3.826
1990	2.951	3.053	2.804	2.219	2.317	3.165	16.953	49.4765	30.9722	9.86	5.73	4.24
1991	3.36	2.28	2.08	2.62	2.78	5.96	28.4368	49.1045	30.7176	16.3539	8.41	6.62
1992	5.066	3.566	3.212	3.062	3.001	4.553	16.513	32.733	19.516	19.216	12.216	7.61
1993	6.79	4.577	3.684	3.544	3.76	10.327	41.118	32.337	30.931	19.152	9.491	5.881

1994	4.123	6.607	2.647	2.16	2.617	8.006	22.912	30.473	28.182	10.36	7.184	5.069
1995	3.39	2.379	2.364	2.082	2.944	6.808	22.152	254.211	190.508	45.506	18.039	40.47
1996	3.06	2.01	2.16	2.74	5.85	19.039	43.537	53.632	31.214	16.193	8.232	5.855
1997	4.39	3.03	2.91	2.27	4.89	10.56	25.68	36.02	18.79	19.24	12.07	6.07
1998	4.15	2.68	2.37	1.94	4.44	9.3	30.41	43.61	31.85	32.98	11.21	7.56
1999	5.43382	3.4723	2.88631	2.41737	3.98602	12.9948	47.4478	42.0176	25.6304	32.1662	10.4434	7.52966
2000	4.65042	3.18038	2.70661	3.33656	3.29449	7.11358	23.7967	66.1606	24.6692	40.2755	13.9832	6.93849
2001	4.62425	3.41852	3.18937	2.41837	3.53848	15.4889	46.7854	66.6539	22.5664	12.9183	7.23631	5.43745
2002	4.23337	2.97972	2.93206	2.30501	2.154	7.28134	24.9336	40.9172	20.1372	10.9027	6.10313	3.7665
2003	2.951	2.203	1.976	1.645	1.594	5.759	44.553	59.928	42.312	15.342	7.483	5.159

A$_2$ Sample Monthly Rainfall at Dangila Gaging station

Time-Series Type: Rainfall (mm)

Longitude: 264988.35E Latitude: 1264843.747N Elevation: 2116m

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001.00	0.00	0.10	14.50	13.90	157.30	321.30	380.00	253.30	150.60	97.90	3.30	0.00
2002.00	0.00	2.73	11.90	14.80	52.10	278.80	298.90	345.80	182.70	123.10	30.40	2.00
2003.00	0.00	4.50	7.50	2.30	23.20	330.60	338.90	279.20	301.90	26.90	55.00	0.00
2004.00	0.00	9.20	2.30	90.70	60.70	230.60	487.90	363.90	266.70	94.80	21.10	0.00
2005.00	4.00	0.50	29.20	7.40	48.30	271.00	303.50	344.80	320.80	54.20	6.00	0.00
2006.00	2.90	0.00	0.10	47.90	258.90	339.70	440.20	392.90	227.60	186.80	6.80	19.00
2007.00	0.00	1.00	12.30	50.60	131.70	269.60	314.30	384.40	176.20	61.00	59.40	0.00
2008.00	40.10	0.00	2.50	119.70	251.30	292.10	434.80	421.90	359.00	28.70	6.80	0.00
2009.00	0.00	6.90	19.00	11.90	24.10	317.10	340.20	706.00	139.20	154.70	26.70	0.30
2010.00	2.90	0.00	0.50	31.50	183.10	192.80	339.86	350.90	294.80	67.30	14.20	6.30
2011.00	4.00	2.00	31.20	20.60	228.90	272.10	339.00	432.70	217.20	48.00	4.00	0.00

A$_3$ Sample Monthly Rainfall at Durbetie Gaging station

Time-Series Type: Rainfall (mm)

Longitude: 332939.28E Latitude: 1148381.05N Elevation: 2234m

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2005.00	0.00	0.00	16.76	31.22	177.69	320.07	431.83	397.15	212.62	82.12	18.50	0.00
2006.00	0.00	0.00	2.30	30.30	232.80	454.50	528.80	320.70	228.80	166.70	1.50	32.00
2007.00	0.30	1.00	15.10	35.10	135.90	300.80	329.30	364.70	181.20	66.60	48.80	0.00
2008.00	27.70	0.00	1.30	64.00	152.50	334.90	566.10	440.60	210.40	28.70	10.80	1.80
2009.00	6.46	16.60	88.00	31.22	177.69	313.40	456.60	514.60	160.00	83.70	4.90	31.20
2010.00	17.70	0.00	0.00	19.30	92.10	329.50	360.20	279.50	180.60	43.70	7.50	7.90
2011.00	18.50	2.30	19.50	3.20	205.90	350.80	334.70	575.50	326.30	41.60	12.30	0.00
2012.00	0.40	0.00	0.00	4.30	102.40	389.40	456.30	390.60	243.80	36.00	26.70	14.20
2013.00	0.00	12.00	1.90	20.90	146.30	179.90	578.10	429.83	199.70	87.20	48.90	0.00
2014.00	0.00	4.50	43.00	103.60	282.40	302.90	306.30	336.10	214.10	193.00	28.50	0.00
2015.00	0.00	0.00	5.40	0.30	183.50	217.50	424.00	409.50	176.60	85.80	59.70	40.00
2016.00	6.46	0.00	7.90	31.22	243.10	347.20	409.70	307.00	217.30	70.30	12.90	0.00

A_4 Sample Monthly Rainfall at Wotet Abay Gaging station

Time-Series Type: Rainfall (mm)

Longitude: 286328.92E Latitude: 1257497.67N Elevation: 1920m

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2003.00	0.00	17.50	15.20	1.30	16.70	366.70	272.90	320.36	208.80	31.80	32.10	1.30
2004.00	19.20	5.20	2.80	74.20	7.20	276.50	354.10	227.90	235.40	82.90	10.10	12.70
2005.00	1.90	0.00	31.30	31.00	111.30	301.40	394.30	371.00	341.00	70.00	32.00	0.00
2006.00	0.00	0.00	0.00	38.70	288.10	469.60	419.30	386.70	232.50	215.50	0.00	38.50
2007.00	0.00	0.00	30.00	36.10	56.00	371.80	436.50	523.00	367.50	70.00	50.00	0.00
2008.00	62.50	0.00	0.00	101.40	159.30	375.80	538.00	326.00	198.50	48.50	0.00	0.00
2009.00	0.00	12.00	28.10	18.00	39.50	280.40	487.30	414.00	53.50	40.00	6.00	25.00
2010.00	7.60	2.67	20.82	30.33	109.10	375.70	662.70	663.80	320.70	36.60	0.00	9.00
2011.00	0.00	0.00	9.20	0.00	106.00	115.80	447.51	406.32	274.52	0.00	0.00	0.00
2012.00	7.60	0.00	0.00	0.00	81.00	226.50	277.00	406.32	274.52	0.00	0.00	0.00
2013.00	0.00	0.00	0.60	0.00	82.00	199.10	705.30	397.70	374.90	66.81	12.11	10.92
2014.00	0.00	0.00	119.70	93.60	20.00	526.40	316.20	314.10	381.60	94.30	12.00	4.20
2015.00	7.60	0.00	11.50	0.00	201.80	218.40	543.90	397.40	207.60	85.00	15.20	51.20
2016.00	0.00	0.00	22.20	0.00	249.40	187.90	410.10	533.90	372.20	93.90	0.00	0.00

A_5 Sample Monthly Rainfall at Merawi Gaging station

Time-Series Type: Rainfall (mm)

Longitude: 312925.30E Latitude: 1268726.49N Elevation: 1958m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005.00	4.46	2.70	52.00	20.40	107.30	214.60	445.70	285.30	296.50	109.60	22.60	0.00
2006.00	0.40	0.00	0.80	0.80	235.20	407.00	536.10	448.90	285.40	163.20	0.20	11.20
2007.00	0.00	0.00	26.90	25.50	99.30	455.00	273.50	270.50	279.60	86.90	52.00	0.00
2008.00	12.10	0.00	0.00	141.90	188.40	328.90	386.00	302.10	190.30	57.20	31.20	0.00
2009.00	4.46	35.50	21.00	36.10	158.20	199.40	470.30	469.30	117.40	108.10	19.90	22.20
2010.00	11.50	0.00	1.10	27.60	166.80	307.56	333.70	330.60	145.70	71.10	24.40	0.00
2011.00	20.60	0.00	0.00	10.30	158.20	401.50	354.40	338.40	264.40	79.10	27.10	0.00
2012.00	0.00	0.00	4.00	1.30	35.90	249.80	579.80	437.00	282.00	19.30	11.60	7.50
2013.00	0.00	0.00	0.00	1.80	154.40	220.70	510.90	239.90	159.60	135.60	31.60	0.00
2014.00	0.00	3.50	74.00	157.20	183.10	243.70	243.20	361.50	181.30	105.40	5.00	0.00
2015.00	0.00	0.00	8.40	0.00	226.10	244.40	282.20	337.50	128.50	0.00	0.00	0.00
2016.00	0.00	0.00	50.60	10.30	185.50	418.20	227.10	229.00	130.30	85.05	20.51	0.00

A_6 Sample Monthly Rainfall at Meshenti Gaging station

Time-Series Type: Rainfall (mm)

Longitude: 312925.30E Latitude: 1268726.49N Elevation: 1958m

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2003.00	0.00	3.20	8.30	1.30	2.10	340.70	479.30	263.60	277.90	70.60	4.50	18.10
2004.00	10.20	7.30	3.00	18.50	5.90	193.10	386.30	269.80	139.30	81.30	0.00	0.00
2005.00	2.72	0.00	22.80	16.60	44.40	161.30	383.70	243.70	308.76	95.55	20.00	0.00
2006.00	0.00	2.40	0.00	20.60	176.40	371.80	552.90	370.50	254.70	252.10	0.00	37.20
2007.00	0.00	2.90	18.60	31.80	109.30	381.80	269.40	290.30	123.90	164.91	28.70	0.00
2008.00	19.50	0.00	0.00	36.30	60.20	201.20	344.00	311.60	153.40	84.70	13.20	0.00
2009.00	2.35	14.20	70.10	24.17	88.40	59.80	233.70	288.50	52.10	90.27	12.36	6.30
2010.00	0.00	0.00	33.80	3.90	0.00	263.69	433.50	434.10	133.30	79.50	6.40	0.00
2011.00	0.00	0.00	0.00	0.00	154.16	343.20	306.90	436.90	220.00	29.80	13.90	0.00
2012.00	0.00	0.00	26.00	0.00	8.30	254.60	752.60	273.30	237.00	11.70	0.00	8.43
2013.00	0.00	0.00	41.30	9.10	0.00	136.70	559.70	328.90	130.90	50.80	25.30	0.00
2014.00	0.00	4.80	48.50	73.90	215.70	149.20	461.60	215.70	172.70	64.40	0.00	0.64
2015.00	0.90	0.29	5.62	256.30	363.10	372.20	330.02	316.89	49.70	58.72	10.32	20.43
2016.00	65.50	13.10	12.50	3.40	127.90	239.10	31.70	36.30	39.60	0.00	10.04	0.00

A$_7$ Sample Monthly Rainfall at Bahir Dar Gaging station

Time-Series Type: Rainfall (mm)

Longitude: 321189.60E Latitude: 1282837.72N Elevation: 1800m

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001.00	0.00	0.00	1.00	22.70	54.80	249.30	380.60	562.10	142.50	92.70	12.50	16.90
2002.00	0.00	1.20	8.20	15.90	2.00	437.20	465.00	405.00	154.90	17.80	0.50	1.00
2003.00	0.00	0.00	0.30	0.00	1.20	239.20	616.20	451.10	258.30	74.20	5.20	5.70
2004.00	8.70	20.50	5.10	39.20	7.30	144.30	503.30	294.50	232.00	89.90	7.40	0.00
2005.00	0.70	9.00	85.60	9.90	74.60	188.80	533.30	247.50	278.00	52.80	7.40	0.00
2006.00	3.10	0.20	0.10	6.70	151.20	225.50	563.90	364.10	211.00	153.70	0.00	3.70
2007.00	0.00	0.00	1.10	29.20	16.20	285.60	314.80	328.80	203.40	115.60	11.40	0.00
2008.00	1.80	0.00	0.00	104.30	87.80	175.60	481.50	337.60	150.20	56.50	33.10	0.00
2009.00	0.00	0.00	7.70	3.00	8.00	66.30	319.50	618.50	112.10	56.80	3.00	0.00
2010.00	13.30	0.00	0.00	34.00	72.10	127.30	407.80	449.30	182.20	54.60	1.50	0.00
2011.00	0.00	0.00	28.40	12.90	103.00	169.00	415.40	312.80	144.00	37.90	28.10	0.00
2012.00	0.00	0.00	1.00	0.00	25.40	122.00	466.50	504.40	255.90	7.60	2.00	11.20
2013.00	0.00	0.00	1.40	1.40	88.00	148.60	594.00	350.30	137.90	169.10	16.60	0.00
2014.00	0.00	0.00	65.90	66.60	163.70	178.40	378.40	480.80	260.00	117.40	0.00	0.40
2015.00	0.00	0.80	0.40	0.00	136.80	89.30	302.20	248.90	223.90	116.70	12.20	31.80
2016.00	0.00	0.00	23.80	8.50	171.20	248.80	409.60	274.40	104.80	0.50	0.00	0.00

A$_8$ Sample Monthly Rainfall at Adet Gaging station

Time-Series Type: Rainfall (mm)

Longitude: 335503.14E Latitude: 1246697.22N Elevation: 2179m

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001.00	0.00	10.40	2.70	44.90	137.10	194.80	340.90	369.10	146.40	95.60	25.40	10.80
2002.00	11.80	3.80	39.40	35.60	50.60	136.20	281.80	198.70	122.40	55.00	9.00	13.50
2003.00	0.00	8.00	10.20	6.10	16.20	162.80	340.90	292.70	205.20	52.80	21.70	3.30
2004.00	5.50	4.43	2.10	37.20	10.40	189.30	286.50	247.10	204.20	120.70	21.17	3.30
2005.00	1.90	0.00	27.90	40.40	30.20	105.60	332.40	221.00	192.30	153.00	27.80	0.00
2006.00	0.00	0.80	4.30	19.00	116.60	175.20	439.30	422.90	236.80	128.20	17.80	18.13
2007.00	3.60	1.00	14.10	20.40	94.30	305.20	304.00	220.90	137.70	60.20	27.00	0.00
2008.00	15.40	1.00	0.00	168.30	179.30	142.60	331.20	320.30	146.60	79.70	23.50	0.00
2009.00	0.17	10.90	17.90	32.60	8.00	100.80	286.60	281.80	126.60	80.70	7.30	15.10
2010.00	22.50	0.00	0.00	44.90	78.70	160.50	364.20	249.50	182.80	69.70	1.30	1.50
2011.00	4.37	0.00	24.00	70.50	161.90	84.00	339.00	214.10	155.10	69.60	1.30	1.50

Filled Raw data

A$_9$ Sample Annual Rainfallfor each Gaging station

Time-Series Type: Rainfall (mm)

Year	Dangila	Durbetie	Wotet Abay	Merawi	Meshenti	Bahir Dar	Adet
2001	1392.2	1434.795	2261.119	1601.128	1832.831	1535.1	1378.1
2002	1343.234	1799.911	1140.43	1649.482	1172.086	1508.7	957.8
2003	1370	1788.788	1284.66	1736.567	1469.6	1651.4	1119.9
2004	1627.9	1775.619	1308.2	1640.491	1114.7	1352.2	1131.899
2005	1389.7	1687.96	1685.2	1561.16	1299.523	1487.6	1132.5
2006	1922.8	1998.4	2088.9	2089.2	2038.6	1683.2	1579.033
2007	1460.5	1478.8	1940.9	1569.2	1421.61	1306.1	1188.404
2008	1956.9	1838.8	1810	1638.1	1224.1	1428.4	1407.9
2009	1746.1	1884.372	1403.8	1661.86	942.2545	1194.9	968.4697
2010	1484.16	1338	2239.015	1420.064	1388.186	1342.1	1175.6
2011	1599.7	1890.6	1359.346	1654	1504.861	1251.5	1125.366
2012	1447.804	1664.1	1272.938	1628.2	1571.93	1396	1257.135
2013	1712.564	1704.73	1849.431	1454.5	1282.7	1507.3	1093.869
2014	1794.083	1814.4	1882.1	1557.9	1407.142	1711.6	1160.567
2015	1654.756	1602.3	1739.6	1227.1	1784.499	1163	1221.592
2016	1700.413	1653.082	1869.6	1356.555	579.1394	1241.6	808.4443
Mean	1600.176	1709.666	1695.952	1590.344	1377.11	1422.544	1169.161

Extended data

7.2. **Appendix B: Stream and basin characteristics of the watershed**

B_1: Basin-characteristics for each selected site

Station Name	Stream flow Gauging Station Location (WGS 1984)		Basin Characteristics		
	Longitude	Latitude	Area(km2)	P (m3/s)	SLP_{ave} (%)
Out let	284920	1258283	238.15	12.00	10.34
DSW_1	286436	1257805	227.73	11.44	10.49
DSW_2	288977	1256678	194.23	9.68	11.26
DSW_3	293821	1255247	171.88	8.52	11.80
DSW_4	302067	1255000	169.45	8.39	11.87
RSW_1	302783	1253692	155.44	7.66	12.34
RSW_2	307939	1246377	100.84	4.89	16.25
RSW_3	306827	1249611	58.96	2.83	22.61
RSW_4	309301	1243572	35.87	1.71	25.81

B_2Stream-characteristics for each selected site

Station Name	Analysis Period of Record	Q_{mean}	R_{coeff}
KWS(outlet)	1959-2003	4.72	0.39
DSW_1		4.81	0.42
DSW_2		4.60	0.48
DSW_3		4.40	0.52
DSW_4		4.21	0.50
RSW_1		3.87	0.51
RSW_2		2.94	0.60
RSW_3		2.19	0.77
RSW_4		1.35	0.79

7.3. **Appendix C: Data analysis**

C_1: Results of outlier test of each stations

Dangila Station Outlier Test	
K_n	2.28
s;	0.05
Higher Limit;	2096.51
Lower Limit;	1204.42
Meshenti Station Outlier Test	
K_n	2.28
s;	0.13
Higher Limit;	2597.37
Lower Limit;	579.05
Adet Station Outlier Test	
K_n	2.28
s;	0.07
Higher Limit;	1659.41
Lower Limit;	804.71

Durbetie Station Outlier Test	
K_n	2.28
s;	0.05
Higher Limit;	2177.33
Lower Limit;	1328.11
Merawi Station Outlier Test	
K_n	2.28
s;	0.05
Higher Limit;	2089.90
Lower Limit;	1212.28
Bahir Dar Station Outlier Test	
K_n	2.28
s;	0.05
Higher Limit;	1859.70
Lower Limit;	1073.41

C_2: Results of stationary and homogeneity test of Koga stream flow gauging station

Ascending order of data	Rank	data1 (split from Original Data)	order from Asce.data
2.524420822	1	2.952881577	4
2.578827712	2	3.573499815	8
2.730963671	3	3.655884347	9
2.952881577	4	4.029795685	11
3.005890155	5	4.267216806	17
3.006340554	6	4.283761568	18
3.116257959	7	4.507067712	20
3.573499815	8	4.593011731	21
3.655884347	9	4.744756257	23
3.656245407	10	4.838125936	24
4.029795685	11	4.843635178	25
4.049662929	12	4.906368822	26
4.075580096	13	5.083052723	28
4.1056115	14	5.133780414	29
4.124527896	15	5.1718147	30

Ascending order of data	Rank	data2 (split from Original Data)	order from Asce.data
4.595435589	22	2.524420822	1
4.744756257	23	2.578827712	2
4.838125936	24	2.730963671	3
4.843635178	25	3.005890155	5
4.906368822	26	3.006340554	6
4.995438736	27	3.116257959	7
5.083052723	28	3.656245407	10
5.133780414	29	4.049662929	12
5.1718147	30	4.075580096	13
5.410324557	31	4.1056115	14
5.574264901	32	4.124527896	15
5.626160074	33	4.214914178	16
5.633423502	34	4.421400007	19
5.743389799	35	4.595435589	22
5.92256497	36	4.995438736	27

4.214914178	16	5.574264901	32
4.267216806	17	5.626160074	33
4.283761568	18	5.633423502	34
4.421400007	19	5.92256497	36
4.507067712	20	6.266825521	42
4.593011731	21	9.207257413	44
		p	21
		R	514

5.998902448	37	5.410324557	31		
6.006311885	38	5.743389799	35		
6.091266878	39	5.998902448	37		
6.105393905	40	6.006311885	38		
6.176384446	41	6.091266878	39		
6.266825521	42	6.105393905	40		
6.287437936	43	6.176384446	41		
9.207257413	44	6.287437936	43	q	23

N	44	
V	283	
W	200	
U	200	SMALLER OF V OR W
Ū	241.5	N>20 and p,q>3
VAR U	1811.25	
VAR $U^{0.5}$	42.55878288	
µ	-0.975121871	Homogenous and non-Stationary
$\mu_{0.025}$ =	1.96	(If $\lvert U \rvert < U_{0.025}$)

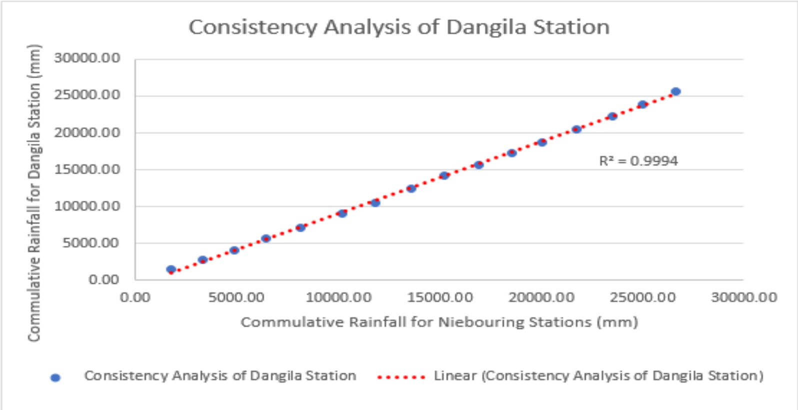
C_3: Results of Stationary and Homogeneity test of each rainfall gauging Stations

Characters	Stations Name						
	Dangila	Durbetie	W. Abay	Merawi	Meshenti	Bahir Dar	Adet
p	7	7	7	7	7	7	7
q	9	9	9	9	9	9	9
N	16	16	16	16	16	16	16
V	51	33	33	16	25	15	28
W	12	30	30	47	38	48	35
U	12	30	30	16	25	15	28
$\bar{U}$	31.5	31.5	31.5	31.5	31.5	31.5	31.5
VAR U	89.25	89.25	89.25	89.25	89.25	89.25	89.25
VAR $U^{0.5}$	9.45	9.45	9.45	9.45	9.45	9.45	9.45
μ	-1.06	-0.37	-0.37	-1.64	-0.69	-0.37	-0.37
$\mu_{0.025}$	1.96	If $\mu < \mu_{0.025}$, Homogenous and non-Stationary					

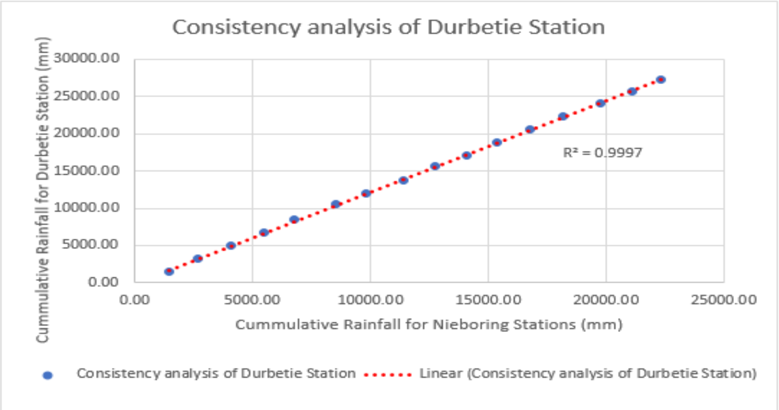
C$_4$: Results of Trend test of each Stations

Characters	Stations Name					
	Dangila	Durbetie	Merawi	Meshenti	Bahir Dar	Adet
Total Sum of D_i^2	320	730	1088	742	988	758
Rsp	0.529	-0.074	-0.600	-0.091	-0.453	-0.115
Degree of freedom, f=	14	14.000	14.000	14.000	14.000	14.000
computed t_t	1.335	-0.276	-1.606	-0.343	-0.901	-0.432
t_t at 5% sign. Level from student, table for f = n-2	1.68	=IF (ABS(t_t Computed) < (t_t from table), "No Trend", otherwise "there is Trend")				

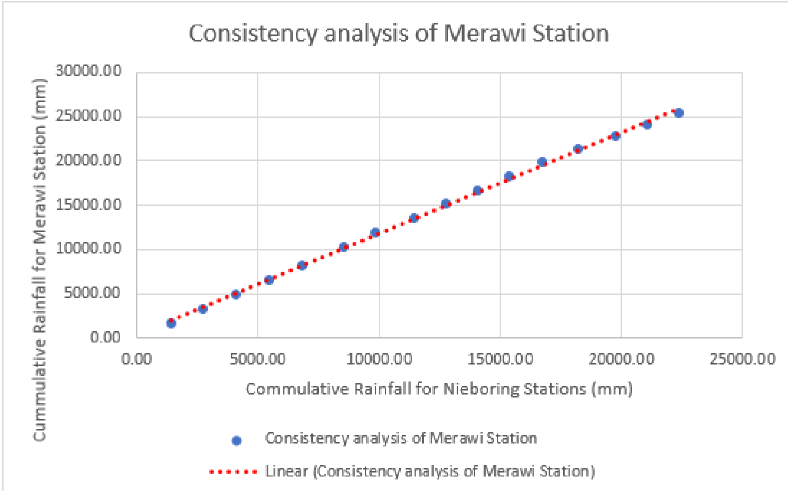
C$_5$: Results of Consistency test of each Stations



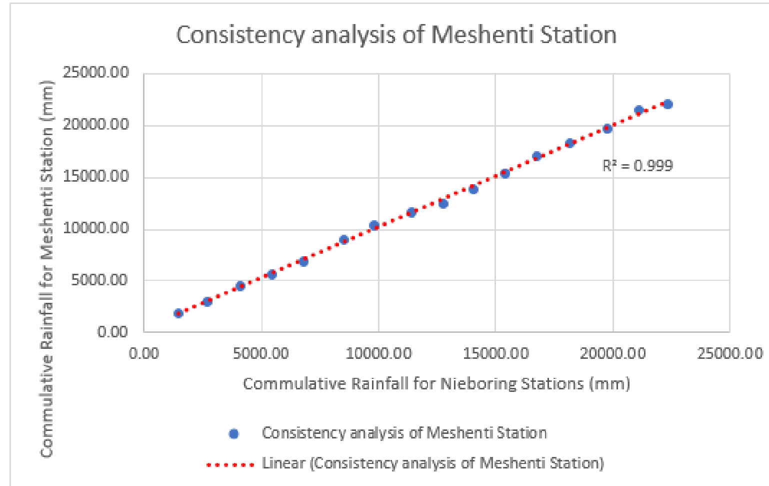
Consistency of Wotet Abay Station with Bahir Dar, Adet and Dangila as a nieboring station



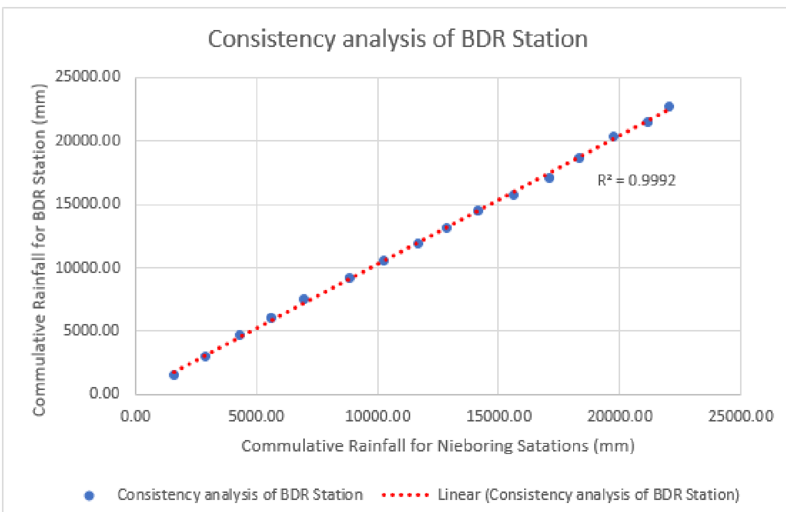
Consistency of Wotet Abay Station with Bahir Dar, Adet and Dangila as a nieboring station



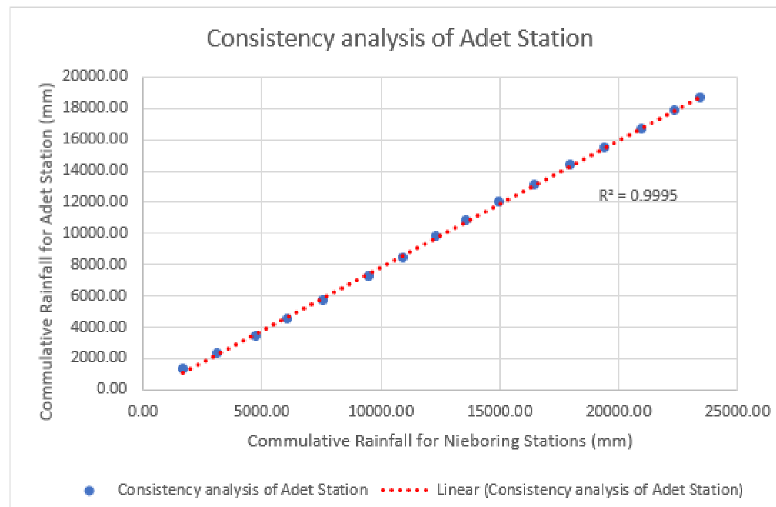
Consistency of Wotet Abay Station with Bahir Dar, Adet and Dangila as a nieboring station



Consistency of Wotet Abay Station with Bahir Dar, Adet and Dangila as a nieboring station



Consistency of Wotet Abay Station with Bahir Dar, Adet and Dangila as a nieboringt station



Consistency of Wotet Abay Station with Bahir Dar, Adet and Dangila as a nieboring station

C_6: Flow duration curve determination

low	high	IN BIN (in between)	cumulative	Number of Greater Values	% OF GREATER		
0	0.6	23	23	505	95.64	0.74	for 90%
0.6	0.8	43	66	462	87.50		
0.8	1	51	117	411	77.84	1.17	for 70%
1	1.2	49	166	362	68.56		
1.2	1.4	40	206	322	60.98		
1.4	1.6	27	233	295	55.87	1.96	for 50%
1.6	2	34	267	261	49.43		
2	3	56	323	205	38.83	3.84	for 35%
3	4	24	347	181	34.28		
4	6	36	383	145	27.46		
6	8	34	417	111	21.02		
8	10	23	440	88	16.67		
10	15	48	488	40	7.58		
15	20	27	515	13	2.46		
20	30	12	527	1	0.19		
30	40	1	528	0	0.00		
	TOTAL	528					

7.4. **Appendix D: Locations of stations and outlet points**

D_1:Locations of Outlet point of a watershed.

Outlet Name	UTM Location		Koga Watershed		Koga upstream	
	Longitude	Latitude	Q_{ave}	R_{coeff}	Q_{ave}	R_{coeff}
Koga outlet	284920	1258283	4.72	0.39	2.13	0.52
DSW_1	286436	1257805	4.81	0.42	2.34	0.67
DSW_2	288977	1256678	4.60	0.48	1.93	0.50
DSW_3	293821	1255247	4.40	0.52	1.52	0.71
DSW_4	302067	1255000	4.21	0.50	1.45	0.75
RSW_1	302783	1253692	3.87	0.51		
RSW_2	307939	1246377	2.94	0.60		
RSW_3	306827	1249611	2.19	0.77		
RSW_4	309301	1243572	1.35	0.79		

D_2: Locations of Potential Sites and estimated dependable Power (kw)

Site Name	Coordinate WGS1984 (m)		Weighted Value	90% dependable power	70% dependable power	35% dependable power	Rank
	X	Y					
Site 1	310403.39	1241594.3	0.452501	16.20	38.77	143.25	7
Site 2	310407.82	1242528.6	0.420529	18.19	36.97	131.72	9
Site 3	309293.26	1243909.4	0.465154	24.69	46.28	161.57	6
Site 4	308465.03	1245342.5	0.546126	30.55	53.9	185.03	3
Site 5	305955.53	1250502.7	0.799342	30.97	53.73	183.53	1
Site 6	289847.7	1256509	0.315993	28.29	48.32	164.31	11
Site 7	289074.42	1256549.4	0.32232	54.47	79.57	268.22	10
Site 8	287873.6	1256442.5	0.525506	14.68	29.6	105.27	4
Site 9	287677.68	1257113.9	0.434816	15.71	30.29	106.55	8
Site 10	308285.81	1246875.3	0.516418	39.91	53.65	184.22	5
Site 11	308197.18	1247626.4	0.546267	28.60	49.55	168.48	2

D_3: Locations of Gauging Stations

No.	Meteorological gauging Station Name	Longitude	Latitude	Elevation
1	Koga stream flow	284920	1258283	1989
2	Dangila	264988.348	1264843.747	2116
3	Durbetie	332939.2813	1148381.048	2234
4	Merawi	299679.4824	1262059.674	2000
5	Wotet Abay	286328.92	1257497.67	1920
6	Meshenti	312925.3004	1268726.486	1958
7	Bahir Dar	321189.6	1282837.722	1800
8	Adet	335503.14	1246697.22	2179

7.5. **Appendix E: Regression outputs**

E_1: Summary output for stream and basin characteristics.

Regression Statistics	
Multiple R	0.9999
R Square	0.9997
Adjusted R Square	0.4995
Standard Error	0.1089
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	94.00	31.33	2644.49	0.01
Residual	2	0.02	0.01		
Total	5	94.03			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
A	-0.10	0.51	-0.20	0.86	-2.30	2.10
P(m3/s)	1.93	9.43	0.20	0.86	-38.63	42.49
$1/SLP_{ave}$	64.21	89.51	0.72	0.55	-320.92	449.33

E_2: Summary output for R_{coeff} and $R_{accu}$for us section.

Regression Statistics	
Multiple R	0.977450145
R Square	0.955408786
Adjusted R Square	0.949038613
Standard Error	0.032181115
Observations	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.155324571	0.155324571	149.9815979	5.546E-06
Residual	7	0.007249369		0.001035624	
Total	8	0.16257394			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.840462078	0.025810741	32.56249341	6.66592E-09	0.779429375	0.901494782
Racc	-0.038550907	0.003147861	-12.24669743	5.546E-06	-0.045994417	-0.031107397

E_2: Summary output for R_{coeff} and R_{accu} for ds section.

Regression Statistics	
Multiple R	0.944850289
R Square	0.892742069
Adjusted R Square	0.856989425
Standard Error	0.320816389
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.569987028	2.569987028	24.9699596	0.015417823
Residual	3	0.308769466		0.102923155	
Total	4	2.878756494			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.436831573	0.261787622	9.308429301	0.002624736	1.603706522	3.269956625
P	-0.50971957	0.102005218	-4.996995057	0.015417823	-0.834345698	-0.185093441

7.6. **Appendix F: Ranking procedures for pair wise comparison**

F_1Comparing the matrix

No.	Factors	Value	Description
1	Power-Head	2	Slightly favors
2	Power-Discharge	3	Slightly favors
3	Power-Accessibility	6	Strongly favors
4	Head-Discharge	2	Slightly favors
5	Head-Accessibility	5	Strongly favors
6	Discharge-Accessibility	4	Strongly favors

F_2Completing the matrix

No.	Factors	power	Head	Discharge	Accessibility
1	power	1	2	3	6
2	Head	1/2	1	2	5
3	Discharge	1/3	1/2	1	4
4	Accessibility	1/6	1/5	1/4	1
	Sum	2	3.7	6.25	16

F_3Normalization & weight determination

No.	Factors	Head	Discharge	power	Accessibility	Priority vector or Weight
1	power	0.5	0.540540541	0.48	0.375	0.4739
2	Head	0.25	0.27027027	0.32	0.3125	0.2882
3	Discharge	0.166666667	0.135135135	0.16	0.25	0.1780
4	Accessibility	0.083333333	0.054054054	0.04	0.0625	0.0600

F_4Consistency ratio calculation

No.	Factors	λ_{max}
1	power	0.94777027
2	Head	1.0663125
3	Discharge	1.112190315
4	Accessibility	0.95954955
5	SUM of the above factors	4.085822635
6	Consistency Index, CI	0.028607545
7	Consistency Ratio, CR	0.031786161

F_5Random consistency index table

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	**0.90**	1.12	1.24	1.32	1.41	1.45	1.49

RI - is Random Consistency Index

n - is the number of factors **(Saaty, 1980)**

7.7. **Appendix G: Validation head records**

G_1 Coordinates and elevations with head for predicted (calculated using GIS) and Observed (measured using GPS)

Site name	Coordinates WGS 84		Predicted Head			Coordinates WGS 84		Observed Head		
	X	Y	Elev. at site	Elev. after 500m	Head	X	Y	Elev. at site	Elev. after 500m	Head
$Site_1$	310403	1241594	2249	2229	20	310459	1241668	2250	2231	19
$Site_2$	310408	1242529	2226	2212	14	310394	1242563	2229	2214	15
$Site_3$	309293	1243909	2166	2152	14	309098	1244025	2170	2156	14
$Site_4$	308465	1245342	2129	2116	13	308421	1245739	2132	2120	12
$Site_5$	305956	1250503	2064	2048	16	305957	1250498	2064	2050	14
$Site_6$	289848	1256509	1965	1954	11	289846	1256490	1960	1951	9
$Site_7$	289074	1256549	1947	1937	10	288841	1256361	1946	1939	7
$Site_8$	287874	1256442	1935	1918	17	287816	1256158	1938	1922	16
$Site_9$	287678	1257114	1915	1904	11	287502	1257242	1919	1911	8
$Site_{10}$	308286	1246875	2110	2098	12	308277	1247062	2107	2097	10
$Site_{11}$	308197	1247626	2094	2084	10	308035	1247654	2095	2087	8

G_2Sample photos taken during field observation.