Hydropower Potential Estimates for Runoff River Using Integrated GIS Based Hydrological Modelling

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Abstract

Most of the world's energy demand is fulfilled from non-renewable energy resources, but these resources are depleting because of the increasing demand for energy due to population growth and climate change. Hydropower has attracted a lot of attention because it is a clean source of energy and a good way to provide electricity to remote areas in hilly areas. Hydropower plants have very low operating costs as associated to thermal or nuclear power plants.

Accurate topography (primarily elevation) and flow data, as well as comprehensive analysis of these data, are required for a proper assessment of a site's hydropower potential. Recent advances in remote sensing (RS), geographic information systems (GIS), and hydrological modelling have resulted in realistic, up-to-date, and reliable data for hydropower energy potential. Because GIS can manage all factors relating location and can provide a good image of the hydropower project region and its influence area, evaluating accurate topography, land-use pattern, river morphology, and geology data is easier in a GIS context than in a typical field survey.

This study's objective was to select potential sites for the Run of the River (RoR) projects and determine their theoretical power potential using the SWAT model. The Gilgit River basin theoretical power potential has been estimated using the power formula and regional flow duration curve. Flow at 40th, 60th and 90th percentiles have been considered in the study. GIS-based tools and hydrological model SWAT have been implemented to identity the point for theoretical power potential. Total 109 sites have been identified in the basin. The hydro power potential ranges from 24.95MW to 115.0MW at 40th percentile ,8.06MW to 38.35MW at 60th percentile and 1.22MW to 6.10MW at 90th percentile. A good way to assess the potential of small hydroelectric power facilities is to use remote sensing and GIS software.

Key words

CC	Climate Change
ET	Evapotranspiration
FAO	UN Food and Agriculture Organization
IPCC	Intergovernmental Panel on Climate Change
RMSE	Root Mean Squared Error
SWAT	Soil and Water Assessment Tool
WAPDA	Water and Power development Authority Pakistan
T_{max}	Maximum air temperature
T_{min}	Minimum air temperature
PMD	Pakistan Meteorological Department
FDC	Flow Duration Number
GMRC	Glacier Monitoring Research Centre
SWHP	Surface Water Hydrology Project
DEM	Digital Elevation Model
NSE	Nash–Sutcliffe efficiency
RoR	Runoff the River
ICIMOD	The International Centre for Integrated Mountain Development
GLOF	Glacial Lake Outburst Flood

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1.INTRODUCTION

1.1 Background

The high cost of imported fossil fuel for thermal power generation is putting a strain on them and exacerbating the problem. Hydropower has attracted a lot of attention because it is a clean source of energy and a good way to provide electricity to remote areas in hilly areas. Hydropower plants have very low operating costs as compared to thermal or nuclear power plants.

Energy is one of a country's most valuable commodities. It is the foundation of a country's economic growth. It is important to the entire industrial and residential sectors. With the advent of mechanized agriculture, the agriculture sector has become increasingly reliant on these energy resources, also known as electricity. Electricity illuminates our homes, powers a wide range of industrial equipment, and helps to make our lives more comfortable. Several different methods for harnessing electrical energy have been established over time. Coal, oil, gas, steam, and water are some of the most popular methods for obtaining electrical energy that have been in use for many years. Wind energy, renewable energy, and nuclear energy are only a few of the recent innovations(Ali 2018).

Today's world is shifting toward solutions that are more energy efficient, long-lasting, and environmentally friendly. This is not shocking, given that the use of fossil fuels to generate electrical energy caused more damage than good. The burning of fossil fuels is one of the primary sources of enhanced Green House Gas emissions, which are the primary cause of global warming. According to the US Energy Information Administration, fossil fuel generation accounted for 32% of GHG emissions in 2016. Coal and natural gas fired power plants account for more than 70% of overall electricity generation (Sieminski 2016). One of the reasons why our planet is heading toward a more volatile climate regime with deviations from normal climatic trends is that our world is becoming more unpredictable. Pakistan, on the other hand, is in a much worse condition. According to the Asian Development Bank (ADB), the energy crisis that Pakistan has been experiencing for the past few years is costing the country about 2% to 3% of GDP due to circular debt, costly fuel sources such as natural gas and coal, and an insufficient electrical distribution channel (Sieminski 2016). Even though Pakistan is not a big emitter of greenhouse gases (GHG), it is seriously impacted by the adverse impacts of climate change. Accelerated floods, accompanied by reduced river flow due to glacier melt, intensified drought, increased disease risk, decreased freshwater supply, crop yield, and biodiversity are just a few of the major adverse impacts of climate change that Pakistan is experiencing (Parthadas Gupta 2007). However, currently Pakistan suffers from yet another major menace Energy Crisis’. The country's growing population and economic expansion have rendered it incapable of meeting escalating energy demands, resulting in a massive energy shortage. Power outages lasting several hours have become relatively regular around the country. This is limiting Pakistan's ability to make considerable economic progress. (Ali 2018).

Hydropower has been used in Pakistan for a long time and is one of the most important contributors to the country's energy sector. Based on the above-mentioned climate change challenges, Pakistan would be wise to focus on more environmentally friendly and long-term energy solutions rather than relying on fossil fuels for electricity generation. Hydropower is one such solution which is quite suitable for Pakistan's situation, which being a developing country, is not able to afford huge nuclear power plants or vast areas of land and expensive equipment for wind and solar farms. Fortunately, nature has blessed Pakistan with immense hydroelectric resources, the most of which are still unexplored. (Ali 2018). This could be one of the answers to Pakistan's energy problems.

1.2 Research Motivation

The Pakistan suffers from a severe energy crisis. Although gross installed electricity capacity enhanced during a couple of year, but unfortunately gross generation could not be enhanced significantly as mostly fossil fuel fried plants are set which are not easy to operate by a developing country i.e., Pakistan. Thus, it is need of hour to consider the renewable and sustainable source for generation of electricity and in this contest hydropower generation is one of the best choices among the other. The motive of this research to point out the theoretical hydropower potential sites in Indus basins.

1.3 Objectives:

My study is based on these two objectives:

1. Estimation of flow rates through SWAT hydrological model
2. Estimation of hydroelectric potential with the integration of hydrological and physical characteristic of Gilgit river basin

2 LITERATURE REVIEW

2.1 Need for hydropower development in Pakistan

Energy is a key indicator considered for a country's social and economic growth (Ali et al. 2019). In the global context, most of the world's energy demand is fulfilled by petroleum, natural gas, and coal which are examples of non-renewable energy sources, consequently boosts up carbon dioxide in the atmosphere, which is considered as the primary driving force behind climate change and ultimately triggering environmental degradation together with serious global social and political pressure to drop down emissions (Inglesi-Lotz and Dogan 2018). Non-renewable energy resources are responsible for 61% of the emissions into the atmosphere that can lead to potential climate change (Belmonte et al. 2009).

According to a special article on renewable energy and mitigation of climate change by IPCC 2011, renewable energy sources have a potential to contribute towards social and economic development, safe energy supply to all and also ensuring environmental and health safety if fully implemented. From renewable energy resources hydropower seems to be most efficient and green energy resource and its use will be significantly rise in the future to due to low level of emissions, because its functionality only depends upon water flow and a turbine to convert kinetic energy into electricity (Kusre et al. 2010), having high efficiencies as compared to other power plants such as natural gas power plant (Wegner et al. 2020).

Currently the total installed capacity of hydropower is increasing at average rate of 24.3 GW per year and it is estimated that it will double in the future by 2050 (IEA 2012) 20% of the world's energy demand is fulfilled by renewable energy resources out of which 70% comes from hydropower plants (Bank 2017).

To meet the needs of growing population and for sustainable economic development of a country hydropower growth plays strategic role in meeting the energy demand (Kumar and Katoch 2015) along with efficiently mitigating climate change by reducing greenhouse emissions in terms of shifting from non-renewable energy resources towards renewables resources. It can also help developed countries to lower their GHG's emissions according to the Paris protocol to drop down the CO2 level to pre-industrial era by increasing the share from RE to their energy nexus (Inglesi-Lotz and Dogan 2018) and meeting the 7th sustainable developing goal to confirm approach to reasonable, reliable and green energy to all by 2030 (Romanelli, J. P., Silva, L. G., Horta, A., & Picoli 2018). In climate change mitigation policies small hydroelectric power is encouraged at national level.

Although it contributed only 2% of the total hydropower potential, but due to easy applicability, globally it has the 75GW installed capacity and 173GW still needs to be developed only concerted in the hilly terrain (Kelly-Richards, S., Silber-Coats, N., Crootof, A., Tecklin, D., & Bauer 2017). Small hydropower is considered as efficient source of energy for the electrification of rural areas which lacks access to power grid, but also to combat climate change without posing much environmental degradation such as social displacement, biodiversity loss and not need complex infrastructure like large storage dams (Winemiller, K. O., McIntyre, P. B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., ... & Sáenz n.d.). Run of the River SHP are small diversion systems, without storage requirements are capable of producing low cost and stable electricity source alternate to burning of fossil fuels(Hennig, T., & Harlan 2018).

2.2 Application of hydrological modelling and GIS in RoR

The traditional way of surveying for the site selection was a time-consuming and difficult task with lots of economic expenses. However, with the advent of novel tools and technology within the interface of Geographic information systems, along with the applicability of hydrological modelling and remote sensing data, it has become easier to pre-plan the selection of potential sites for small hydropower on the complex stream network and terrain. In the of penstock and then powerhouse to compute generation capacity. GIS tools and remote sensing data can be used to generate the stream network grid map from digital elevation model that can be further utilized in pinpointing the sites for SHP and assessing potential by applying hydrological.

In Herman, authors established a graphical simple computer program within the interface of Microsoft excel to select the site for run of the river hydropower based on head and power criteria then to find the discharge at that sites, HEC-HMS and WMS hydrological modelling was applied. Gene expression programming was utilized to generate flow duration curves (Al-Juboori, A. M., & Guven 2016).

Hydrological modelling (SWAT) along with GIS tools has been explored by (Kusre et al. 2010) and (Pandey, A., Lalrempuia, D., & Jain 2015) for the evaluation of hydropower potential in Hassam India. Sites for hydropower was selected using DEM, river network within GIS environment while discharge (Q) at potential sites was simulated using SWAT modelling and concluded that Indian basin has potential has up to 132.67MW (Nistoran, D. E. G., Abdelal, D., Ionescu, C. S., Opriş, I., & Costinaş 2017) in Romania assesses the theoretical power potential of the sites using mean and annual river flows, GIS and open-source satellite data, HEC-GeoHM to generate stream network and then the stream network was overlaid on DEM to determine head drop.

Linear theoretical power potential was calculated and compared with already operating 17 plants in the basin. Sammartano et al.,2019 also make use of SWAT and GIS technology to identify location for RoR and then to estimate power potential in Umber leigh river basin. By using different power thresholds, many sites have been identified, but by applying various filters, only those locations were selected that were environmentally and economically feasible to maximize profit with the least environmental degradation across the basin. Some of the researchers have used multidecision criteria analysis along with the use of hydrological models for the optimal (Sammartano, Liuzzo, and Freni 2019)

2.3 Working principle of Runoff River hydropower plant

The working principle of the runoff the river hydropower plant is simple Figure 1

- It composes of a take-off point, penstock, and a turbine.
- The take-off point is located at a higher elevation, from where water is diverted via penstock toward the turbine.

Where turbine converts the potential energy to rotational energy and then water is released back to the river, or it can be utilized for other purposes such as irrigation or the domestic purpose (Aslan, Arslan, and Yasar 2008).

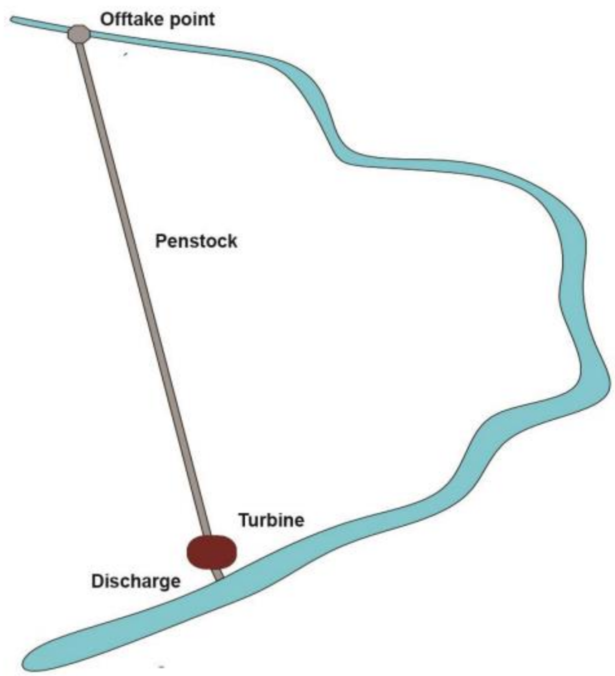

Figure 1: Working Principle of Run of the River hydropower

2.4 Turbines for hydroelectric projects

A turbine is a device that converts velocity and pressure in a water flow into rotating motion. It consists of a nozzle or stator, runner, and shaft.. Work that is mechanical. The flow is directed by the nozzle or stator. It’s possible that the runner is an aperture that produces a high-speed jet (Behrouzi, F., Maimun, A., & Nakisa 2014). Alternatively, it could be a collection of vanes. The runner is a system that redirects fluid flow to convert hydraulic energy into mechanical power. The runner is normally equipped with cups or blades that interact with flowing water and cause it to rotate; the mechanical effort is then transferred to a generator through the shaft (Aslan et al. 2008).

2.4.1 Types of turbines

There are two types of hydro turbines, which are detailed further below.

2.4.1.1 Impulse turbines

The pressurized water in the penstock is converted into high-speed water jets that provide kinetic energy to the turbine blades or cups, creating spinning (Benzon, D., Židonis, A., Panagiotopoulos, A., Aggidis, G. A., Anagnostopoulos, J. S., & Papantonis 2015). The nozzle causes a pressure drop in the water flow, whereas the runner functions at atmospheric pressure. The Pelton wheel, Turgo wheel, and cross-flow turbines are all examples of impulse turbines. Impulse turbines work best with a medium or high head of water (above 10 m).

2.4.1.2 Reaction turbines

Turbines that produce torque by reacting to the pressure or density of a gas or fluid are known as reaction turbines. The operation of reaction turbines is described by Newton's third law of motion (action and reaction are equal and opposite). In a reaction turbine, water enters the wheel under pressure and passes over the vanes. Because the water running over the vanes is under pressure, the turbine's rotor fills up and either sinks below the tailrace or discharges into the atmosphere(Date, A., Vahaji, S., Andrews, J., & Akbarzadeh 2015)

2.5 Turbine type selection

The turbine that is chosen is determined by the parameters of the site. The available head and flow, the desired generator running speed, and whether the turbine will be expected to operate in changeable flow conditions are the primary factors to consider when choosing a turbine type.
Based on the flow pattern in the turbine and the specific speed, hydro turbines can be divided into two classes (Sangal, Garg, and Kumar 2013).

2.6 Analytical hierarchy process (AHP)

The analytic hierarchy process (AHP) is a thorough, logical, and structural framework that decomposes an issue into a hierarchical structure to facilitate comprehension of complicated decisions. Dr. Thomas Saaty created AHP as a decision-making help in the 1970s (Saaty 1989)

Three principles govern the AHP: I breakdown of the choice issue, ii) relative evaluation of the elements, and iii) prioritization synthesis. The initial step is to create a hierarchical framework for the choice problem. The decision's goal is at the highest level of the organization order. The standards relevant to this aim are found at the next level, while the criteria relevant to this goal are found at the lowest level. Are the alternatives that need to be weighed. The second stage is to weigh the options and make a decision. The requirements They are assessed to each component of the next higher level in pairs. The fundamental scale can be utilized for this relative comparison. It allows to make comparisons using everyday language, which are then converted into numerical equivalents Finally, we aggregate the comparisons to establish the priority of the alternatives in terms of each criterion, as well as the weights of each criterion in terms of the goal. The weights of each criterion are then multiplied by the local priorities. The findings are added together to determine the overall significance of each option (Hussain et al. 2021)

Table 1:Saatay's Criteria

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2,4,6 and 8 can be used to express intermediate values. Intensities 1.1,1.2,1.3, etc can be used for elements that are very close in importance		

3 MATERIALS AND METHODS

The figure illustrates the methodology overview of this study

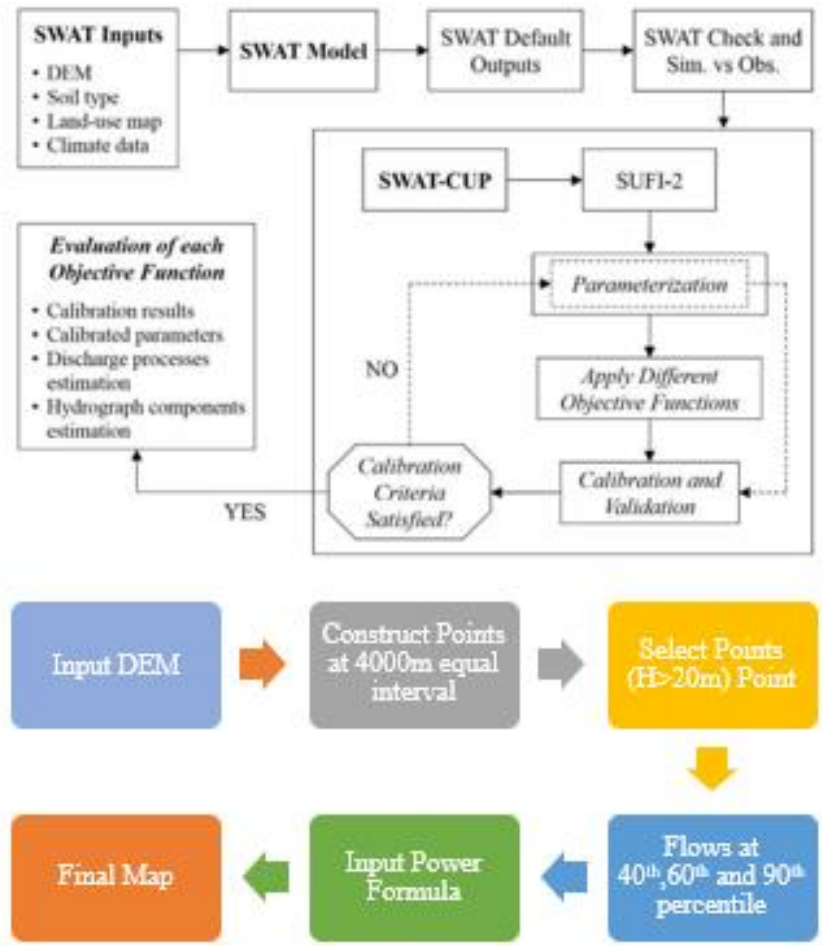

Figure 2:Methodology Overview

3.1 Study Area

The Gilgit River Basin is found in Pakistan's Hindu Kush and Karakoram Mountains. Gilgit-province Baltistan's capital is located in the basin's lower reaches. The Gilgit River Basin is located in Pakistan's mountainous mountains, between latitudes 3580'N and 3691'N and longitudes 7253'E and 7470'E. The area's climate is characterized by hot summers that last only a few weeks and chilly winters (Ali et al. 2017). The area of the watershed over 5000 meters is mostly covered in permanent snow, and the glaciers are mostly conserved. Ghizar, Yaseen, Ishkuman, and Hunza rivers make up the Gilgit River Network. The mean annual discharge of Gilgit River at Gilgit gauging station is roughly 238 m3/s, according to 38 years of SWHP-WAPDA records (1970-2008). (Adnan et al. 2017). Glaciers and seasonal melting have an important role in the basin's river flows. After the melting of seasonal snow, the glacier begins to melt around July.

The glacier melts slowly and continues until October, when the accumulation period begins. At Gilgit station, the average monthly maximum temperature is between 9.5 and 36.2°C, while the average monthly minimum temperature is between -2.5 and 18.3°C. (Adnan et al. 2017). The average annual rainfall is around 134mm, with roughly 70% of that falling during the summer months (April-September). Natural dangers such as avalanches, landslides, rock falls, debris flows, flash flooding, and Glacier Lake bursting are common in the mountains (GLOF)(Zaidi and Khan 2018)

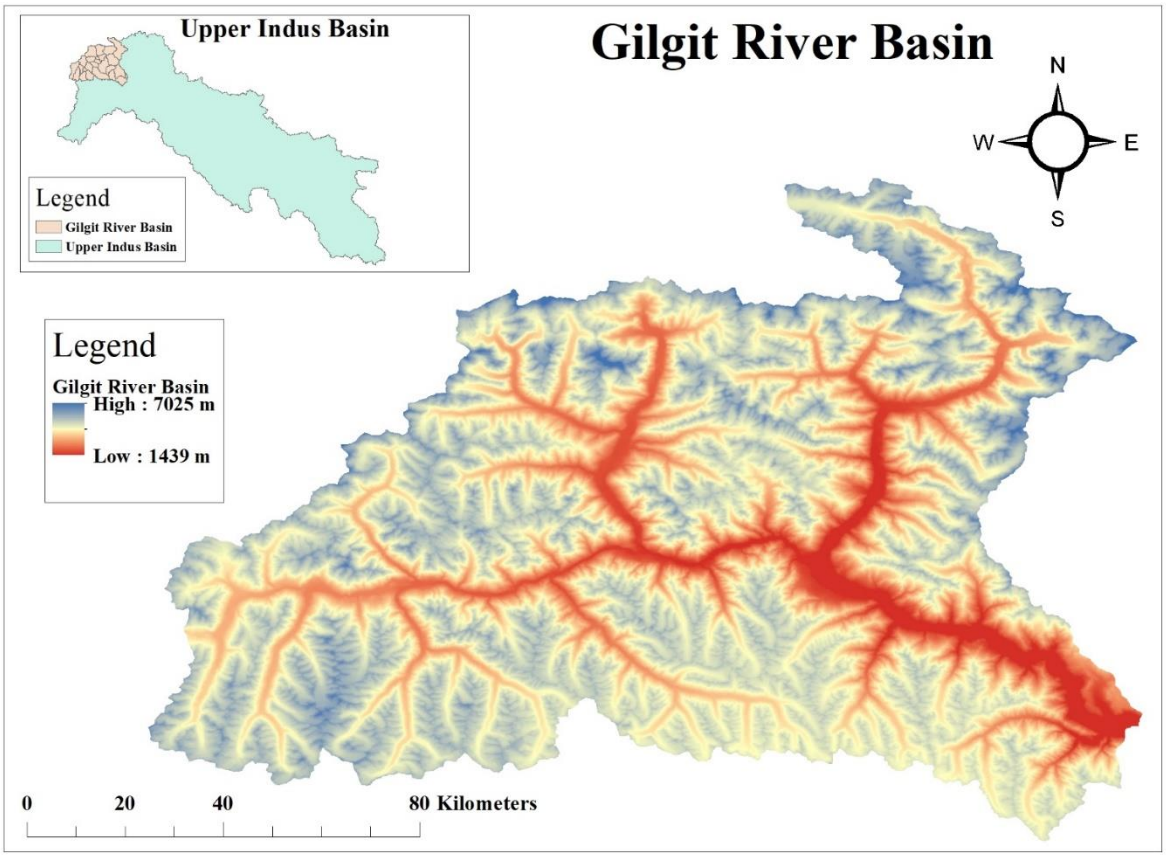

Figure 3: Map showing study area

3.2 Datasets

ASTER Global Digital Elevation model was acquired from NASA Earth explorer with 30 m resolution, which was utilized to divide the entire catchment into sub sub-catchments based on elevation and generate stream network and head calculation at potential sites. Soil Data and LULC will be acquired from Food and Agriculture Organization (FAO) and The International Centre for Integrated Mountain Development (ICIMOD) respectively There are many meteorological stations in Gilgit river basin located at different elevations within the catchment. Climate data includes daily precipitation, daily Tmax and Tmin, was acquired from Glacier Monitoring Research Centre (GMRC)., WAPDA, Pakistan for last 21 years (1995-2016) for four stations. Daily discharge data collected from Surface Water Hydrology Project (SWHP), WAPDA, Pakistan. Climatic data will be utilized in generation of input files for SWAT model, while observed flow data will be used to analyze flood frequency and hence for model calibration and validation.

Table 2: Dataset selection

Sr.no	Data	Type	Period	Resolution	Source
1.	Climatic data (Baseline)	Precipitation, Temperature	1995-2016	Daily	GMRC
2.	Hydrological	Daily River Discharge at gauging station	1995-2016	Daily	(SWHP), WAPDA
3.	Land-use Data	Land use and Land cover (LULC),	2010	30-m	ICIMOD
4.	DEM	ASTER Digital Elevation Model from NASA	2017	30-m	USGS Earth Explorer
5.	Soil Data	FAO Soil Map of the World	1970	1:5 000 000 scale	FAO-UNESCO

3.2.1 Digital Elevation Model

Digital Elevation models (DEM) has out-root of application in variously fields and has diversely been used in all over the world. It is consisting of raster imagery/ pixel defined image. Each pixel has some size corresponding to its area cover which defines its horizontal resolution. Vertical values are also contained into pixel in numerical form. These numerical values are the average of the vertical gradient inside the pixel area. Quality of the DEM is defined by its resolution and quality of its retrieval. Finer the resolution tends to well define the elevation distribution across the topography. Contemporary, most commonly available fine DEM are up to 30m to 10m. In ARC SWAT hydrological modelling DEM is one of the primary inputs and it is intrinsic to have good Quality DEM for better modelling, but it came with the tradeoff of Computational effort. Considering this preposition, we set to agree on 30m DEM resolution. DEM of ASTER 30m resolution was obtained from USGS Earth explorer web plate form.

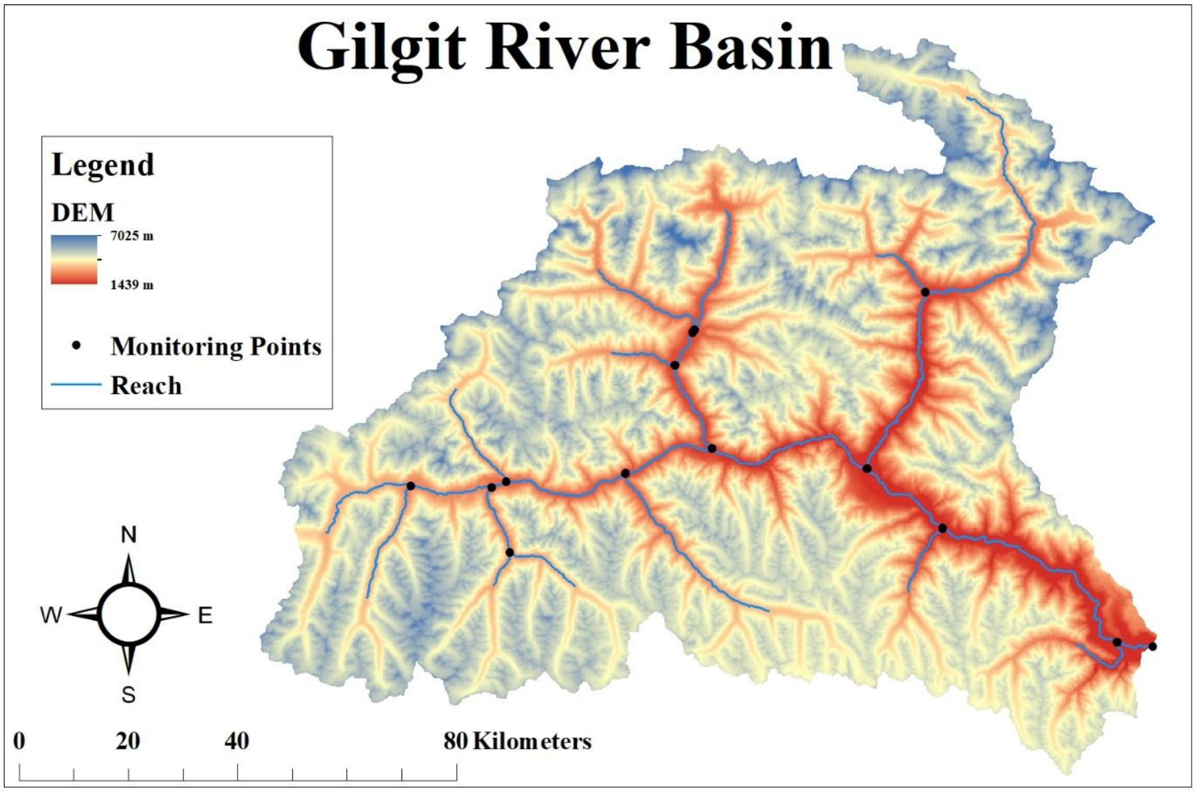

Figure 4:Gilgit River Basin

3.2.2 Land use land cover (LULC)

In ARC SWAT, land use/ Land Cover is significant input that controls the sensitivity parameters like evapotranspiration and curve number CN addition to that formation and classification of HRUs are depended upon the land use/cover of the area therefore Land use and Land cover (LULC), was obtained from ICIMOD. All the major land use are fractioned into 7 categories

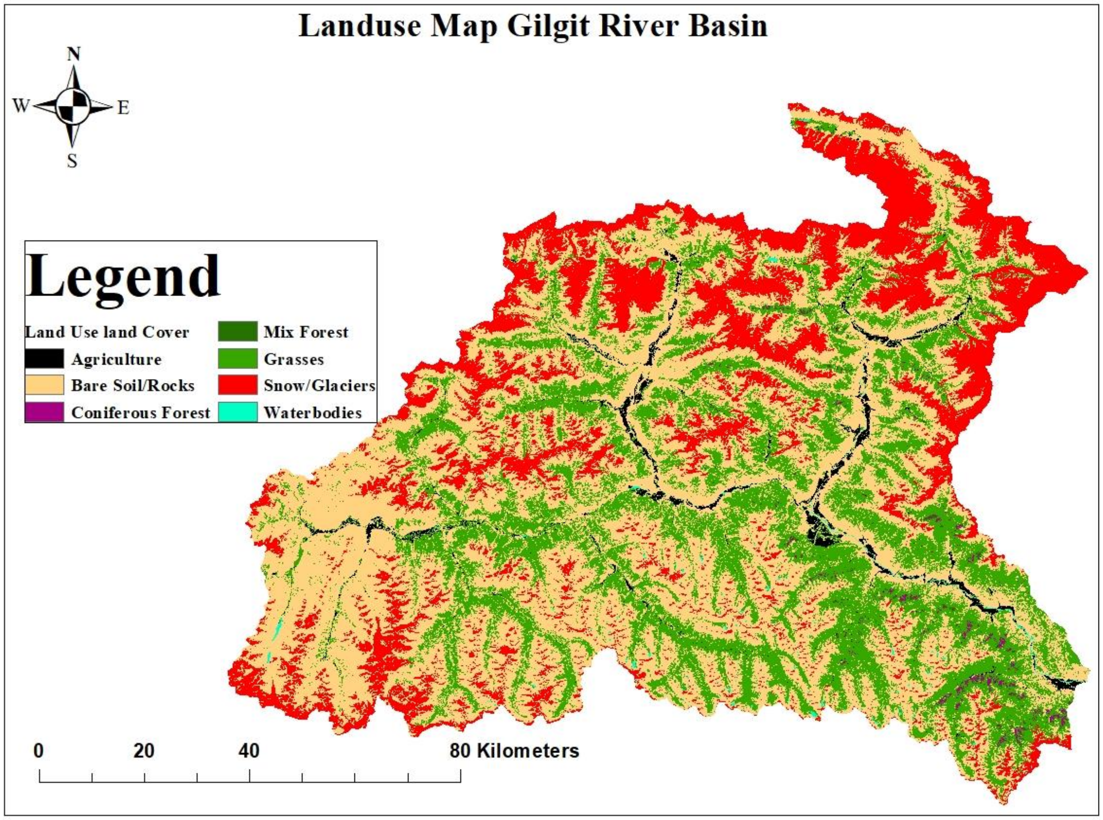

Figure 5: Land-use land cover map of Gilgit River basin

3.2.3 Soil classification of Gilgit river basin

To define parameters such as accessible water content, hydraulic conductivity, bulk density, and organic carbon content for distinct strata of each soil type, ARC SWAT requires a soil dataset as a key input. For SWAT modelling, soil data was obtained from open-sourced FAO/UNESCO resolution of 900m and was projected based on UTM

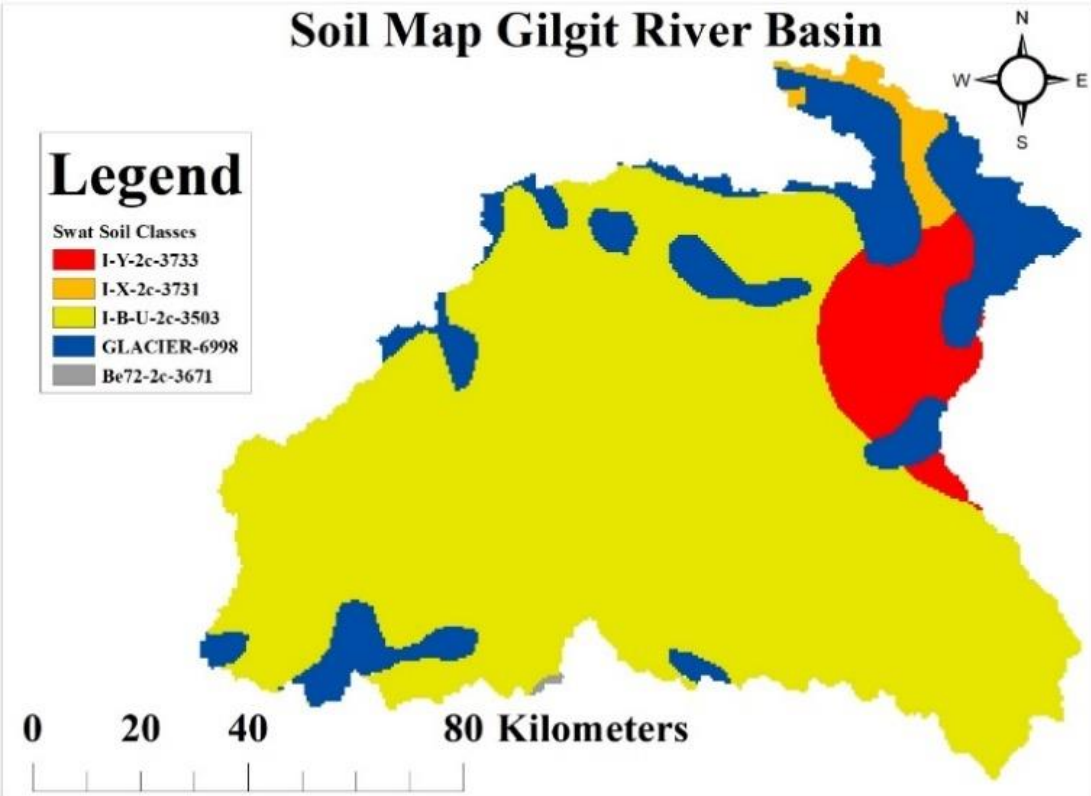

Figure 6: Soil classification map of Gilgit River basin

Table 3: Description of soil type in the watershed

No	Soil Type	Texture	%Clay	%Silt	%Sand
1	Glacier-6998	UWB	5	25	70
2	I-Y-2c-3733	Loam	23	39	38
3	I-X-2c-3731	Loam	22	33	45
4	I-B-U-2c-3503	Loam	26	30	40
5	Be72-2c-3671	Loam	22	36	42

3.2.4 Hydrological data

Observation flow is indeclinable the one of most imperative observation reading that is used to testify the model output. Observation flows are generally used as a reference for calibration and validation of the model therefore, reliability of flow data just like observed precipitation is considered as highly significant however unlike precipitation, runoff data are less susceptible to uncertainty due to more consistent and stable methodology also highlighted by Dahri in 2018. In Pakistan river flow observation record is kept by WAPDA. They use weekly current meter measurement and daily gauge readings to generate daily flow measurement through rating curve. Daily Observation flow data of Gilgit River at Gilgit city was obtained from the WAPDA between the periods of 1995 to 2016

3.2.5 Precipitation & temperature

Precipitation and temperature data was collected. Glacier Monitoring Research Centre (GMRC)., WAPDA for Ziarat, Gupis,Naltar,Gilgit and Khunjarab between the periods of 1995 to 2016

3.3 Methodological framework for hydropower site selection

The research focuses on the methodical framework for site selection of runoff the river (RoR) type hydropower site selection which is essential in planning before implementation and theoretical power potential of locations. The Gilgit river basin has been estimated using power formula under present and future scenario. The working principle of RoR comprises a penstock or a weir used to divert the river flow into the turbine and then water is returned to the river, there is no storage reservoir required, which makes its application easy

Essential factors in identifying the power potential of sites. GIS-based tools and hydrological model SWAT has been implemented to select the sites to pinpoint weir, powerhouse, head acre, and penstock and then stimulate discharge at the selected potential sites by developing regional flow duration curve at the sites(Pandey, A., Lalrempuia, D., & Jain 2015).

The mathematical formula for theoretical power potential of proposed can be estimated as:

$$P = \gamma * \eta * Q * h$$

$$\gamma = \rho g$$

Where, P is the power (W)

ϒ = ρg = Specific weight of water (N/m^3 g = Acceleration due to gravity (m/s^2)

ρ = Density of Water = (1000 kg/m^3)

Q = Discharge (m^3 /sec)

H = Head (m)

Ƞ = overall efficiency = 1

In this case Head and Discharge are the two basic requirements for the power potential, head is calculated using DEM and other GIS tools, discharge is estimated by applying rainfall-runoff modelling. Efficiency depends upon type of turbine, distribution of head and availability of flow rates. Pelton and Turgo turbines are suitable for a high head (>50m) but require relatively low flow rates, Crossflow and Francis are suitable for a low head (<50m) but variable flow rates and some turbines such as Kaplan can be operated on the head lower than 10m but requires very high flow rates. Framework the methodology is shown below

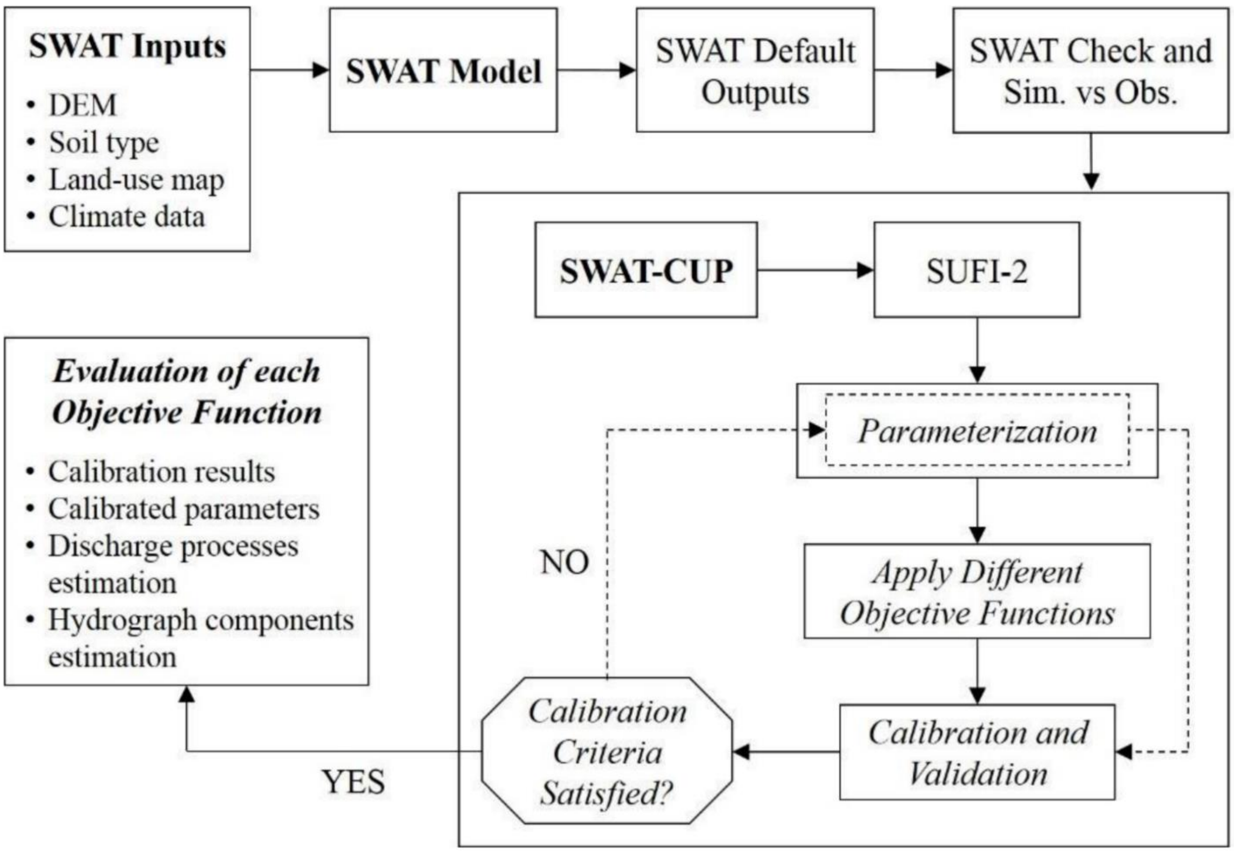

Figure 7:Flow chart showing methodology for objective 1

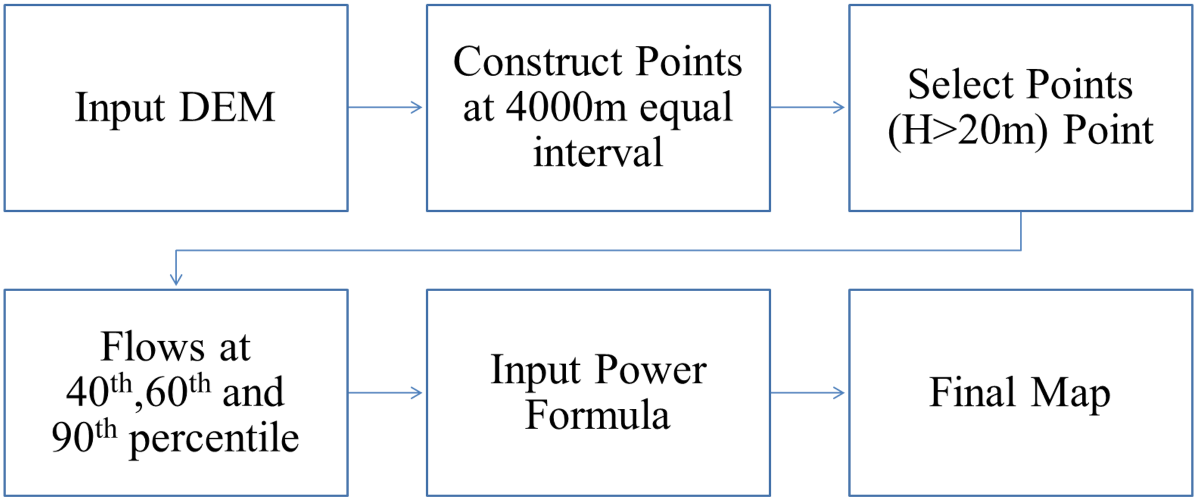

Figure 8:Flow chart showing methodology for objective 2

3.4 Softwares used in the study

Softwares applied to achieve the objectives are as follows:

- ArcMap (version 10.5)
- Arc-SWAT
- SWAT-CUP
- Google Earth Pro
- Microsoft Excel

3.5 Hydropower site selection and head assessment

A 30x30m resolution DEM was used to outline the watershed and extract the stream network and sub-basin using ArcMap's arc hydrology toolset to produce river-bed slope and retrieve the elevation generated along the river channels for head assessment. Points at a 4000m interval were constructed using the construct tool in ArcGIS to calculate the head of the selection of suitable locations. Each successive point symbolizes a starting point at a higher elevation where water is diverted to the plant and a finishing point at a lower height where water is pushed back to the river. The digital elevation model was placed on the skull, drop along each pair of points to examine it.

For the selection of the potential site for the RoR hydropower projects following criteria have been set:

1. Assuming that flow in the subbasin remain constant.

2. Hydraulic head greater than 20 meters has been considered.

3. Minimum distance between two the potential sites must be equal or greater than 4000m

3.6 Determination of flow rates

The Soil Water Assessment Tool (SWAT) would be used to compute the discharge at the potential location and produce future flows to assess the impact of climate change on electricity potential. It's a semi-distributed model that was originally designed for rainfall-runoff modelling, water quality, and reliability in vast river basins. The SWAT model works within the ArcGIS interface, and it splits the watershed into homogeneous units, or hydrological response units (HRU), depending on land use, soil, and slope (Rospriandana and Fujii 2017). Daily temperature (T_{max} and T_{min}), precipitation, DEM, LULC map, and Soil and Slope map of the research area are all essential data inputs for the SWAT model. SWAT model operates by following water balance equation to derive hydrological cycle within the basin as: (Garee et al. 2017).

$$SW_t = SW_o + \sum(R_{day} - Q_{surf} - E_a - w_{seep}\ t\ i{=}1 - Q_{gw})$$

- t is the time of day i
- SW_t and SW_o is the final and initial amount of soil water content (mm)
- R_{day} is the amount of precipitation on day i (mm)
- Q_{surf} is the amount of runoff on day i (mm)
- Ea is the amount evapotranspiration on day i (mm)
- W_{seep} is the amount of water entering into the vadose zone from soil profile on day i (mm)
- Q_{gw} is the amount of return flow on day i (mm)

ArcSWAT version 10.5 was utilized in this study to delineate watershed and generate stream network while calibration and validation.

The setting of the model was done using the protocol provided by Anjum et al., 2016 for the Swat River Basin. The was calibrated on a daily and monthly basis by using the flow data at the basin outlet. Model performance was examined both qualitatively and quantitively. Qualitative via visual inspection and interpretation, timing of the peaks in the graph and quantitative by using objective function such as Nash-Sutcliffe co-efficient of efficiency (NS), Root Mean Squared Error (RMSE), Percent Bias (PBIAS) (Hasan, M. M., & Wyseure 2018)

$$NSE = \frac{\sum_{i=1}^{n}(Qi^{obs} - Qi^{sim})2}{\sum_{i=1}^{n} Qi^{obs} - Q^{mean})2}$$

$$R^2 = \frac{[\sum_{i=1}^{n}[Qi^{Obs} - Qi^{sim}][Qi^{sim} - Qi^{sim\ mean}]]^2}{\sum_{i=1}^{n}[Qi^{obs} - Qi^{mean}]^2 \sum_{i=1}^{n}[Qi^{obs} - Qi^{mean}]^2}.$$

Where Qi^{Obs} and Qi^{Sim} are observed and simulated values, and Q^{mean} and $Q^{simmean}$ are the average values of observed and simulated discharge.

After the getting calibrated SWAT, it was then run along the potential sites that have been selecting for RoR projects and flow was generated for different periods.

3.6.1 Model uncertainty and sensitivity analysis

It is required to optimize the model that best reflects the observed condition in order to check the uncertainties of a hydrological model. It is performed by performing a sensitivity analysis to determine which parameters are the most sensitive. The technique of checking model performance by modifying input parameters is known as sensitivity analysis. More sensitive are the parameters that have a bigger impact on model output.

The SWAT model includes two types of sensitivity analysis tools. The first is global sensitivity analysis, which examines the sensitivity of one parameter in relation to others. The t-test score and p-value are used to determine the parameter's sensitivity. The second category of sensitivity analysis is one-at-a-time sensitivity analysis, in which the influence of each parameter is examined separately. Sensitivity in this case is checked by visual inspection of flow graphs. Twenty different parameters were selected based on literature, out of which only 13 were found sensitive.

3.6.1.1 SWAT calibration uncertainties program (SWAT-CUP):

SWAT calibration uncertainties program (SWAT-CUP) was developed to automatically configure sensitivity of the SWAT model parameters and to carry out Calibration & Validation procedure on simulations from SWAT model. SWAT CUP have integrated with multiples calibration/ uncertainty analysis algorithms such as

- Sequential Uncertainty Fitting version 2 (SUFI-2)
- Particles Swarm Optimization (PSO)
- Generalized Likelihood Uncertainty Estimation (GLUE)
- Parameter Solution (ParaSol)

- Markov Chain Monte Carlo (MCMC)

For considering uncertainty analysis the model simulation is obtained from ‘TxtInOut’ folder presented in SWAT scenario. Further after setting up, for evaluating the sensitive parameters are assumed and added into model addition to observation data. Process evaluates the effectiveness of each parameter to drive the simulation. Identified parameters are than set to calibrate and validate accordance to provided period range**.**

3.6.1.2 SWAT Calibration and Validation

Model calibration and validation are critical in every hydrological model to ensure that simulated flow conditions match observed flow conditions by adjusting model parameters according to certain criteria. Manual calibration and auto-calibration are the two different types of calibration and validation methodologies used in SWAT. Manual calibration is a time-consuming and labor-intensive technique that requires altering parameters until the predicted flow matches the observed flow. However, automatic calibration inside the SWAT-CUP software interface, as well as Monticello simulation, are utilized to determine the parameter range. Model calibration is carried done using SWAT cup using a predetermined algorithm. The Sufi-2 technique is used to optimize the model to obtain flow rates at ungauged sites.

Table 4: Sensitive Parameters

NO.	PARAMETERS	DESCRIPITION
1	r__CN2.mgt	SCS runoff curve number
2	v__ALPHA_BF.gw	Base flow alpha factor (days)
3	v__GW_DELAY.gw	Groundwater delay
4	v__GWQMN.gw	Threshold in the shallow aquifer for return flow to occur
5	v__GW_REVAP.gw	Groundwater ‘‘revap” coefficient
	v__REVAPMN.gw	
6	v__SLSUBBSN.hru	Average slope length.
7	v__HRU_SLP.hru	Average slope steepness.
8	v__OV_N.hru	Manning's "n" value for overland flow.
9	r__SOL_AWC.sol	Available water capacity of the soil layer.

10	v__ESCO.bsn	Soil evaporation compensation factor
11	v__EPCO.bsn	Plant uptake compensation factor
12	v__SURLAG.bsn	Surface runoff lag time
13	v__SFTMP.bsn	Snowfall temperature.
14	v__SMTMP.bsn	Snow melt base temperature.
15	v__SMFMX.bsn	Maximum melt rate for snow during year (occurs on summer solstice).
16	v__SMFMN.bsn	Minimum melt rate for snow during the year (occurs on winter solstice).
17	v__SNO50COV.bsn	Snow water equivalent that corresponds to 50% snow cover.
18	v__SNOCOVMX.bsn	Minimum snow water content that corresponds to 100% snow cover.
19	v__TIMP.bsn	Snow pack temperature lag factor.
20	v__PLAPS.sub	Precipitation lapse rate

4 RESULTS AND DISCUSSION

4.1 Head Drop across the selected sites

DEM and river network has been utilized to estimate head at the potential sites. Points has been generated along the river network at the equal interval using construct tool in editor toolbar. For head drop across each pair of points, they were overlaid on the digital elevation model and elevation at those points have been obtained

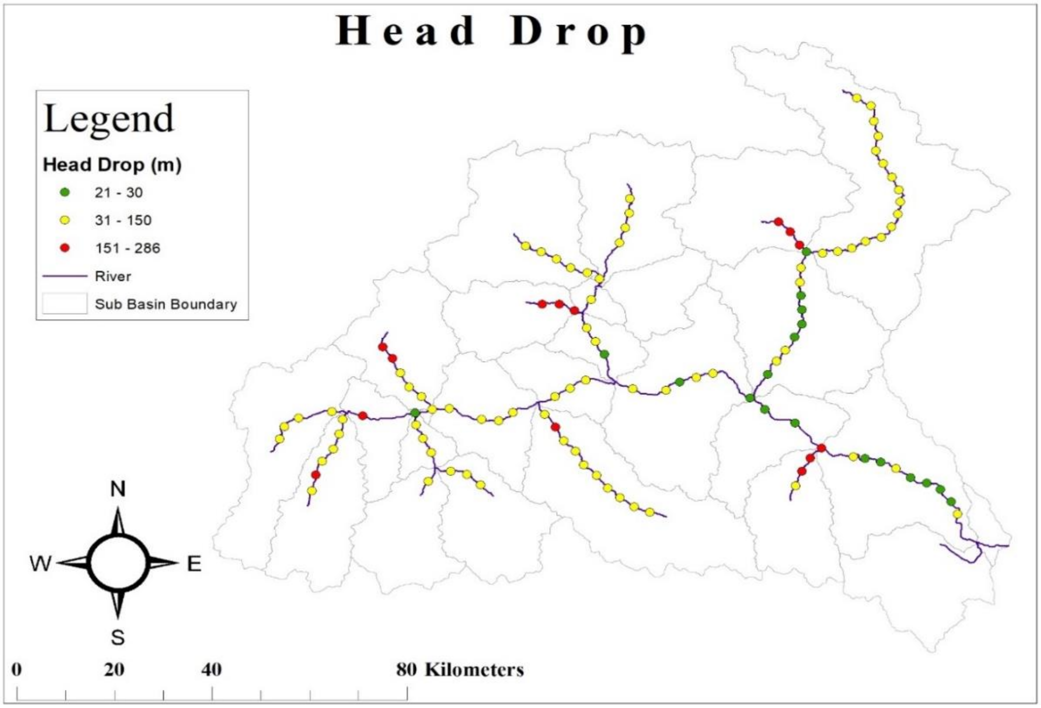

Figure 9: Head Drop Map

Table 5: Head Drop across the selected sites

Sr #	Head (m)	No of Sites	Range
1	21-30	18	Low
2	31-150	77	Medium
3	151-256	14	High

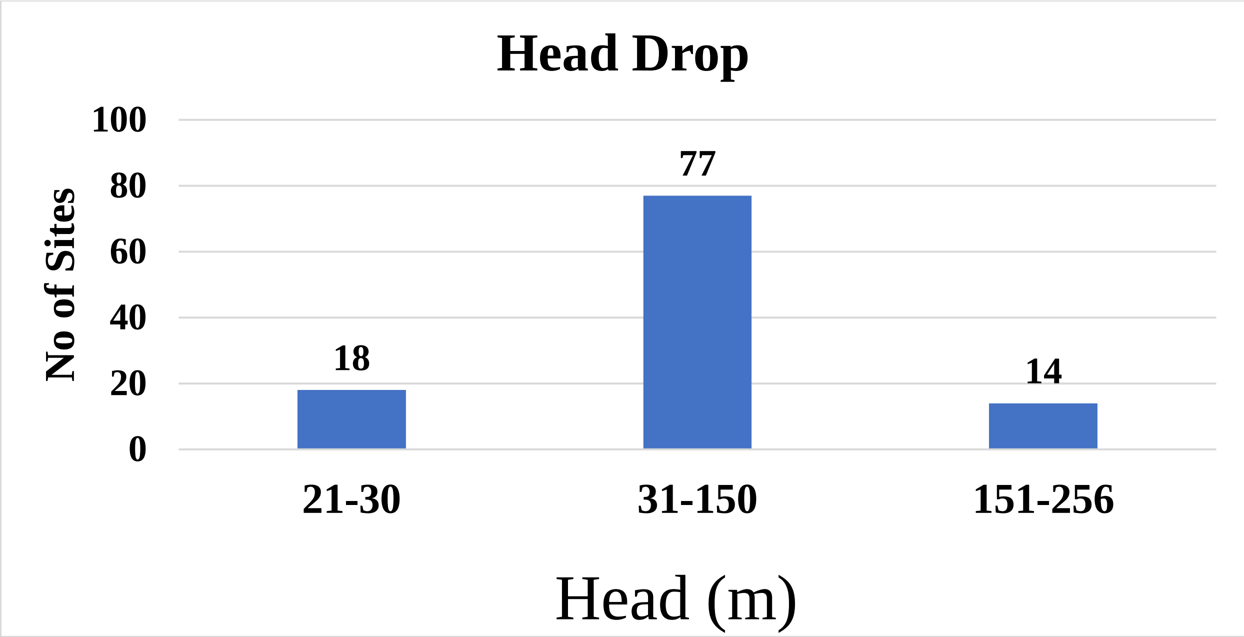

Figure 10: Graph of Head Drop across the selected sites

4.2 Theoretical power Potential Estimation

4.2.1 Flow Duration Curve for theoretical power computation

After calibration and validation of the SWAT model to get the discharge at potential sites, twenty-one years of run data were used to construct flow duration curves at 27 sites and estimate theoretical hydropower production and theoretical hydroelectric power production using power formula. Construction of flow duration curve is essential to get a dependable discharge for the ROR and exceedance of flow availability throughout the year, hence for the Swat River basin, dependable discharge at 60th ,40^{th} and 90^{th} percentile was computed for the optimal power production.

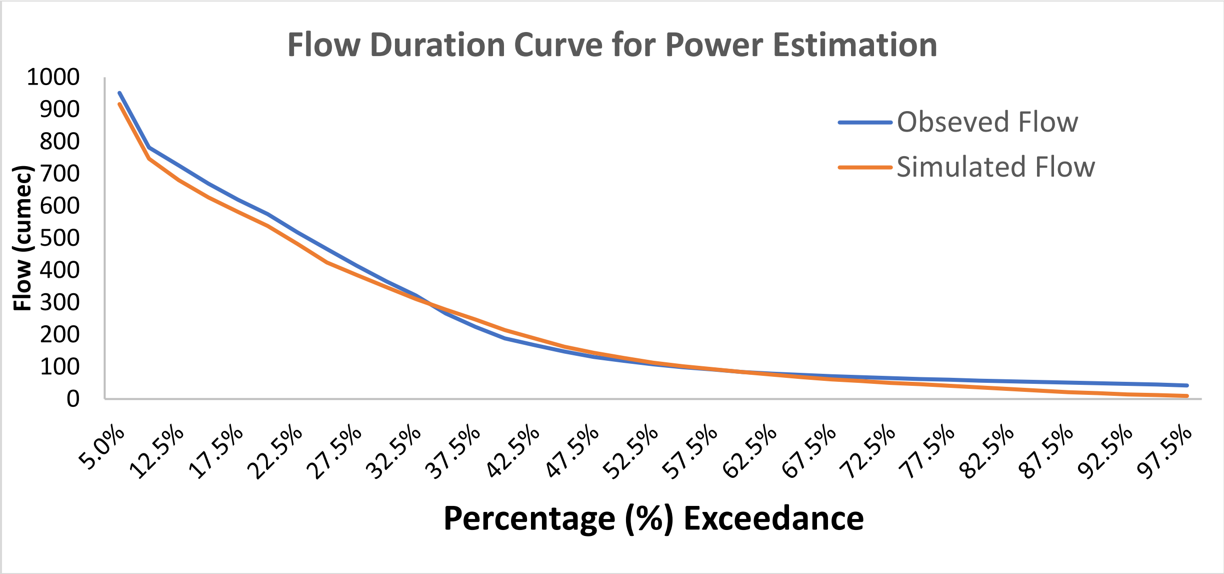

Figure 11: Flow Duration Curve for Power estimation

4.2.1.1 Calibration and validation

Graphical Daily Flow Hydrographs are shown for both Calibration and Validation time periods. Precipitation dataset was primary differentiator for stream flow simulations Calibration of the model was done on a time i.e., from 1998 to 2004 on monthly time scale. Sensitivity analysis was performed prior to manual calibration. Calibration parameters lie within acceptable range. For calibration, $R^2$and Nash-Sutcliff coefficient show a value of 0.86 and 0.89 respectively. For validation, monthly validation was performed for a time of 2005-2008.Nash-Sutcliff and R^2 values come out to be 0.85 and 0.89 respectively.

Table 6:Reference table for the model performance evaluation

Performance Evaluation Table			
Performance Rating	**NSE**	**KGE**	$\mathbf{R^2}$
Very Good	0.75 < NSE < 1.00	0.85 < KGE < 1.0	$0.8 < R^2 < 1.0$
Good	0.65 < NSE < 0.75	0.75 < KGE< 0.84	$0.75 < R^2 < 0.79$
Satisfactory	0.50 < NSE < 0.65	0.65 < KGE < 0.74	$0.65 < R^2 < 0.74$
Un-Satisfactory	NSE < 0.50	KGE< 0.65	$R^2 < 0.65$

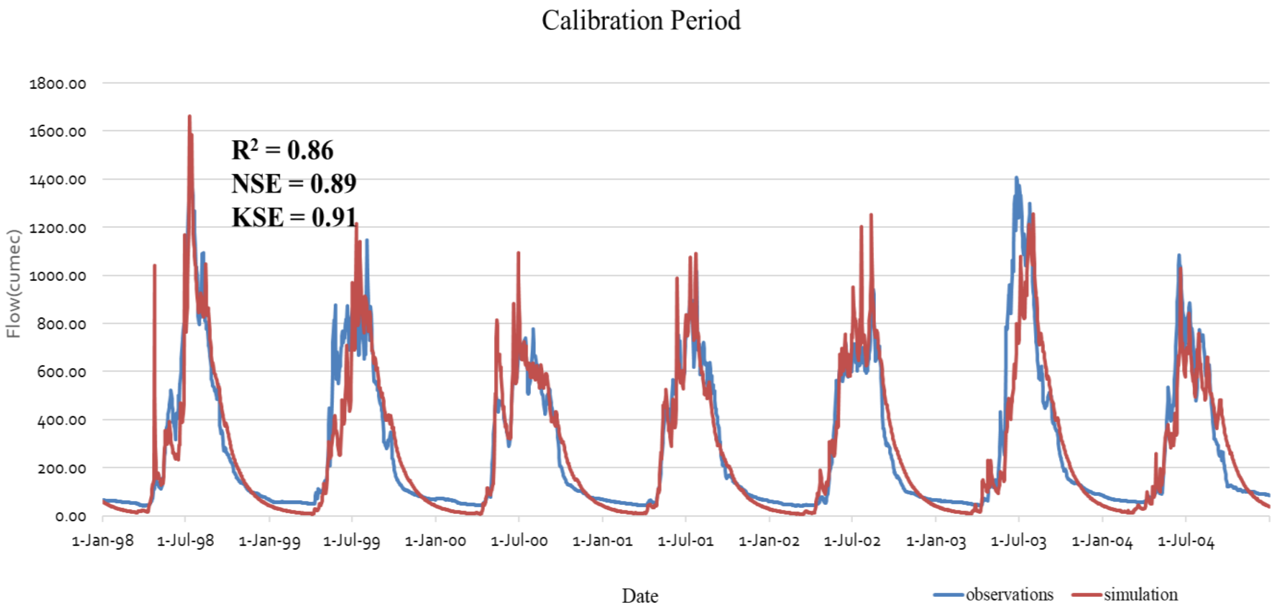

Figure 12:Calibrated flow simulations of resultant models for the period of (1998-2004) corresponding to observed daily Gilgit river flow.

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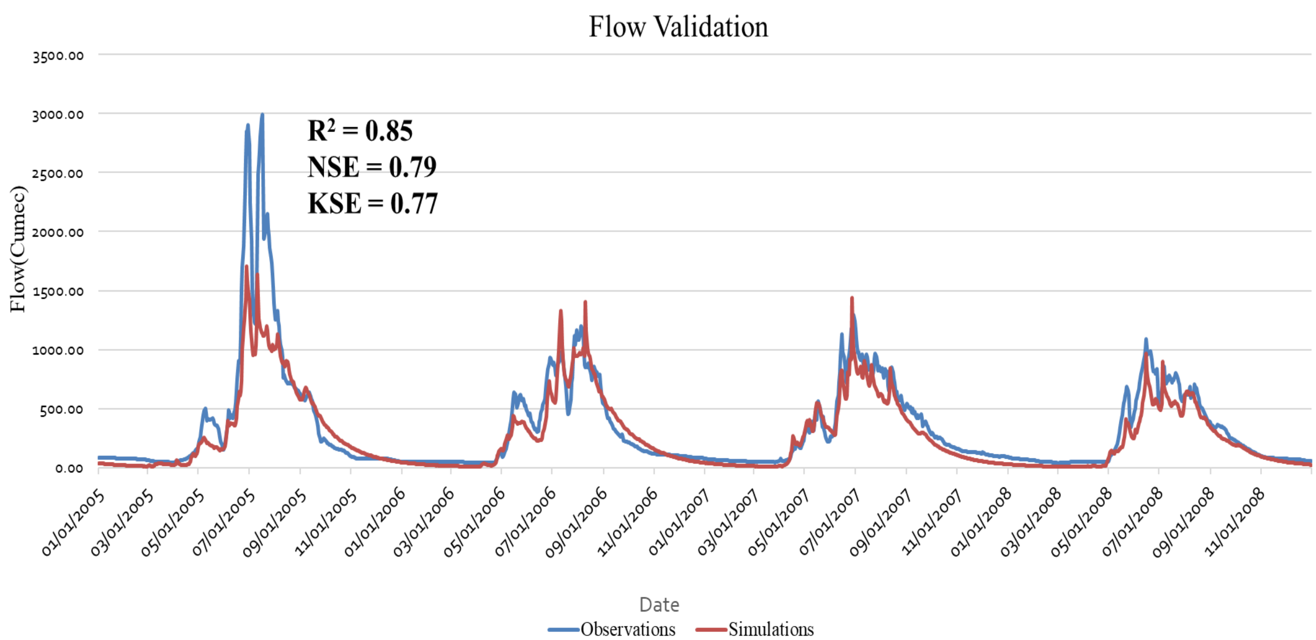
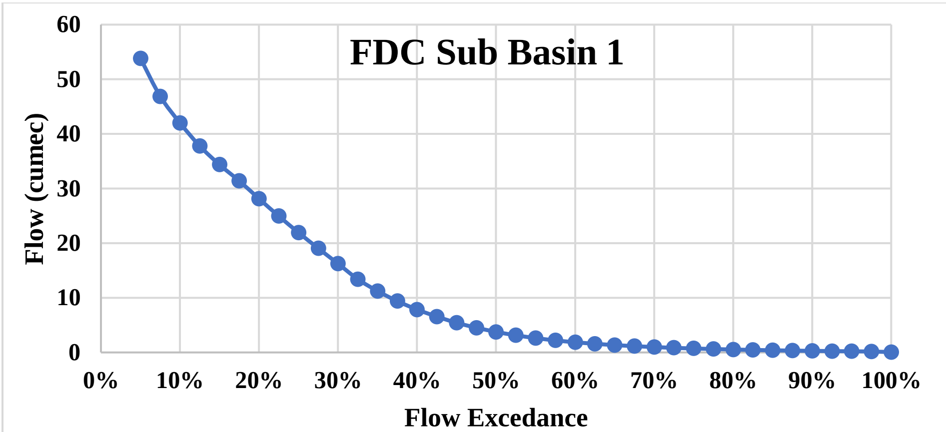
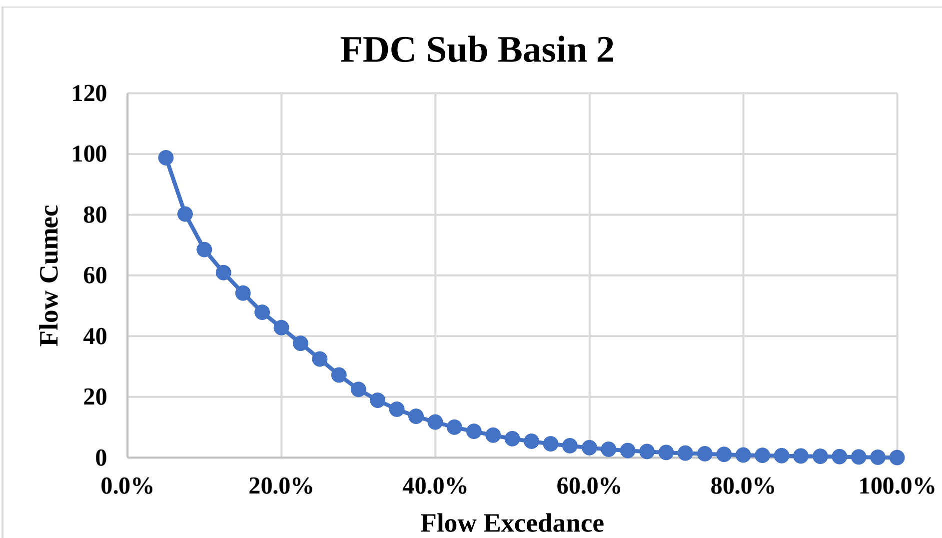


Figure 13: Validated flow simulation of resultant models for the period of (2005-2008) corresponding to observed daily Gilgit river flow





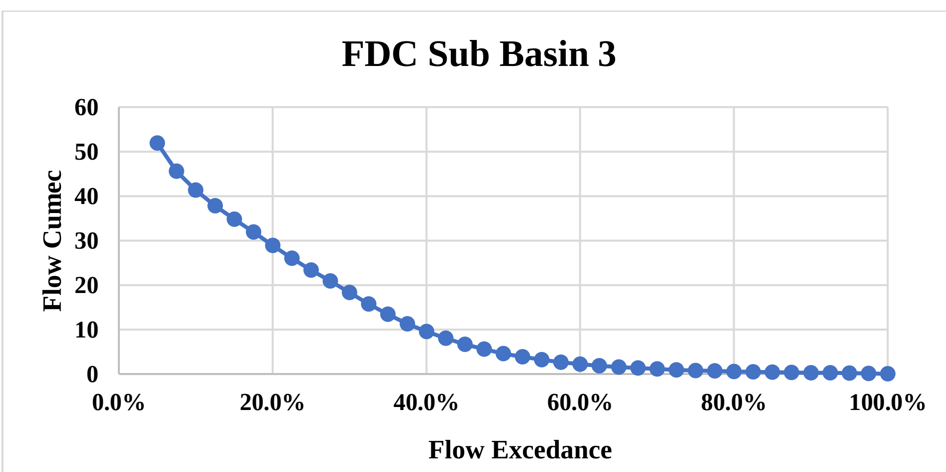


Figure 14: FDC Sub Basin 1-3

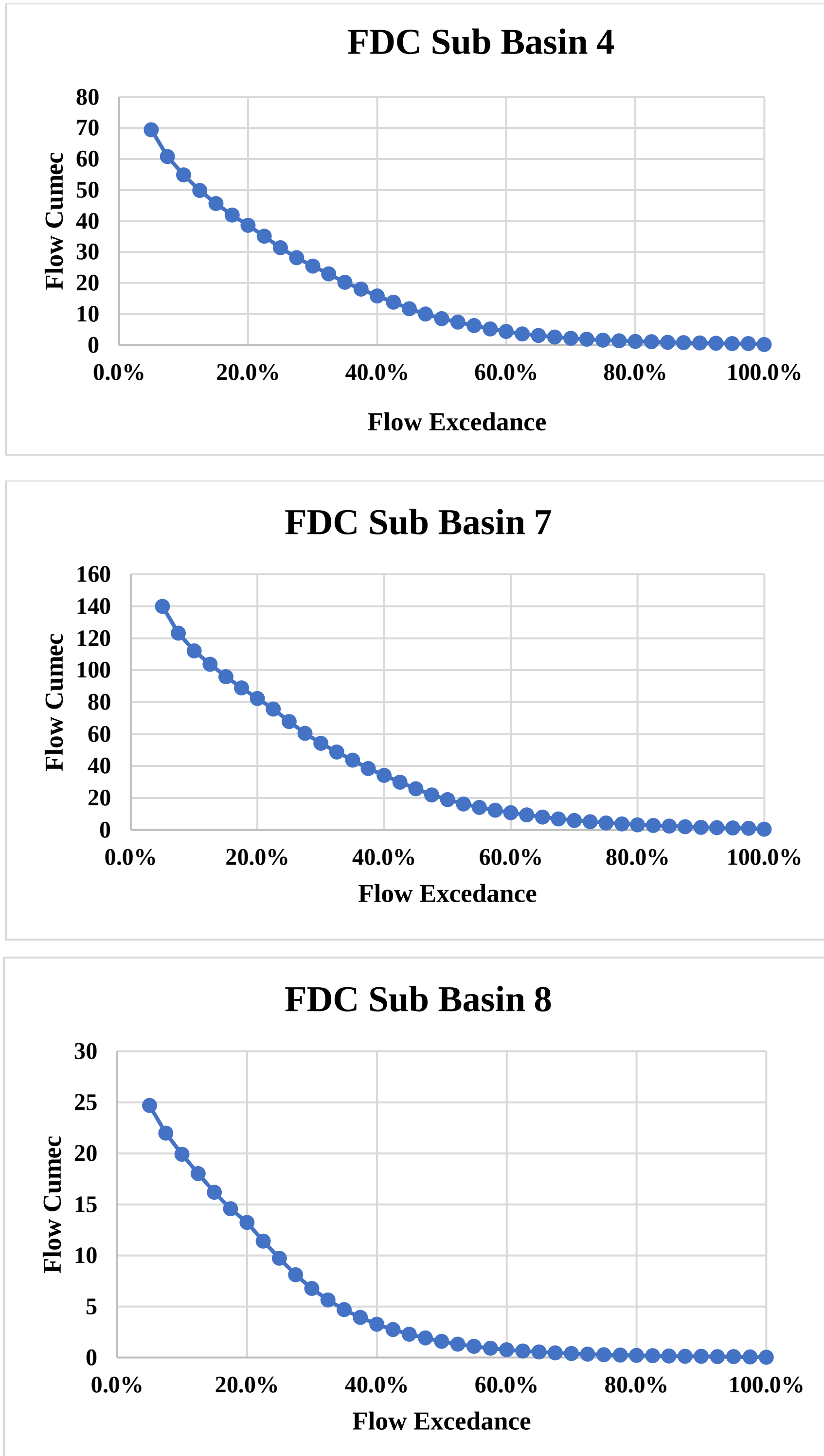
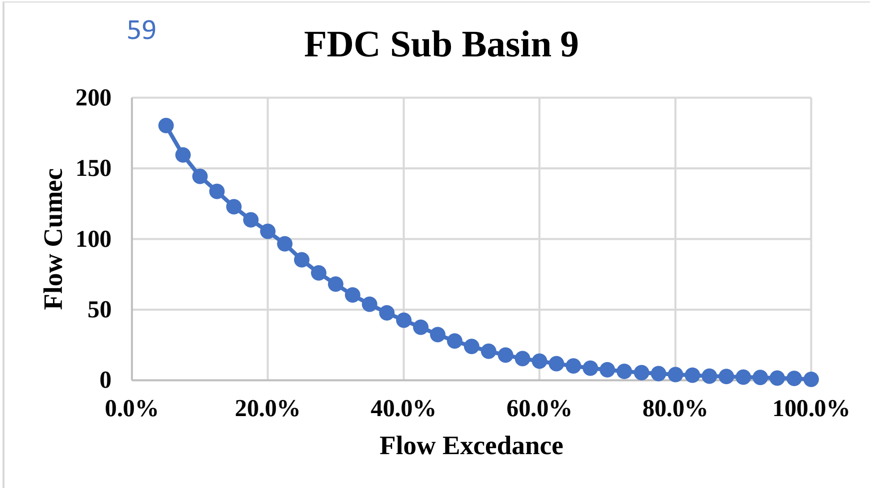
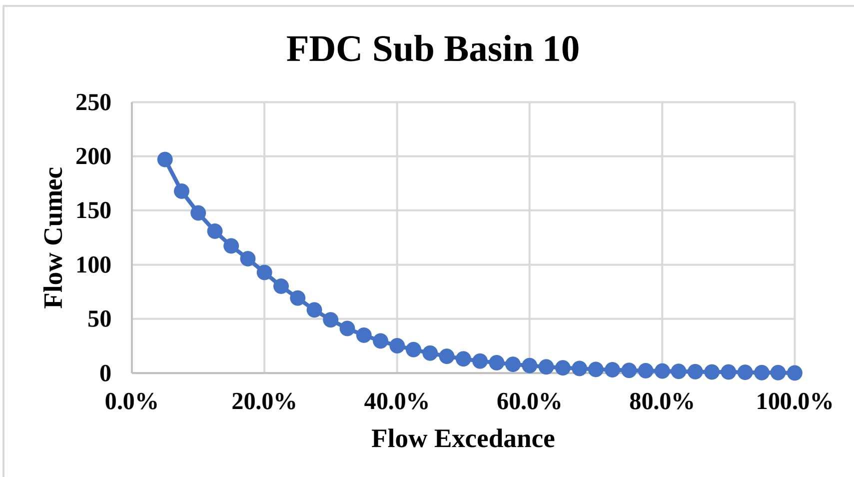


Figure 15: FDC Sub Basin 4,7-8





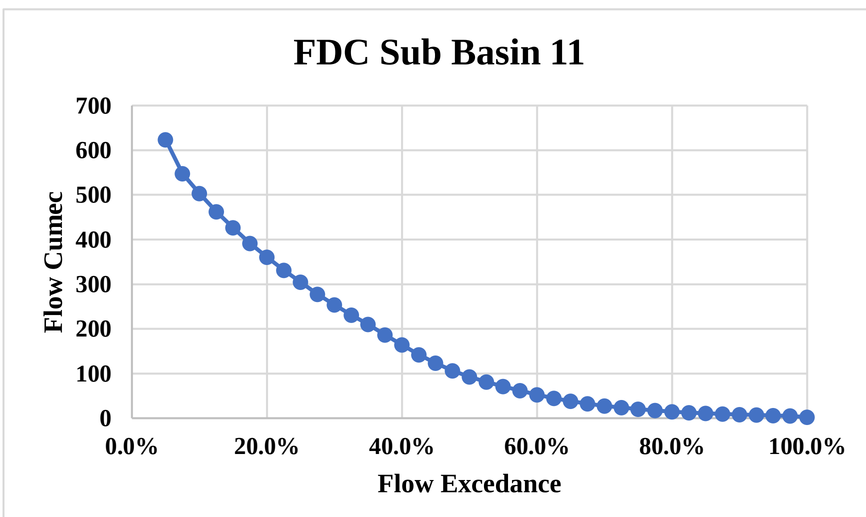
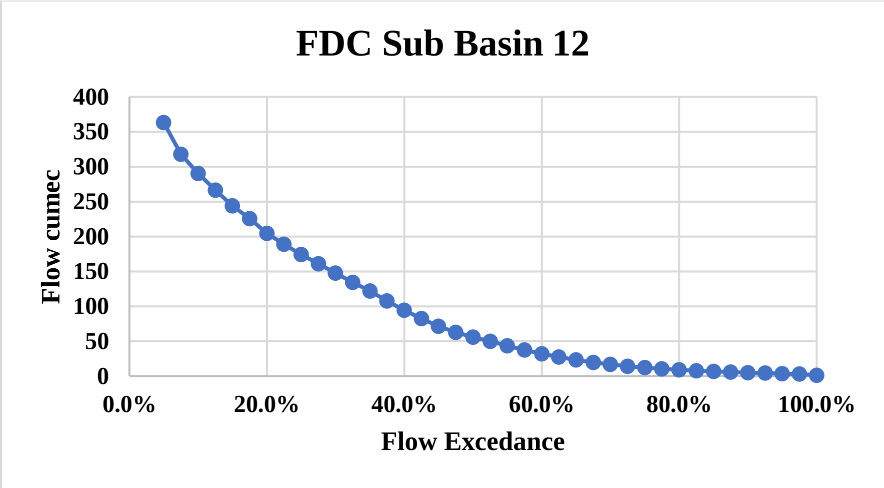
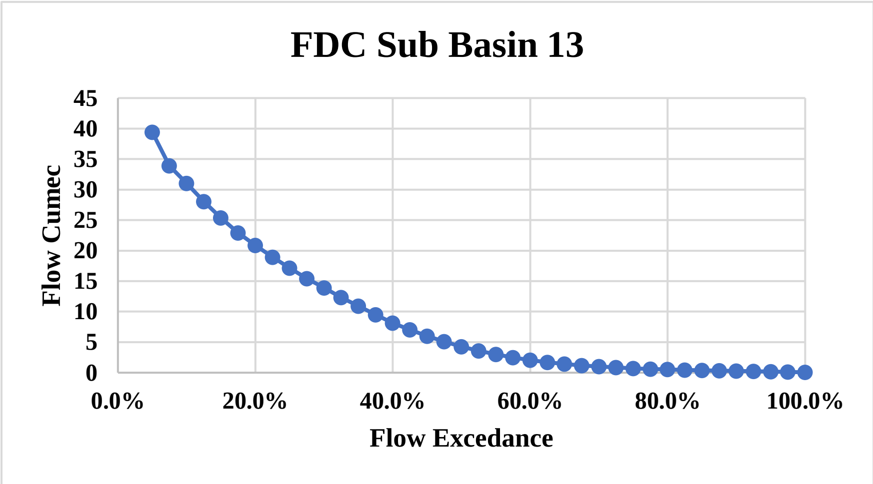


Figure 16: FDC Sub Basin 9-11





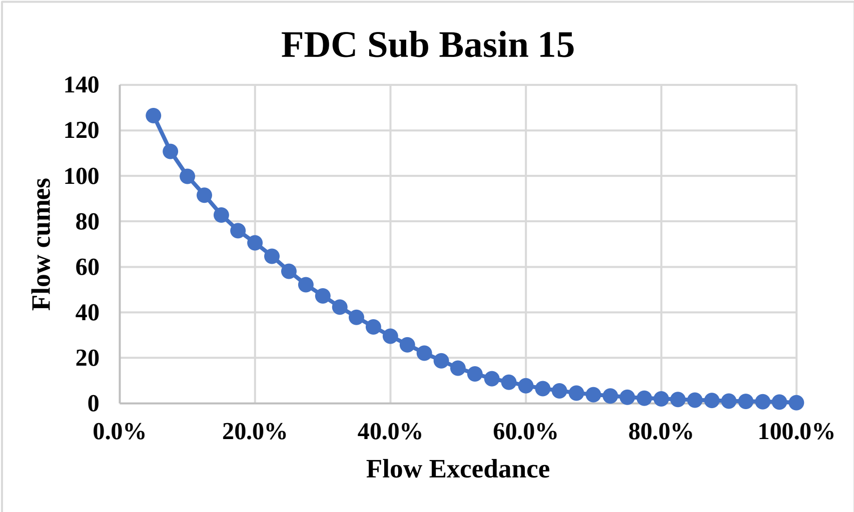
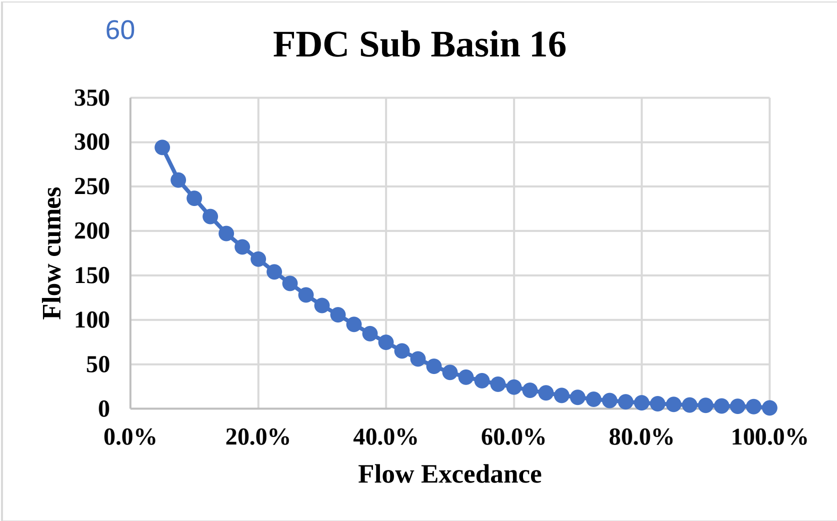
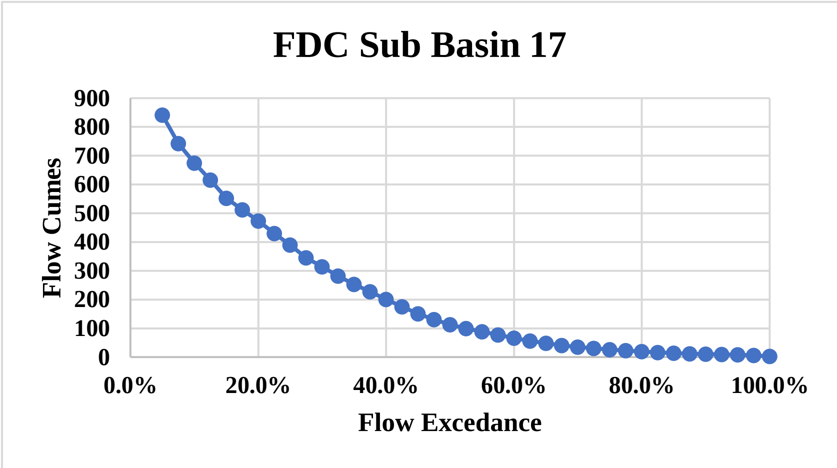


Figure 17:FDC Sub Basin 12-13,15





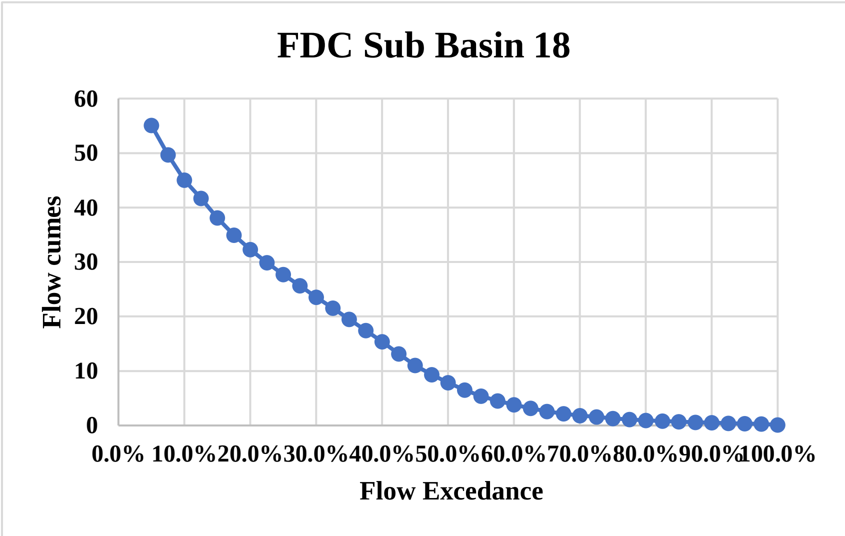


Figure 18: FDC Sub Basin 16-18

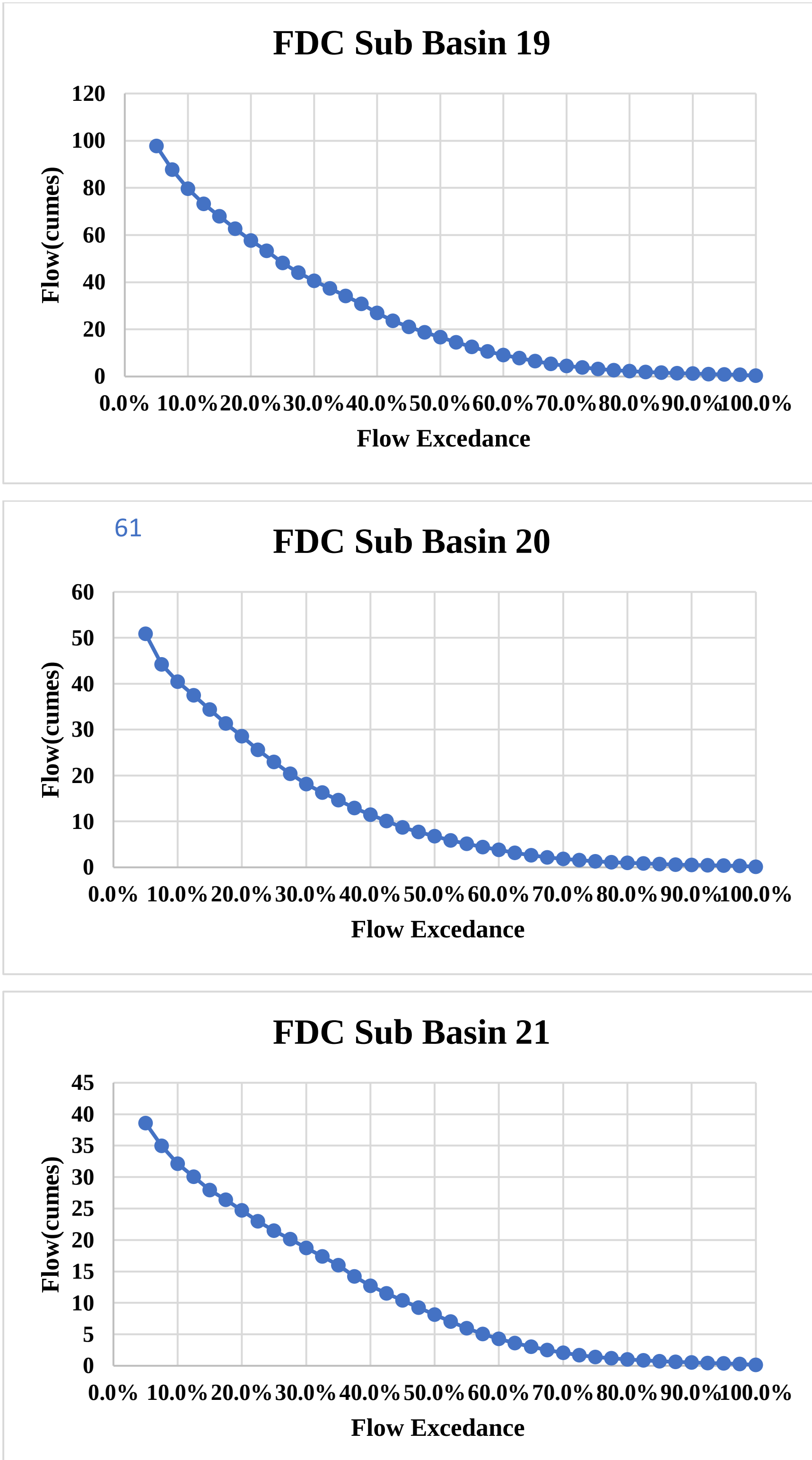
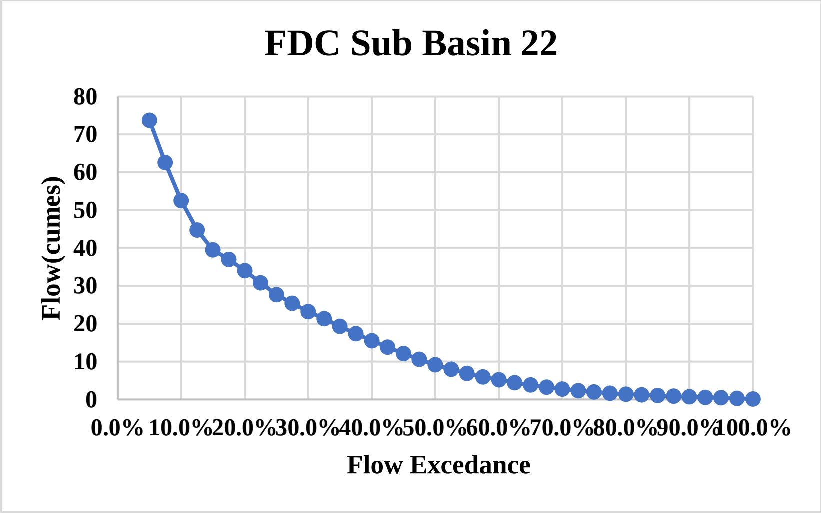
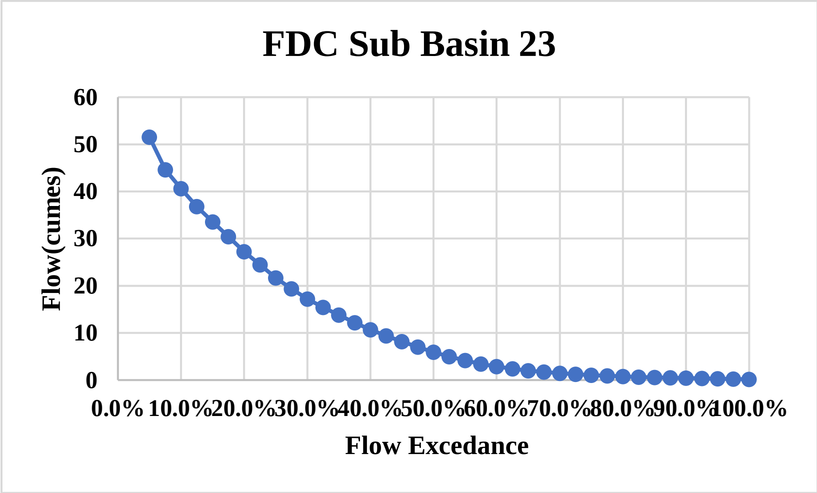


Figure 19: FDC Sub Basin 19-21





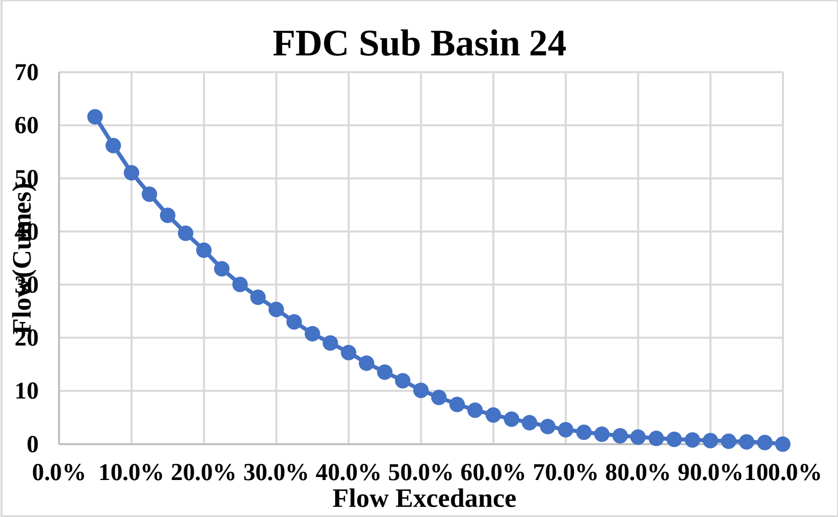


Figure 20: FDC Sub Basin 22-24

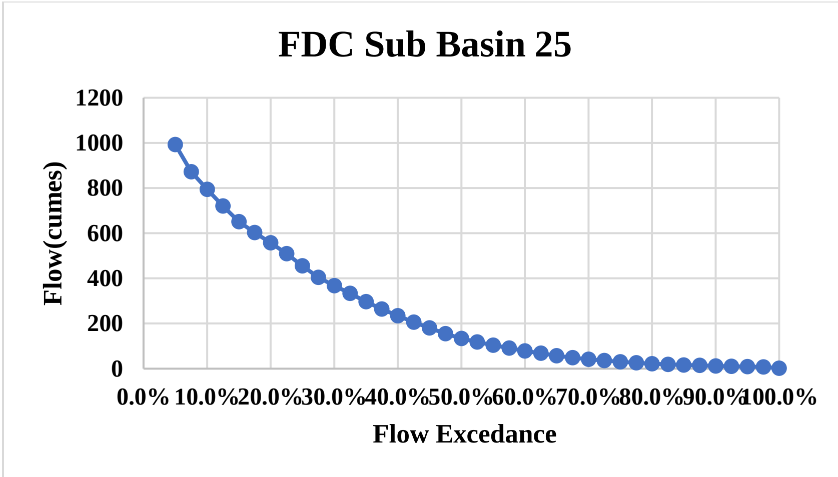


Figure 21: FDC Sub Basin 25

4.2.2 Theoretical power potential

Theoretical power potential was calculated for the given points using the power formula the difference in potential was mainly due to difference in head and flowrates. The hydro power potential ranges from 24.95MW to 115.0MW at 40th percentile ,8.06MW to 38.35MW at 60th percentile and 1.22MW to 6.10MW at 90th percentile.

The hydroelectric potential ranges from 20.55MW to 100.14MW at 40th percentile ,6.64MW to 33.36MW at 60th percentile and 1.01MW to 5.31MW at 90th percentile

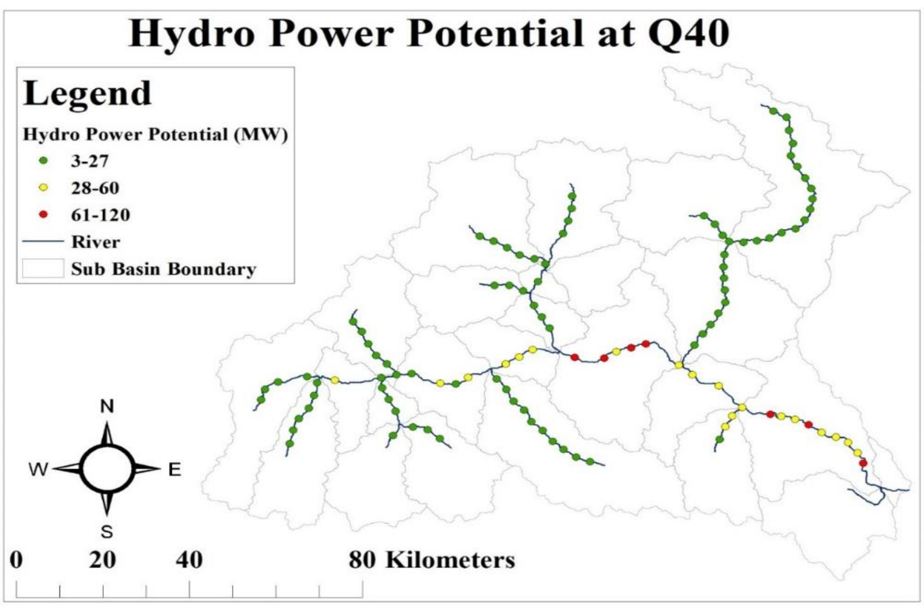


Figure 22: Hydro power potential at Q40

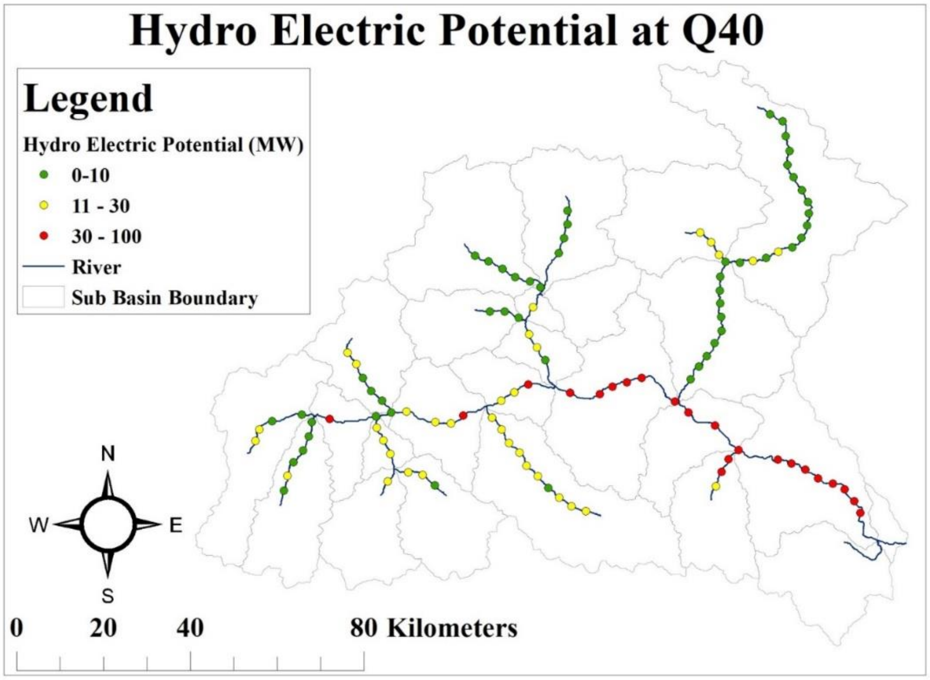
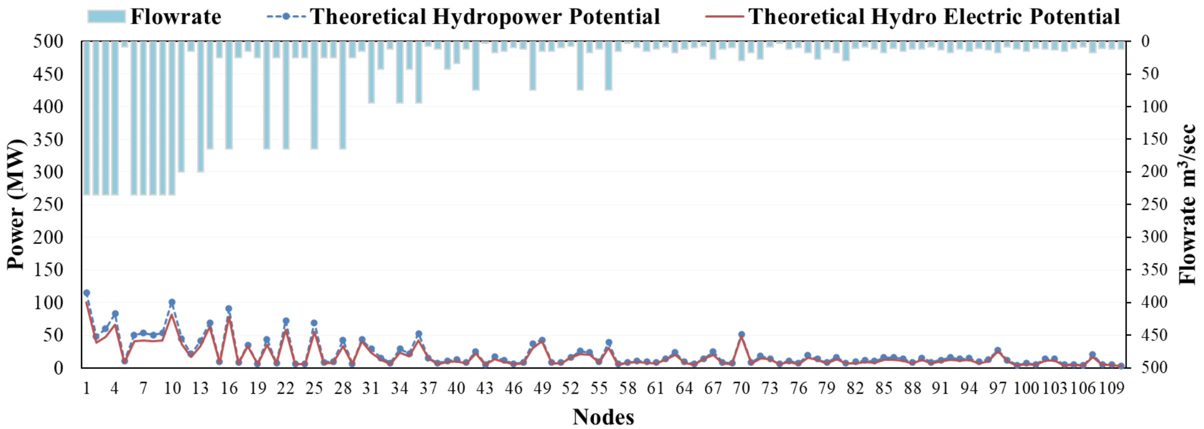


Figure 23:Hydro Electric power potential at Q40

Table 7:Potential at Q40

Hydro Electric Power Potential (MW)	No of Sites	Hydro Power Potential (MW)	No of Sites
0-10	58	3-27	81
11-30	29	28-60	19
30-100	21	61-120	7



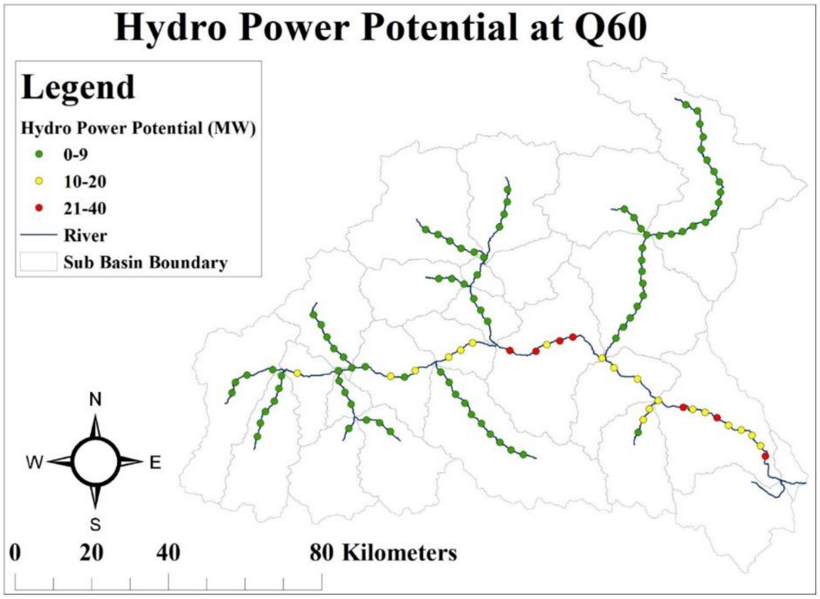


Figure 24: Hydro power potential at Q60

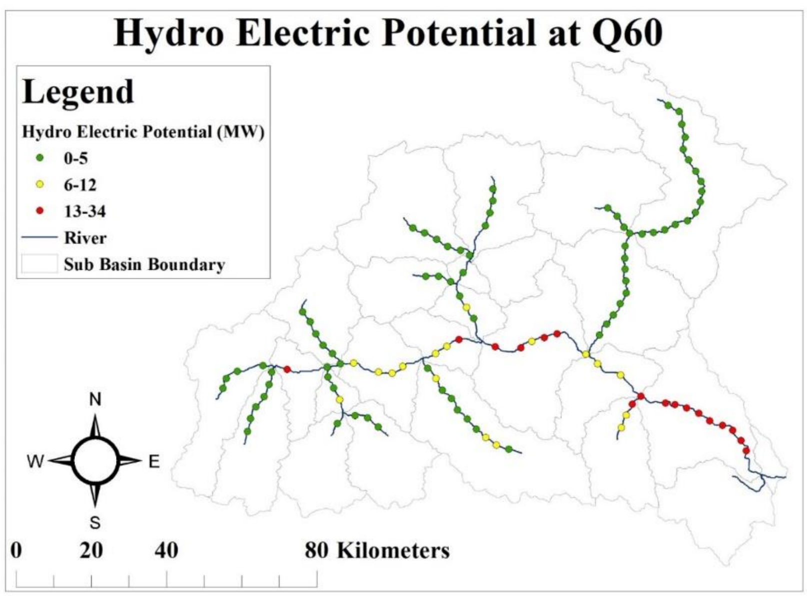
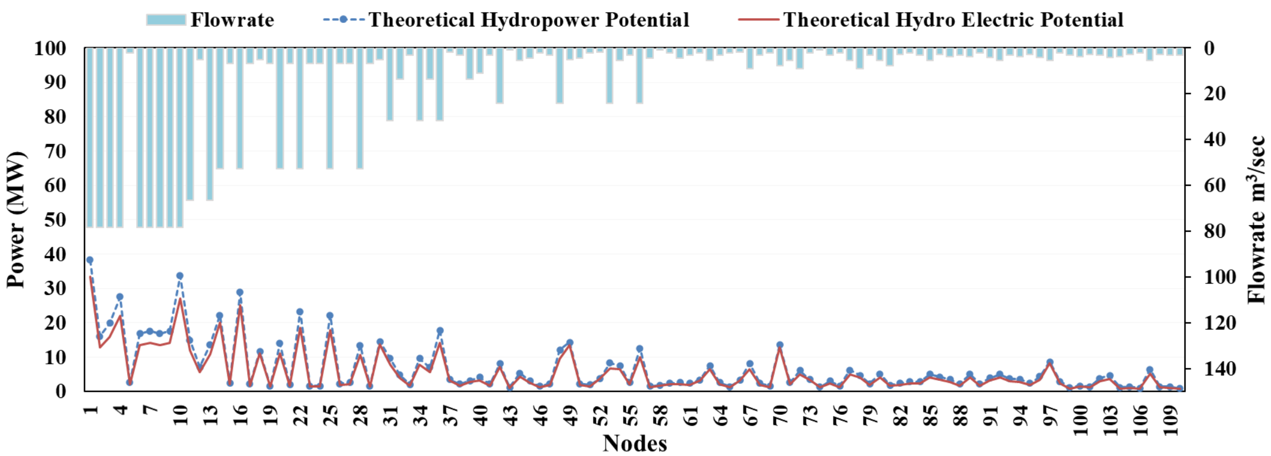


Figure 25: Hydro Electric power potential at Q60

Table 8:Potentials at Q60

Hydro Electric Power Potential (MW)	No of Sites	Hydro Power Potential (MW)	No of Sites
0-5	78	0-9	83
6-12	14	10-20	16
13-34	12	21-40	5



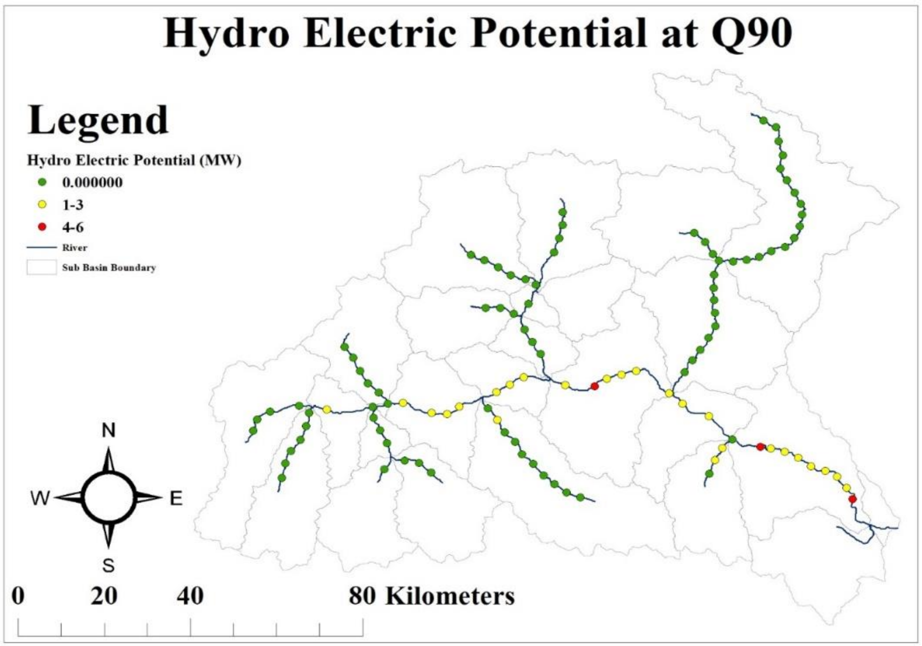


Figure 26:Hydro Electric Power Potential at Q90

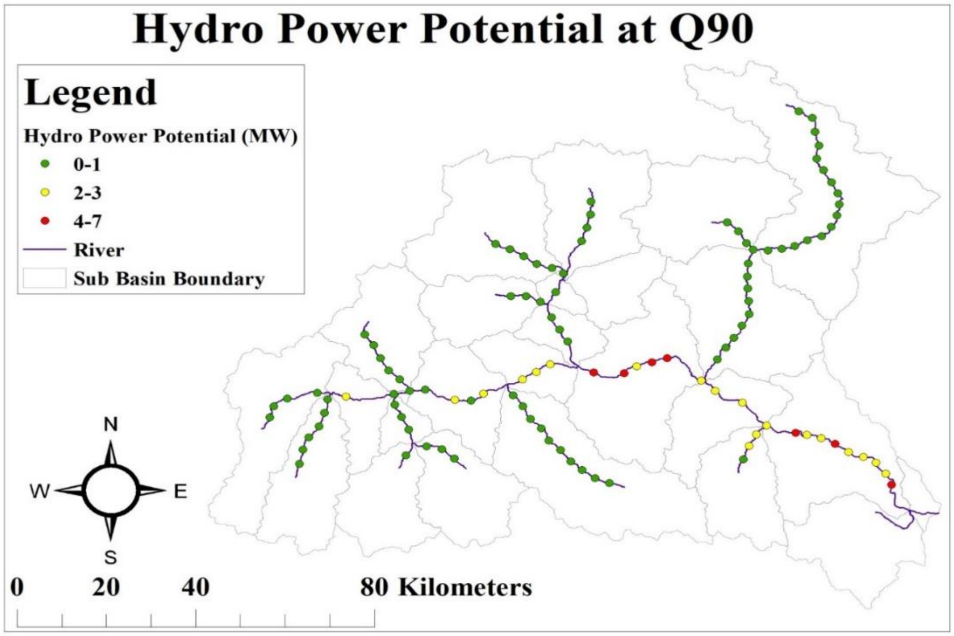
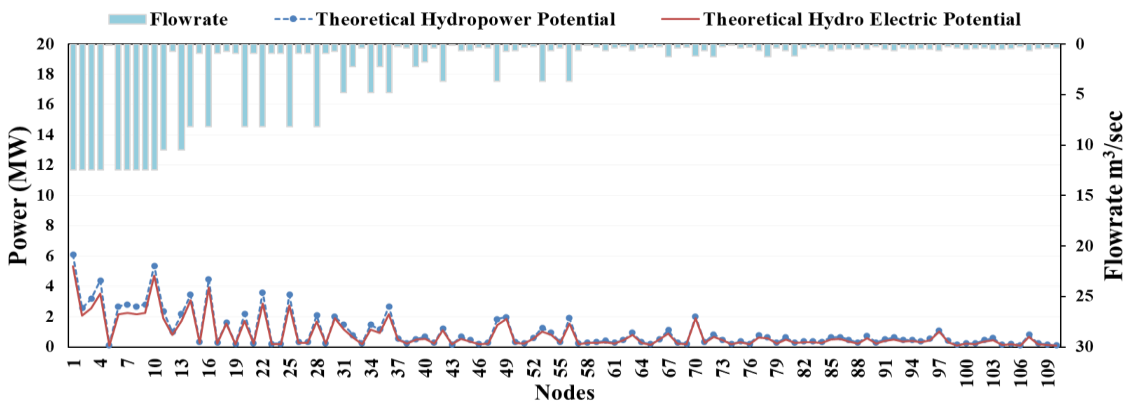


Figure 27:Hydro Power Potential at Q90

Table 9: Potentials at Q90

Hydro Power Potential (MW)	No of Sites	Hydro Electric Potential (MW)	No of Sites
0-1	89	0	81
2-3	15	1-3	23
4-7	4	4-6	5



4.3 Results anahytical hieracry process (AHP)

Thomas Saaty developed the Analytic Hierarchy Process (AHP) theory for analyzing intangible elements using paired comparisons and judgments on a 1 to 9 fundamental scale, which results in factor priority.

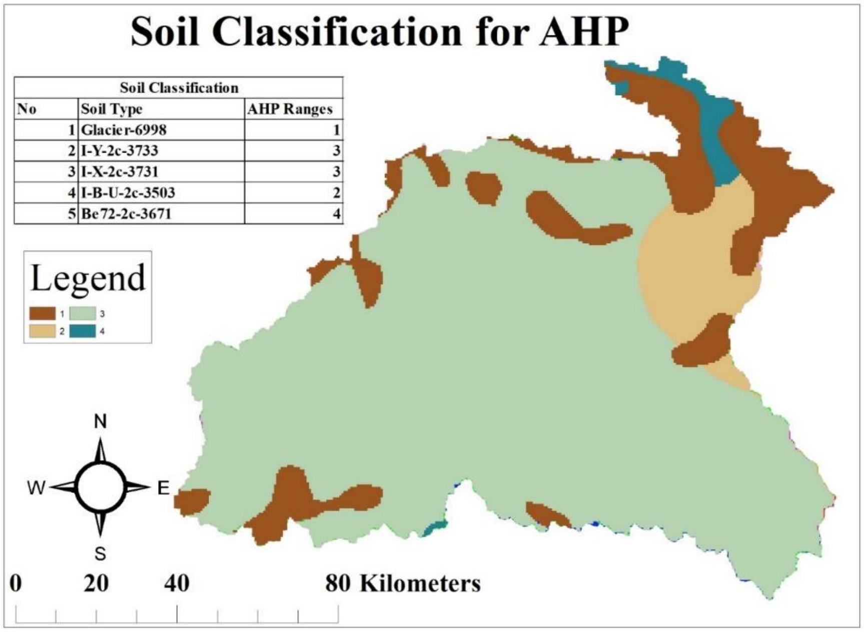


Figure 28:Soil Classification Map for AHP

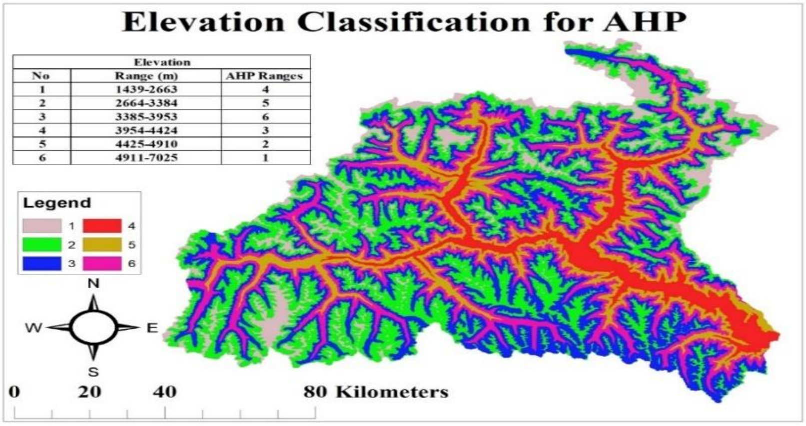


Figure 29:Elevation Classification Map for AHP

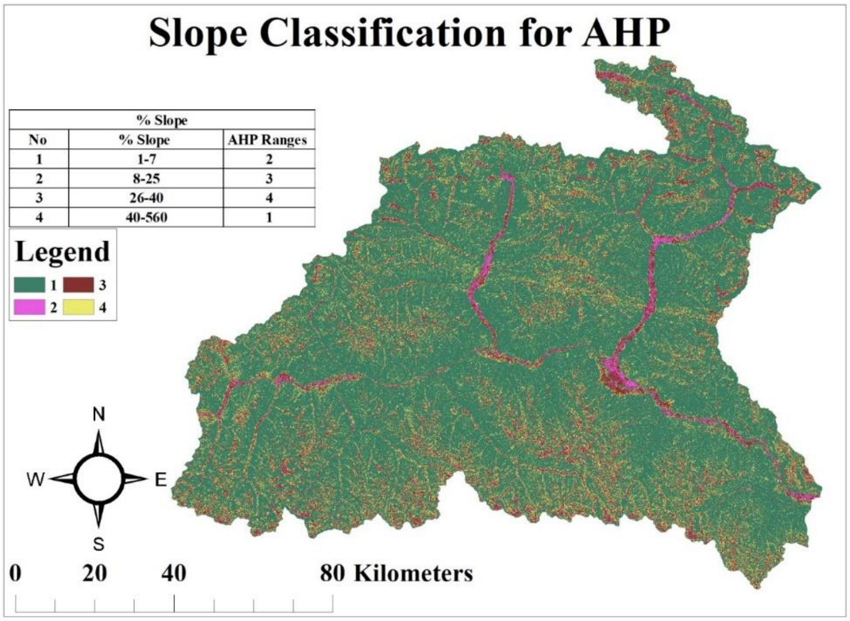


Figure 30:Slope Classification Map for AHP

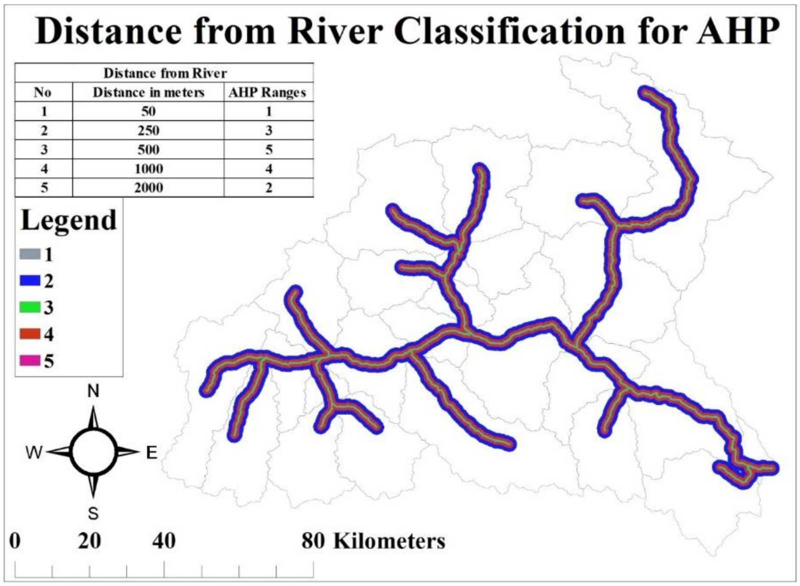


Figure 31:Distance from River Classification Map for AHP

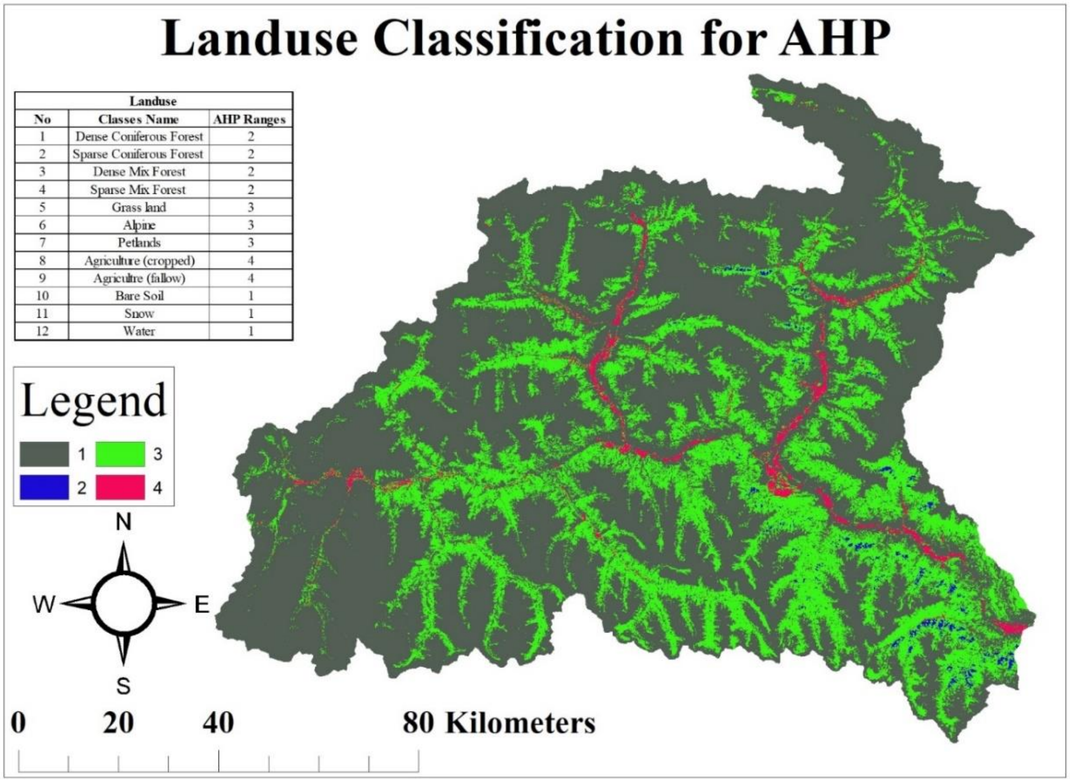


Figure 32:Land Use Classification Map for AHP

Table 10: Criteria Weights for AHP

	Slope	Soil	Land Use	Elevation	Distance from River
Slope	1	0.5	0.5	0.333	0.5
Soil	2	1	0.5	0.333	0.25
Land Use	2	2	1	0.333	0.5
Elevation	3	3	3	1	0.333
Distance from River	2	4	2	3	1

Consistency Ratio = 0.089 (Data is consistent)

These are the optimal sites identified on the given criteria for the installation of turbines.

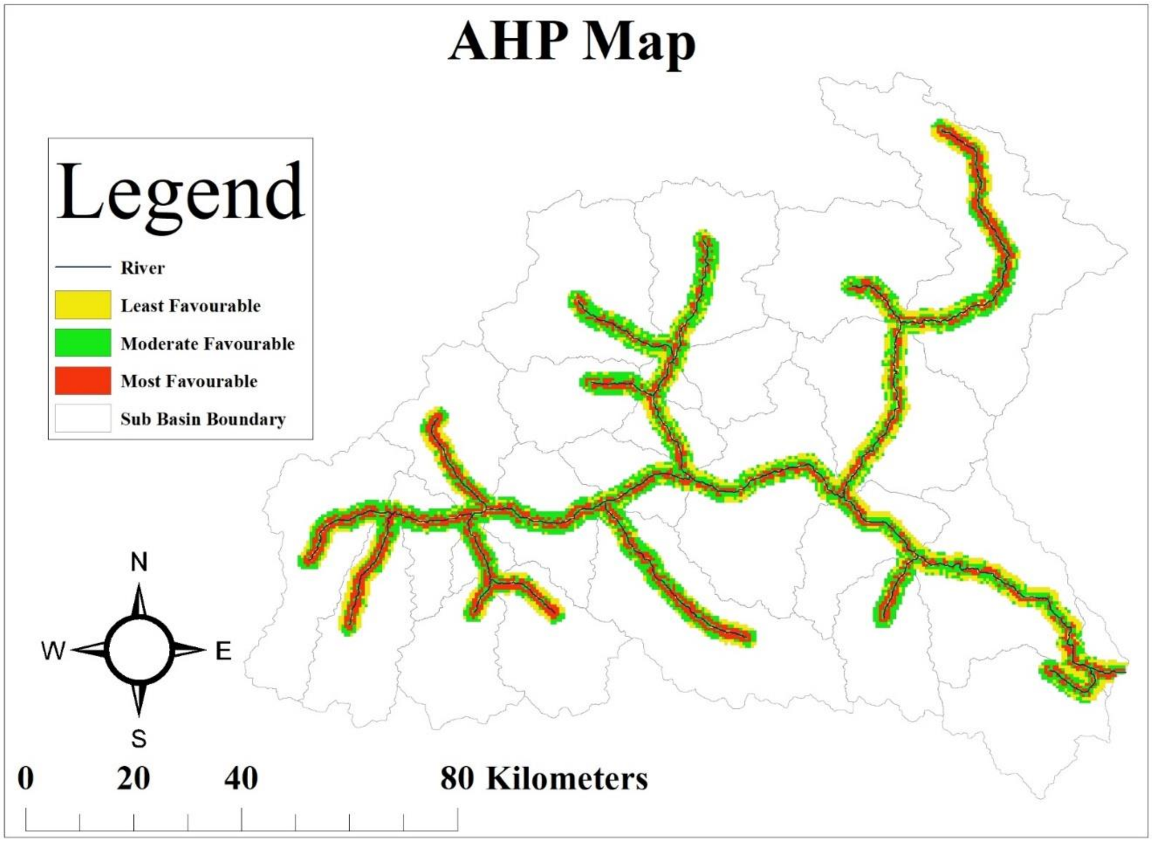


Figure 33:Optimal Sites for Turbines Installation

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

- The research study aims to identify the theoretical power potential of Gilgit river basin and pinpoint the suitable locations for the run of the river hydropower project by using SWAT hydrological model and GIS tools.
- Power potential of Gilgit river was calculated using flows at 40th ,60th, 90th percentiles. The results reveal that Gilgit River basin has enormous hydropower potential that can be extracted by using eco and an economic friendly small run of the river hydropower potential.
- The hydro power potential ranges from 24.95MW to 115.0MW at 40th percentile ,8.06MW to 38.35MW at 60th percentile and 1.22MW to 6.10MW at 90th percentile.
- The hydroelectric potential ranges from 20.55MW to 100.14MW at 40th percentile ,6.64MW to 33.36MW at 60th percentile and 1.01MW to 5.31MW at 90th percentile.
- The use of GIS to find suitable locations revealed that downstream areas were more productive than upstream areas due to the enormous volume of discharge.
- Using Remote Sensing and GIS tools to assess the potential of small hydroelectric power facilities is an effective strategy.

5.2 Recommendations

- Other factors such as population data and energy demand of the area should be incorporated
- Techno-economic analysis can be carried out for more details
- Socio-economic implications of site selection should be considered

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