CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Comparative Evaluation of Hydropower Potential of Jhelum and Indus Basins using GIS

by

Muhammad Ali

A thesis submitted in partial fulfillment for the
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This thesis is dedicated to my family, teachers and all those friends who have supported me since the beginning of this thesis.

CAPITAL UNIVERSITY OF SCIENCE & TECHNOLOGY
ISLAMABAD

CERTIFICATE OF APPROVAL

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List of Publications

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1. **Ali, M and Hassan, I. (2018).** , "Evaluation of Hydropower Potential of Gilgit-Hunza Basin using Geographic Information System," *KSCE Journal of Civil Engineering* ,(Impact Factor: 0.83) (Submitted).

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Abstract

The increasing energy demand, due to the rapidly increasing population, and the resulting strain on our conventional energy sources, has proven the benefits of renewable energy sources as a prerequisite for sustainable economic growth. Hydropower is one such source that is both renewable and sustainable in addition to being environment-friendly. Though Pakistan relies primarily upon hydropower, yet much of the country suffers from massive power shortages owing to the large gap between supply and demand, despite having enormous hydropower potential in the Indus and the Jhelum rivers of Pakistan, most of which still remains untapped. Recent advancements have made possible the management and processing of spatial data using a Geographic Information System (GIS) based environment. The study focuses on assessing the comparative evaluation of hydropower potential of basins, the Indus and the Jhelum of Pakistan, using topographical data, obtained through remote sensing in the form of a digital elevation model, and local stream flow datasets. The data was then processed using the various spatial analyses tools, available in ArcGIS, to identify the potential locations for developing hydropower plants and to evaluate the hydropower potential associated with these areas. In Indus Basin, total length of Indus River along with minor rivers is 1529 Km of river runoff and 628 Km of Jhelum River along with its major tributaries in Jhelum Basin has been evaluated to identify potential sites for setting hydropower schemes. In Indus Basin, 225 No of sites are evaluated with hydropower potential of 44,444 MW. Similarly, in Jhelum Basin, 102 No of sites are evaluated with hydropower potential of 10,100 MW. So by keeping in view the result of this study, total hydropower potential in the vicinity of Indus and Jhelum Basins can be upto 54,544 MW. The results of this study can help increase awareness among the decision-making authorities about the vast renewable energy potential of the Indus and the Jhelum Rivers of the country, in the form of hydropower, which is still untapped. Keeping in view the current economic situation and shortfall of electricity being faced by country in mind readily 50 sites recommended through which 31,900 MW can be generated by installing hydropower schemes. This study will consequently assist the authorities in taking wise decision in favor of a sustainable future and overcome the energy crisis being faced today by Pakistan.

Keywords: Renewable Energy, Hydropower, Sustainable, Geographic Information System (GIS), Remote Sensing and Arc GIS.

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Abbreviations

ADB	Asian Development Bank
AMSL	Above Mean Sea Level
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CPEC	China Pakistan Economic Corridor
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
GDP	Gross Domestic Products
GHG	Green House Gas
GIS	Geographic Information System
HKH	Hindukush Karakoram Himalaya
IDW	Inverse Distance Weighing
IPCC	Intergovernmental Panel on Climate Change
MW	Mega Watt
NASA	National Aeronautics and Space Administration
PPIB	Private Power and Infrastructure Board
SRTM	Shuttle Radar Topography Mission
SWHP	Surface Water Hydrology Project
UIB	Upper Indus Basin
UJB	Upper Jhelum Basin
WAPDA	Water and Power Development Authority

Chapter 1

Introduction and Background

1.1 Background

Energy is one of the most important resources of a country. It is the backbone of the economic development of a country. The entire industrial and residential sector depends upon it. With the introduction of mechanized agriculture, the agriculture sector also relies largely upon these energy resources also referred to as electricity. Electricity lights up our homes, runs all sorts of machinery in industrial facilities and plays a vital role in making our lives comfortable. Over the years, a number of different ways have been developed to harness electrical energy. Harnessing electrical energy from coal, oil, gas, steam and water are some of the most common methods which have been in use since many years. Wind energy, solar energy and nuclear energy are some of the developments which have become popular only in the recent years.

The world today is moving towards more energy efficient, sustainable and environment-friendly solutions. This is not very surprising at all, since the generation of electrical energy by the burning of fossil fuel did more harm than good. Burning fossil fuels is one of the primary factors responsible for the increased Green House Gas (GHG) emissions which in turn are the primary cause of global warming. According to United States Energy Information Administration, 32% of Green House Gas

(GHG) emissions in 2016, largest share of which is contributed by generation of electricity through fossil fuels. Over 70% of totally generated electricity is mostly through coal and natural gas fired plants. One of the reasons that today our world is moving towards a more unpredictable climate regime showing variations from the usual climatic patterns (U.S. Engery Information Administration, 2016).

Unfortunately, for Pakistan, the situation is even worse. According to Asian Development Bank (ADB), approx. 2-3% of GDP is cut down due to energy crisis Pakistan is being suffering for last couple of years which in result of circular debt, expensive fuel sources i.e. natural gas and coal and inadequate distribution and transmission network (U.S. Engery Information Administration, 2016). Although Pakistan is not major contributor of Green House Gas emission (GHG), but Pakistan is severely affected by the negative effects of climate changes. Increased floods followed by decreased river flow due to glacier melt, increased drought, increased risk of epidemic, decreased freshwater availability, crop yield and biodiversity are some of the major negative effects of climate change due to which Pakistan is at risk (LEAD, Pakistan).

However, currently Pakistan suffers from yet another major menace Energy Crisis'. The increasing population and industrial development in the country has made it impossible for it to cope with the increased energy demands, the result is an energy crisis on a huge scale. Long hours of power outages have become quite a common sight in the country. This is hampering Pakistan from making any significant progress in the economic sector.

Hydropower has been in use in Pakistan for quite some time and is one of the major contributors to the energy sector of the country. In light of the climate change issues discussed above, it would be most wise for Pakistan to rely upon more environment-friendly and sustainably energy solutions instead of relying upon 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 in a position to afford huge nuclear power plants or vast areas of land and expensive equipment for wind and solar farms. Fortunately, nature has endowed Pakistan with vast resources of hydropower, a large part of which still remains untapped. This may just be one of the solutions to Pakistan's energy crisis situation.

1.2 Research Motivation

The Pakistan suffers from a severe energy crisis. The increasing population and industrial development in the country has made it impossible to meet the energy demand. Although gross installed electricity capacity enhanced during a couple of year but unfortunately gross generation could not be enhanced significantly as mostly fossil fuel fired 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 Jhelum and Indus basins.

1.3 Problem Statement

Evaluating the hydropower potential of an area involves the assessment of two main variables i.e. runoff and head. The determination of head requires topographical maps of the area which further requires extensive on-ground surveys. The northern areas and Azad Kashmir areas of Pakistan are part of a very complex terrain which is often quite inaccessible or dangerous for on-ground surveys. Furthermore, a long time is required for such surveys which further delays the hydropower project and causes an increase in cost, not to mention that these on-ground surveys are can have a high degree of inaccuracy as well, since they are subject to human error. Another problem is that the traditional topographic maps generated using such an approach are not frequently updated. They do not include the changes in vegetation cover, water bodies and other changes in the landscape. This can lead to an inaccurate estimate of the head available for hydropower generation.

Performing this lengthy process for a number of possible hydropower sites causes a waste of both time and resources (Boustani, 2009).

Today, topographic maps of a higher accuracy and a wider coverage are available for free to everyone, by means of remote sensing. Using this type of data in a geographic information system makes it possible for a researcher to narrow down the number of sites on which a detailed assessment for hydropower needs to be made, saving both time and resources. Most of hydropower schemes are major scale and results in number of environmental hazards and other constraints e.g. construction of large scale dam in order to store water, major population migration, disruption of traditional fishing practices, toxic of water quality due to deposition of silt in rivers, release of methane gas etc. (Boustani, 2009). The conventional methods of hydropower site selection mostly ignoring the environmental and social impacts mainly focusing on engineering and economic criteria (Rojanamon et al., 2009).

Minor scale hydropower schemes are an important means of renewable electricity production capacity. If developed wisely, it has minor environmental hazards and enhanced use of such schemes will help to tackle CO^2 emissions thereby overcome Global Warming challenges (Boustani, 2009).

Furthermore, this approach also provides us with an estimate of the hydropower potential at a number of locations at the earliest. Such an approach can help decision-making authorities in making timely decisions in favor of the country's economic benefits.

“ it is need of an hour to identified and develop the hydropower schemes especially at minor scale as it is the only solution to cut down the emissions of CO2, major cause of global warming as it will minimized the burning fossil fuel for generating of electricity and furthermore the current deficit of electricity shortage being faced by country can also be treated efficiently”.

1.4 Research Objectives

The study is conducted to achieve the following objectives:

1. To investigate and develop an approach to evaluate the hydropower potential using Geographic Information System (GIS).
2. To apply the evaluated approach to work out the hydropower potential of the Jhelum and Indus basins in Pakistan.

1.5 Limitations of Study

Limitations of the study are listed below:

- 90m resolution DEM obtained from NASA's Shuttle Radar Topography Mission (SRTM).
- Daily discharge data obtained from Surface Water Hydrology Project WAPDA for available gauge stations in Jhelum and Indus basins.
- Study area extended to Jhelum and Indus including sub-basins located within Pakistan.

1.6 Organization of the Thesis

The thesis has been divided into five chapters. The thesis has been so organized so that after reading this thesis, both researchers and professionals in the field of civil engineering, energy resources engineering, sustainable engineering, geographic information system & remote sensing at a beginner's level or higher can get a knowhow on how to evaluate the hydropower potential of a basin using the approach that is being used in this study. This article and the ones discussed above fall in chapter 1 making readers aware of why there is a need to research in this area, the importance of this research, the limitations of this study and also it highlights the objectives of this research. Chapter 2 gives an introduction to hydropower developments; it introduces the readers to geographic information systems with a particular focus on ArcGIS furthermore, it briefs the readers about the current situation of the energy sector of Pakistan and discusses the problems faced by this sector. Moreover, it reviews previous similar studies conducted by different researchers across the globe. Chapter 3 describes the study area for which the hydropower is being evaluated and also makes discussion about the data collection and processing and also provides the readers with details of the methodology adopted for the purpose of this study. Chapter 4 presents the results and analysis of this study to the readers and discuss their implications. Finally, chapter 5 concludes the thesis and recommendation for the competent authority.

Chapter 2

Literature Review

2.1 Hydropower

2.1.1 An Introduction

Water Power or hydropower is the power derived from the energy of running and falling water. It is a renewable source of energy that is generated from the energy of water falling from higher to lower elevations. It has proven to be a more mature and predictable technology, in addition to being cost-effective. It has a conversion efficiency which is known to be the best among all of the known energy means i.e. about 90% efficiency, water to wire. Its long lifespan and low operation and maintenance costs balances out the high initial cost (IPCC, 2011).

2.1.2 Working Principles of a Hydropower System

Hydropower needs head (difference of elevations difference) and discharge. Water is diverted from a channel into a conduct, where it is directed downhill and then through the turbine (flow). The vertical drop (head) generates pressure at the bottom end of the conduct. The pressurized water existing from the end of the conduct creates the pressure that drives the turbine. In results turbine runs generator where electrical power is generated. More head or discharge results in generation of more electricity. Due to turbine and system inefficiencies, electrical power output will always be slightly less than water power input. Head or Water pressure resultant due to difference of elevation between water intake and turbine (Gatte and Kadhim, 2012).

2.1.3 Plants Without Storage (Run-Off-River)

Run-Off-River hydropower projects abstract the energy for electricity generation mainly from the available discharge of the river. Such a hydropower plant may include some short-term storage (hourly, daily), allowing for some adaptations to the demand profile, but the power generation will depend upon local river flow conditions to varying degrees. As a result, generation depends on runoff and precipitation and may have substantial daily, monthly or seasonal variations. In Run-Off-River projects where even short-term storage is not provided or if they are located on small rivers or channels that experience widely varying flows Run-Off-River hydropower generation will be even more variable. Installation of Run-Off-River hydropower projects is relatively less costly and such installation have, in general, lower environmental hazards as compared with same size storage hydropower projects (IPCC, 2011).

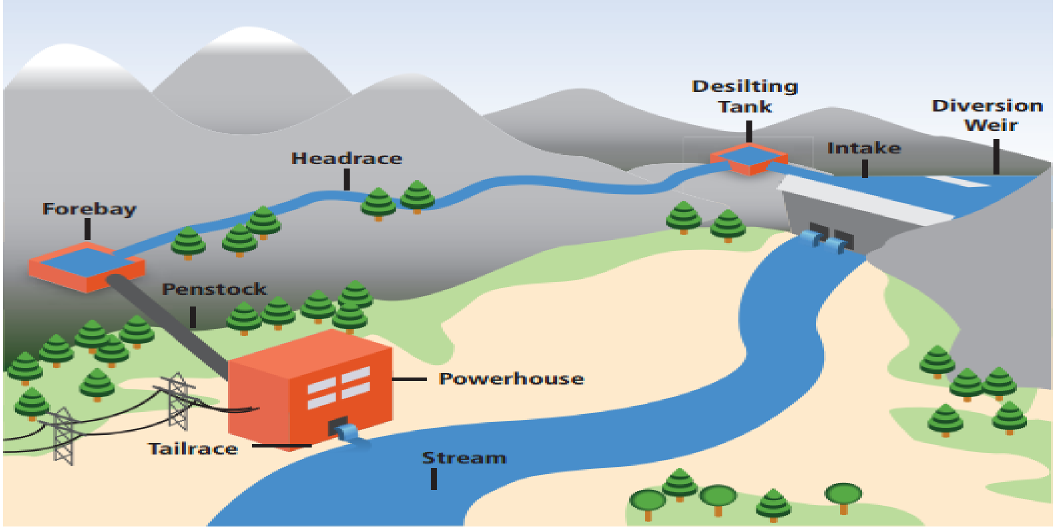


Figure 2.1: Run-Off-River Hydropower Plant (Source: IPCC, 2011)

2.2 An Overview of Geographic Information System

2.2.1 Introduction to Geographic Information System (GIS)

Geographical Information Systems (GIS) are computer operated systems that help users to gather, store and analyze, process and present spatial data.

An electronic representation of information, called spatial data, about the Earth‘s natural and artificial features can be done by using GIS. By using coordinate systems these real world spatial data can be Geo referenced. The real world data can be organized into layer systems. For the purpose of maintenance, analysis and visualization can be stored into different layers by using GIS Systems. For example, layers can show terrain features, population data, ecological, environmental and demographic information data, land use, flood plains and river drainage, roads and rare wildlife habitats. Different applications generate and use different layers. Descriptive information of the map feature which is known as attribute data can also be stored in GIS Systems. The attribute information placed in a database which is separate from graphic data but is connected to them. Attribute and Spatial data can be examined at a time by using GIS.

2.2.2 Arc GIS

Arc GIS is a geographic information system (GIS) for working with geographic information and maps. It is used for; using and creating maps; analyzing mapped information; sharing and discovering geographic information; compiling geographic information; managing geographic information in a database and using maps and geographic information in a range of applications (Wikipedia, 2015).

ArcGIS Desktop v10.5 was used for the purpose of this study. ArcGIS consists of the following product extensions:

- Arc Map
- Arc Catalog
- Arc Toolbox

Using product extensions together, we can perform the full range of GIS tasks including data compilation, geographic data management, and editing, mapping and visualization, and geographic analysis.

2.2.3 Arc Map

Arc Map is the central application in ArcGIS Desktop for manipulation and display of geographic data, including query and selection, mapping and editing (Esri).

Arc Map helps to work and create with map documents. A map document is composed of data frames, symbols, layers, labels, and graphic objects. Arc Map has basically two main windows while working with map documents i.e. display window and table of contents window. The table of contents helps to specify the geographic data that will be drawn in the display window and show the sequence of data drawn in display window. The display window can show either a data view (the geographic data) or a layout view (a page showing how the data and any map elements- such as legends, north arrow, title etc. are arranged).

2.2.4 Arc Catalog

The arc Catalog helps to manage GIS information_ GIS datasets, layer files, map documents and many more. GIS data available in a variety of files and formats. Arc Catalog has associated descriptive information about the geographic features (stored in tables) and information about the datasets, e.g. when the data was gathered, when it was updated, and how accurate it is. Much of information and data get compiled from numerous sources. Arc catalog designed to manage and organize geographic data in various forms (Esri).

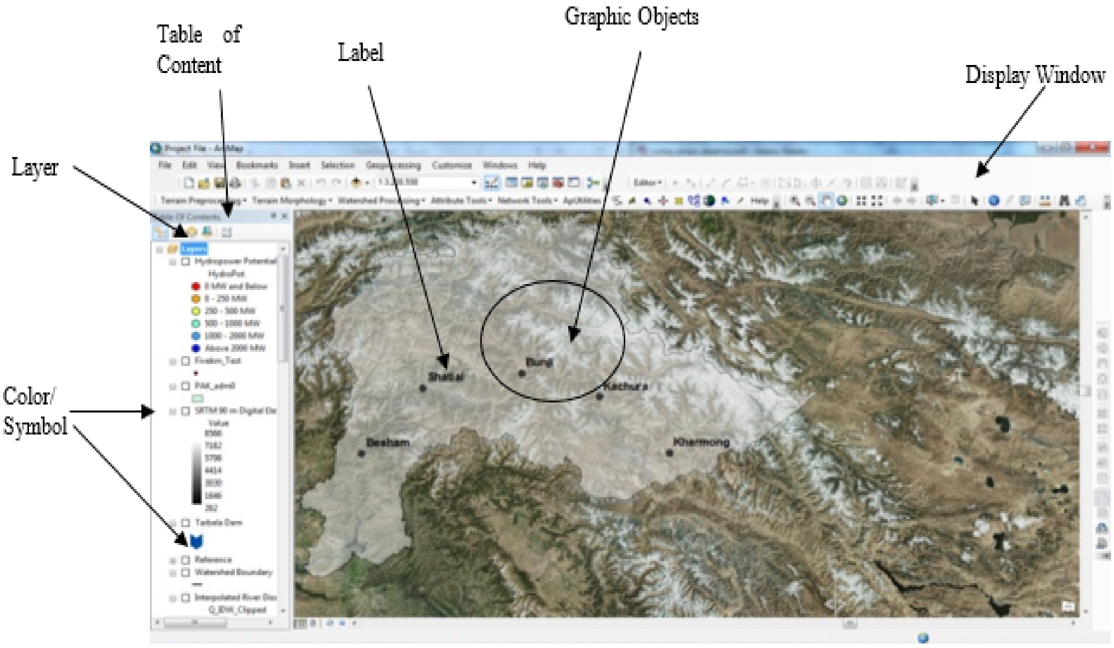


FIGURE 2.2: User Interface of ArcMap 10.5

2.2.5 Arc Toolbox

GIS work mainly involves using Arc Map and Arc Catalog to display, manage and query geographic data. Geoprocessing i.e. processing of geographic data to create new datasets, mostly involve in GIS working. Geo processing involves in all phases of GIS- for compilation, data management, analysis and modeling, for data automation and for advanced cartography. Geo processing operation takes one or more inputs datasets, performs an operation and as a result give the output dataset (Esri).

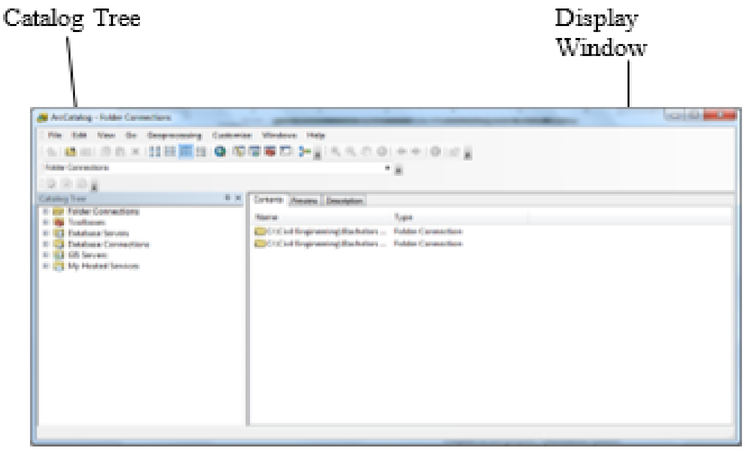


FIGURE 2.3: User Interface of ArcCatalog

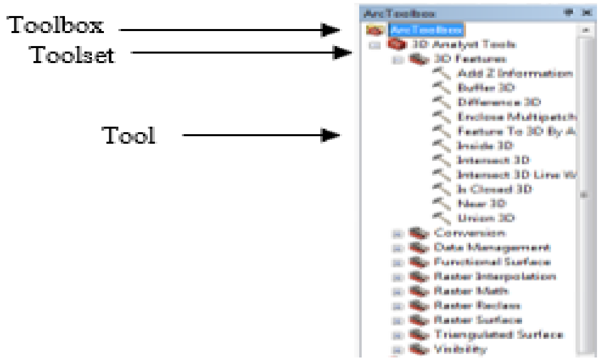


Figure 2.4: User Interface of ArcToolbox

2.2.6 Arc Hydro

Water resource managers use geographic information system (GIS) technology to analyze and visualize hydrologic data for activity such as estimating water availability, planning flooding prevention, assessing water quality, managing water resources and understanding the natural environment (Esri).

Water resource analysis in ESRI Arc GIS software make use of Arc Hydro tools as a starting point and can be downloaded free of cost via the Hydro resource center at resources.arcgis.com/en/communities/hydro.

Arc hydro is a template data model for water resource, updated and developed by pioneers of industry, academia and government. Arc hydro is a GIS data structure that connects water resource modeling to hydrologic data. Dataset built by using Arc hydro can be integrated with water resource models. Water data structures can be standardizes using Arc hydro data model so that data can be used efficiently and consistently to solve water resource issues at any spatial scale. Own built data model can be integrated with Arc hydro tools.

The Arc Hydro data model is complemented by a set of tools for building Arc Hydro-compliant datasets and running the data model. Arc Hydro tools work within ArcGIS for Desktop, but some also require the ArcGIS Spatial Analyst extension. ArcHydro can be used tools to do the following:

- Constructing relationships between core spatial layers.
- Populate and generate Arc hydro geo database from raster and vector data sources.
- Advanced water resource functions can be performed (e.g. watershed characterization and delineation).
- Applying geometric networks for downstream and upstream tracing and resource accumulation.
- Use an XML data exchange framework for data integration with external models.
- Help to develop node-link hydro schema.

Arc Hydro offers menus, toolbars and geo processing tools that helps to model and create an integrated data environment in Arc GIS. Standard Arc GIS and Arc Hydro processing tools to build our own water resource geo processing models, which can be used in web and desktop environment.

2.3 Importance of Hydropower Resources from a Global Perspective

Power derived from the kinetic and potential energy of running and falling water called hydropower. Hydropower has long been used as a renewable source of energy. Hydropower is no doubt one of the oldest methods of producing power. The energy from moving water is used to run the turbines connected to a generator in turn generating electricity, more commonly known as hydroelectricity. About 15 % of the total electricity production of the world is generated through hydropower making its widely used renewable sources of energy. Hydropower has been and is still one of the most important CO^2-free sources for electricity generation globally. The share of hydropower in the total renewable-based electricity generation was more than 68 % in 2016. Asia, in particular China, and North and South America, currently dominate the hydropower scene. The share of the Asian/Pacific region in the worldwide hydropower based electricity generation was 40 % in 2016, followed by America with a share of 34% (International Hydropower Association, 2017). In 2016, a total of 4,102 TWh of hydropower was generated as compared to 2,286 TWh in 1993, the greatest ever contribution from a renewable source (World Energy Council, 2017). Nonetheless, a large demand for energy is still met by burning fossil fuels such as coal, oil, natural gas etc. However, due to the serious environmental hazards associated with these sources and the depleting fossil fuel reserves, these sources cannot be relied upon as a sustainable source of energy. According to the (U.S. Energy Information Administration 2016), 32% of the greenhouse gas (GHG) emissions in 2016 were as a result of electricity generation, over 70% of which results from the burning of fossil fuels, mostly natural gas and coal. Due to these adverse effects, the world today is moving towards the development of more sustainable and eco-friendly energy sources, of which hydroelectric power has a significant potential.“ The World Energy Councils global scenarios work indicates that the electricity generation on the basis of hydropower will rise between two thirds and four quarters by 2060. That results in a nearly stable share of hydropower in the total global electricity generation, which accounted for 16% in 2016. The CO^2 emissions avoided thanks to the use of hydropower are estimated to amount t0 3.3 billion tons annually. From 2015 to 2060 hydropower will help avoid approximately 150 billion tons of CO^2 emissions globally”(International Hydropower Association, 2017). There is still a lot of hydropower potential at global level that can be exploited, which will increase the importance of hydropower in achieving the central energy policy and climate targets. The advantage of minor scale hydropower projects are use of small area, use of local labors and resources, short period of planning and construction, less generation cost of per unit and above all ease of smaller investment (Rojanamon et al., 2009).

2.4 Current Situation in Pakistan

Pakistan relies largely upon hydroelectric power for meeting its energy requirements. In 2015, the country generated 1% from imported electricity from Iran, 5% from nuclear and wind, 30% from hydro, 29% from natural gas and 35% of its electricity from oil. (U.S. Energy Information Administration, 2016). The country has a total power generation capacity of about 25,000 MW, increased 5% from 2014 to 2015, and mainly due to addition of coal fired plants installed under CPEC. Although the installed capacity enhanced, power plants have faced low utilization rates mainly due to chronic natural gas, fuel shortages, expensive fuel sources and circular debt the gross generation capacity is approximately 17000 against an average demand of 21000 MW. In other words, the country suffers from a shortfall of around 4000 MW (U.S. Energy Information Administration, 2016). This shortfall has been the cause of severe power outages throughout the country, hampering the countrys economic growth. In 2015, China and Pakistan signed, the China-Pakistan Economic Corridor (CPEC) agreement, due to which Pakistan would able to overcome electricity shortage and decrease cost of electricity generation by 2020. The agreement helps to alleviate electricity shortage as it also include $34 billion of investment from China will utilize for developing energy infrastructure, also involve setting of 10400 MW capacity power plants from renewable energy and coal. This calls for the identification of potential hydropower development sites in order to meet the energy deficit, being a sustainable and economical solution to the countrys energy crisis.

According to Water and Power Development Authority (WAPDA), there is gross hydropower potential of 60,000 MW in Pakistan, out of which only 7320MW has been developed so far. Most of the untapped hydropower potential lies in the mountainous north along the Indus River in the province of Gilgit-Baltistan and Jhelum River in the provinces of Azad Jammu and Kashmir and Punjab.

In 1991, the hydropower underpinned the countrys power sector, accounting for 45% of total power generation, but this contribution suddenly dropped to about 28% as short term thermal fired plants are preferred over hydropower schemes.

It is estimated that the hydropower potential will contribute up to 40% of the total electricity generation by 2030, and will help to alleviate electricity shortage. (International Hydropower Association, 2017).

2.5 History of Hydropower Development in Pakistan

Initiative of hydropower development with the construction of 1 MW Renala Khurd hydropower station in 1925. After 10 years, 1.7 MW Jaban (Malakand-I) hydropower project was constructed which was later upgraded to a 20MW capacity. Afterwards, Dargai (Malakand-II) hydropower project was commissioned in 1953. When Pakistan came into being in 1947, Pakistan inherited a very small power capacity of only 60 MW for its 31.5 million populations. The countrys total hydropower capacity was enhanced to 119 MW, after creation of WAPDA in 1958. In 1960, Indus Basin Water treaty was signed, Pakistan was entitled to 142MAF (Chenab 26, Jhelum 23 and Indus 93) of surface water. Afterwards, Tarbela Hydropower project of 3478MW, Mangla Hydropower project 1000MW and 240MW of Warsak Hydropower project brings revolution in the energy sector of Pakistan. Hydropower schemes in Pakistan completed so far, also include 1450 MW Ghazi Barotha, 81 MW Malakand-III , 184 MW Chasma, 18 MW Naltar and 30MW Jagran hydropower schemes . The total installed capacity of hydropower projects in the Country till 2011 was 6720 MW, out of which 1699 MW in Punjab, 1039MW in A&JK, and 133MW in Gilgit-Baltistan and 3849MW in Khyber Pakhunkhwa. (Private Power and Infrastructure Board, 2011). Recently on 14th August, 2018 another milestone in the development of hydropower schemes in Pakistan is achieved by commissioning of Neelum Jhelum Hydropwer scheme. The Neelum Jhelum hydropower is basically a Run-Off-River plant. The power station of this plant is located in (Independent) Azad Kashmir, approx. 42 km south of Muzaffarabad and total installed capacity is 969 MW. It will generate 5,150,000 MW per annual at the levelised traffic of Rs. 13.50 per unit for 30 years

(Wikipedia). Whereas now in 2018 its up to 7320MW and abundant hydropower potential is still need to be harnessed.

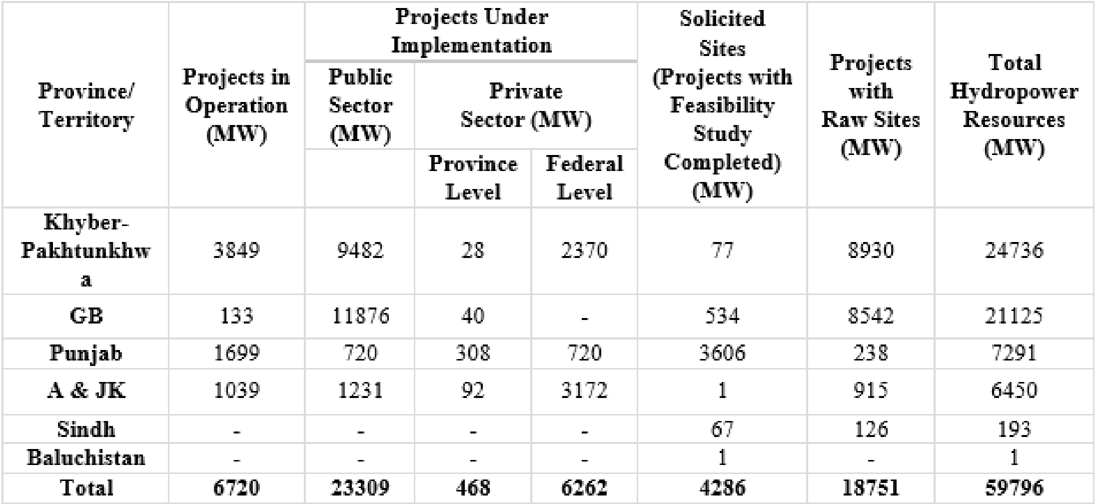
2.6 Recent Development in Hydropower Sector

In Pakistan, several hydropower schemes were constructed and commissioned in 2016, most of which located in Khyber Pakhtunkhwa (KPK) e.g. Machai (2.6 MW), Daral Khwar (37 MW) and Ranolia (17 MW). With the support of Asian Development Bank (ADB), KPK government took an initiative to installed 1000 micro hydropower schemes around the province. The total installed hydroelectric generation capacity of 100MW, such a micro hydropower schemes are designed to facilitate rural, off-grid communities by providing reliable and affordable electricity. Several Schemes are currently under construction and several are under planning phase in the private sector, overseen by the Private Power & Infrastructure Board, including Kohala (1124MW), Karot (720 MW) and Suki (870 MW). The above mentioned projects are a part of the China Pakistan Economic Corridor (CPEC) under which China invested about $34 billion for the development of energy infrastructure. This will boost the economy of the Pakistan.

Currently the public sector projects completed recently include Golen Gol (106 MW), 4th extension of Tarbela. While Neelum-Jhelum (969 MW) is near completion and Dasu (4320 MW) construction just started to meet the increasing energy demand of country.

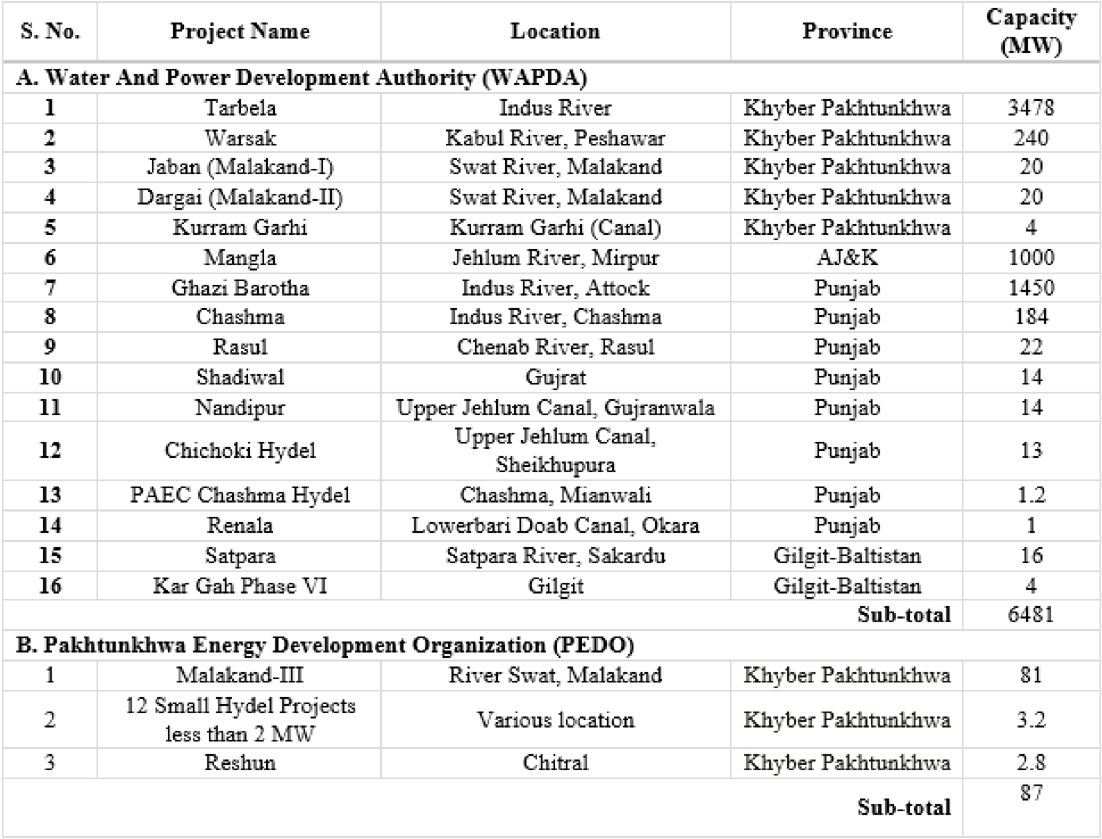
Present government major emphasis is on the development of long term hydropower schemes and in order to fulfill this desire, the government is focusing heavily on foreign donating agencies (e.g. World Bank, Asian Development Bank), foreign investment from private investors, and foreign governments.

Table 2.1: Summary of Hydropower Resources in Pakistan (Source: Private Power and Infrastructure Board, Government of Pakistan, 2011)

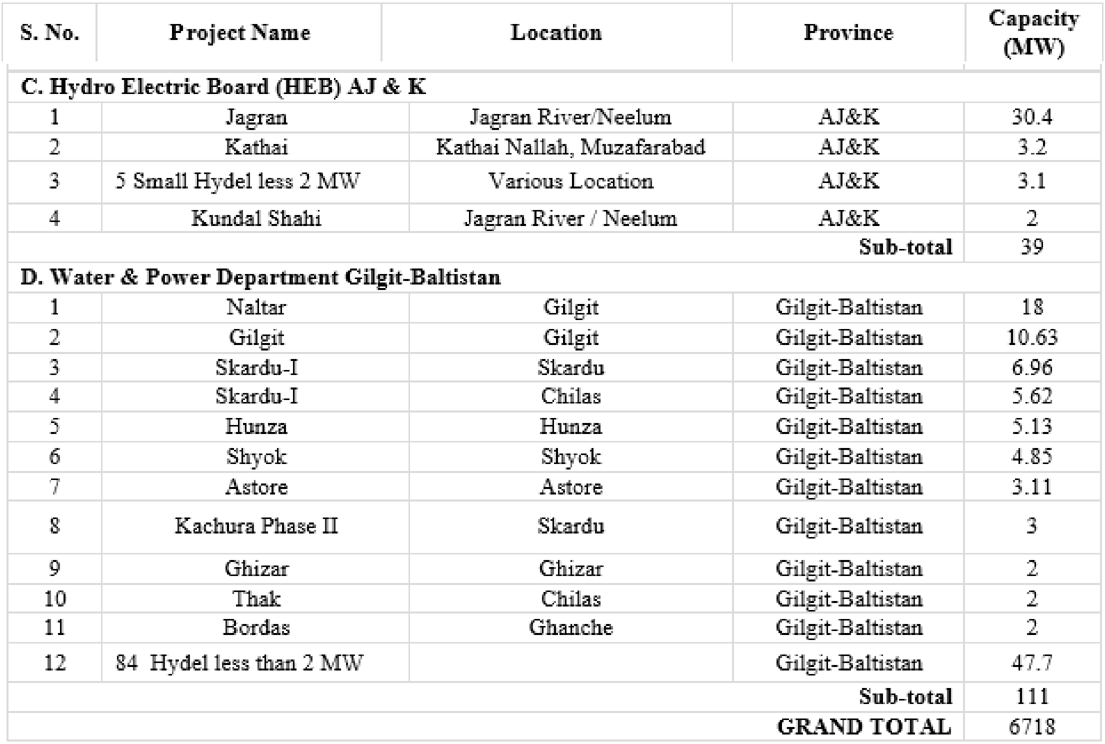


Province/ Territory	Projects in Operation (MW)	Projects Under Implementation			Solicited Sites (Projects with Feasibility Study Completed) (MW)	Projects with Raw Sites (MW)	Total Hydropower Resources (MW)
		Public Sector (MW)	Private Sector (MW)				
			Province Level	Federal Level			
Khyber-Pakhtunkhwa	3849	9482	28	2370	77	8930	24736
GB	133	11876	40	-	534	8542	21125
Punjab	1699	720	308	720	3606	238	7291
A & JK	1039	1231	92	3172	1	915	6450
Sindh	-	-	-	-	67	126	193
Baluchistan	-	-	-	-	1	-	1
Total	**6720**	**23309**	**468**	**6262**	**4286**	**18751**	**59796**

Table 2.2: Existing Hydropower Projects in Operation in Pakistan (Source: Private Power and Infrastructure Board, Government of Pakistan, 2011)



S. No.	Project Name	Location	Province	Capacity (MW)
A. Water And Power Development Authority (WAPDA)				
1	Tarbela	Indus River	Khyber Pakhtunkhwa	3478
2	Warsak	Kabul River, Peshawar	Khyber Pakhtunkhwa	240
3	Jaban (Malakand-I)	Swat River, Malakand	Khyber Pakhtunkhwa	20
4	Dargai (Malakand-II)	Swat River, Malakand	Khyber Pakhtunkhwa	20
5	Kurram Garhi	Kurram Garhi (Canal)	Khyber Pakhtunkhwa	4
6	Mangla	Jehlum River, Mirpur	AJ&K	1000
7	Ghazi Barotha	Indus River, Attock	Punjab	1450
8	Chashma	Indus River, Chashma	Punjab	184
9	Rasul	Chenab River, Rasul	Punjab	22
10	Shadiwal	Gujrat	Punjab	14
11	Nandipur	Upper Jehlum Canal, Gujranwala	Punjab	14
12	Chichoki Hydel	Upper Jehlum Canal, Sheikhupura	Punjab	13
13	PAEC Chashma Hydel	Chashma, Mianwali	Punjab	1.2
14	Renala	Lowerbari Doab Canal, Okara	Punjab	1
15	Satpara	Satpara River, Sakardu	Gilgit-Baltistan	16
16	Kar Gah Phase VI	Gilgit	Gilgit-Baltistan	4
			Sub-total	6481
B. Pakhtunkhwa Energy Development Organization (PEDO)				
1	Malakand-III	River Swat, Malakand	Khyber Pakhtunkhwa	81
2	12 Small Hydel Projects less than 2 MW	Various location	Khyber Pakhtunkhwa	3.2
3	Reshun	Chitral	Khyber Pakhtunkhwa	2.8
			Sub-total	87



S. No.	Project Name	Location	Province	Capacity (MW)
C. Hydro Electric Board (HEB) AJ & K				
1	Jagran	Jagran River/Neelum	AJ&K	30.4
2	Kathai	Kathai Nallah, Muzafarabad	AJ&K	3.2
3	5 Small Hydel less 2 MW	Various Location	AJ&K	3.1
4	Kundal Shahi	Jagran River / Neelum	AJ&K	2
			Sub-total	39
D. Water & Power Department Gilgit-Baltistan				
1	Naltar	Gilgit	Gilgit-Baltistan	18
2	Gilgit	Gilgit	Gilgit-Baltistan	10.63
3	Skardu-I	Skardu	Gilgit-Baltistan	6.96
4	Skardu-I	Chilas	Gilgit-Baltistan	5.62
5	Hunza	Hunza	Gilgit-Baltistan	5.13
6	Shyok	Shyok	Gilgit-Baltistan	4.85
7	Astore	Astore	Gilgit-Baltistan	3.11
8	Kachura Phase II	Skardu	Gilgit-Baltistan	3
9	Ghizar	Ghizar	Gilgit-Baltistan	2
10	Thak	Chilas	Gilgit-Baltistan	2
11	Bordas	Ghanche	Gilgit-Baltistan	2
12	84 Hydel less than 2 MW		Gilgit-Baltistan	47.7
			Sub-total	111
			GRAND TOTAL	6718

2.7 GIS and Hydropower Development

Over the years, Geographic Information Systems (GIS) have proven to be an efficient tool in the identification of potential sites for hydropower development. Such tools can supplement or in some cases completely replace the on ground surveys, necessary for identifying suitable sites for hydropower development, due the topographic inaccessibility. Different studies and research have been done in various parts of the globe on the application of GIS for identifying potential sites for economical hydropower projects.

A study conducted in South Africa discussed the primary assessment of hydropower potential in South Africa by calculating runoff and slope from digital map in order to estimate the actual energy potential. The study used coefficient of variation and low flow indices as potential measures of flow variability and risk. This allowed the rapid evaluation of both the micro and macro hydropower potential (Balance et al., 2000). Another study in Ethiopia evaluated the hydropower potential associated with various pre-selected sites and narrowed down the number of potential sites, based on the possibility of developing on that site, in a GIS environment (Desalegn et al., 2007). Another study suggests a customization in ArcGIS Explorer 900 using SDK in .net framework in order to create an intuitive interface for 3D visualization of identified potential hydropower sites in Alaknanda and Bhagirathi river valleys of Uttrakhand, India (Babu et al., 2010). (Larentis et al. 2010) have presented a methodology for macro scale survey of hydropower potential sites to be applied in the starting phase of hydroelectric development planning. This methodology involves the identification of suitable hydropower sites based on regional stream flow data and remote sensing and was automated in a GIS-based computational program: Hydrospot. This study claims to have a greater potential for spotting hydropower sites than through a traditional survey. This approach also discusses the hydropower potential for different types of dam-hydropower layouts and two types of projects: Run-Off-River and storage projects. Buehler (2011) discussed the design of an ArcGIS toolset to estimate the flow duration curves (FDCs) at locations where data do not exist, helping in deciding the most suitable site for small hydroelectric power development in the Dominican Republic. (Jha 2011) worked out the Run-Off-River type hydropower potential of Nepal by incorporating GIS and a hydropower model, written by the author himself, in FORTRAN programming language. GIS was used for preprocessing of the SRTM (Shuttle Radar Topographic Mission) to generate the stream network and for catchment delineation.

Several studies about climate change have been for Indus and Jhelum basin e.g. (Mahmood & Jia, 2016) made study on Jhelum river basin concludes that half of the annual flow in the catchment will pass by the Azad Pattan discharge gauge station one week earlier than it does now. Similarly, (Moiz, et al 2018) researched that annual precipitation has more decreasing rate in higher altitude catchment and annual stream flows are increasing due to raise of temperature results in melting of glaciers. Furthermore, (Khan, et al 2015) concludes that annual runoff showed an upwelling trend for river Shyok (at Yogo), Shigar (at Shigar) and Indus (at Kachura) upto 9%, 7% and 5% respectively due to warming trend of annual temperature upto 5% (1'C). Several researchers reviewed and compared different software tools developed throughout the past for the planning and design of micro hydropower schemes (Punys et al., 2011). The reviewed tools varied from simple initial estimates to quite sophisticated software. This study covered the software tools developed by various countries e.g. US, Norway, Scotland, Canada and the Italy and concluded that traditional assessment can be facilitate to great extent using GIS techniques that involve the spatial variability of catchment characteristics. A Case Study of Hokkaido, Northern-Tohoku Area and Tokyo Metropolitan, Japan discusses an approach for using GIS along with simulation of meteorological parameters for evaluating the potential of many different forms of renewable energy such as wind energy, mini-micro hydropower, solar power, geothermal energy and biomass energy (Wakeyama and Ehara, 2011). (Feizizadeh and Haslauer 2012) have explained the use of local topographic, monthly evaporation and precipitation data in a GIS-based environment for evaluating the hydropower potential of Tabriz Basin, Iran. The study basically involves the use of GIS-based hydrological modelling using topographical and meteorological datasets for simulating stream flow. Another study discusses the assessment of natural stream sites of hydroelectric dams in the Pacific Northwest Region (Hall et al., 2012). This approach uses EDNA DEM for evaluating the hydraulic head used in evaluating the hydropower potential. (Gergeov et al. 2013) evaluated the hydropower potential of Hornad Basin by using SRTM DEM for evaluating hydraulic head and interpolated the meteorological parameters in space by using Inverse Distance Weighting (IDW). Their evaluation also took into account site restrictions and land use changes by incorporating Natura 2000, UNESCO, RESERVOIRS, Land use and other data sources in their study. (Pudashine, 2013) evaluated the hydropower potential of Dudh Koshi Basin, Nepal by using GIS for catchment delineation and stream network generation, and SWAT model for simulating runoff. The study also took into account the various land use changes and also discussed the spotting of promising Run-Off-River and reservoir storage developments. Furthermore, it also evaluated the hydropower potential of the basin for various IPCC future climate change scenarios. Run-Off-River hydropower potential of Kunhar River in Pakistan by taking discharge analysis was aimed at plotting flow duration curve (FDC) and calculating 40, 50 and 60 percentile discharges (Q40, Q50, and Q60 respectively) using historical flow data and calculated at 500m along the kunhar river (Zaidi, 2015). (Wali 2013) presented an approach for evaluating the hydropower potential of an ungauged stream. The approach uses flow data of an analogue site to generate the data of an ungauged river. The study uses DEM in ArcGIS for determining the relative position of the component of the hydropower plant and its net available head. A more recent study conducted in Ethiopia assesses the feasibility of micro hydropower schemes in Worie Sub basins and Giba of Tekeze River, Ethipoia using runoff coefficient method for estimating the discharge of ungauged catchments. Topographic map and DEM were used for measurement civil work components, calculating area of contributing catchments, construction of Thiessen Polygon network, and analyzing watershed delineation, river networks, location of potential sites and gauging stations using Global Mapper and GIS. The viability of the hydropower potential sites was analyzed using RETScreen software (Abebe, 2014). One GWh of electricity generated by installing a micro hydropower schemes means a reduction of CO^2 emissions by 480 tons. (Rojanamon et al., 2009)

2.8 Summary

It can be concluded that a variety of different GIS-based approaches exist for evaluating the hydropower potential of a given basin/ sub-basin. These approaches have been developed for various countries across the globe. An IDW based evaluation of hydropower potential have been carried out for the Indus river of Pakistan but the trend of discharge are not logical and hence another approach i.e. ratio proportion approach using GIS to sort out the gross theoretical hydropower for the Jhelum and Indus basins. To the best of authors knowledge, electrical storage being faced by the country can only be overcome by erecting hydropower schemes to generate cheap and CO^2 free electricity.

Chapter 3

Study Area, Data Collection and Research Methodology

3.1 Study Area

The study areas are consisting of two catchments.
First study area is located between the longitudes of $72^0$15’00”E to $77^0$50’00”E and latitudes of $33^0$50’00”N to $37^0$05’00”N which is a portion of the Upper Indus Basin (UIB), falling within the boundaries of Pakistan (Figure 3.1). Hindukush-Karakorum-Himalaya (HKH) region constitutes a large part of the basin. The study area has been determined to have a size of nearly 79,372 km^2, much of which falls within the northernmost administrative territory of Pakistan, Gilgit-Baltistan and the elevation in the basin ranges between 277m to 8,566m. The basin is basically the catchment area of the Indus River, upstream of the Tarbela Reservoir which is the country’s largest reservoir. Along the way, Indus River is joined by many small and large tributaries, most prominent of which are Shyok River, Shigar River, Hunza River, Gilgit River and Astore River.

The second study area is Upper Jhelum Basin (UJB) the longitudes of $73^0$00’00”E to $76^0$00’00”E and latitudes of $33^0$00’00”N to $35^0$15’00”N situated in the (N-E) of Pakistan, a highly elevated area, as illustrated in (Figure 3.2). River Jhelum is the largest stream of Jhelum Basin. The Jhelum River, along with Neelum, Kunhar, poonch and kanshi Rivers, the major streams of the Jhelum River, drain the northern slope of the Pir Punjal Mountains and the southern slope of the Greater Himalayas located in Jammu and Kashmir (Figure 3.2). The elevation of the basin ranges between 214m to 6285m and the total area of the basin is about 17,484 km^2.The basin is basically the catchment area of the Jhelum River, upstream of the Mangla reservoir which is the country's second largest reservoir.

Stream flow in River Indus is subject to extreme seasonal variability with snowmelt and glacier runoff being the primary contributors to the runoff in the higher parts of the basin (Ali and Boer, 2007). The river is fed by rainfall runoff in the lower parts of the basin. However, more than 60% of the annual runoff in the UIB basin is attributable to snowmelt in HKH region (Bookhagen and Burbank, 2010). The Upper Indus region has several mountain peaks exceeding 7000 m and possesses the greatest perennial glacial ice area of over 22,000 km^2, outside the Polar Regions (Sharif et al., 2013). The climate of the Indus basin is very sensitive to altitude. The basin has a mean elevation of 4750 m, of which 60% area is above an elevation of 4500 m and 15% above 4750 m (Tahir, 2011). Annual precipitation typically varies from 100 to 200 mm at low altitudes and can be in excess of 600 mm at an elevation of above 4400 m (Cramer, 1993). The basin is marked with low temperatures with mean monthly temperature going below freezing from October to March at locations where elevation is above 3000 m (Archer and Fowler, 2004). Available head for Small Run-Off-River Hydropower Plants has critical influence on its performance. Maximum head with a short water way as possible within Basin is considered to maximize Power generation parallel reduction in plant cost.

The extreme weather patterns and difficult terrain are the primary reasons for the sparse population in the basin.

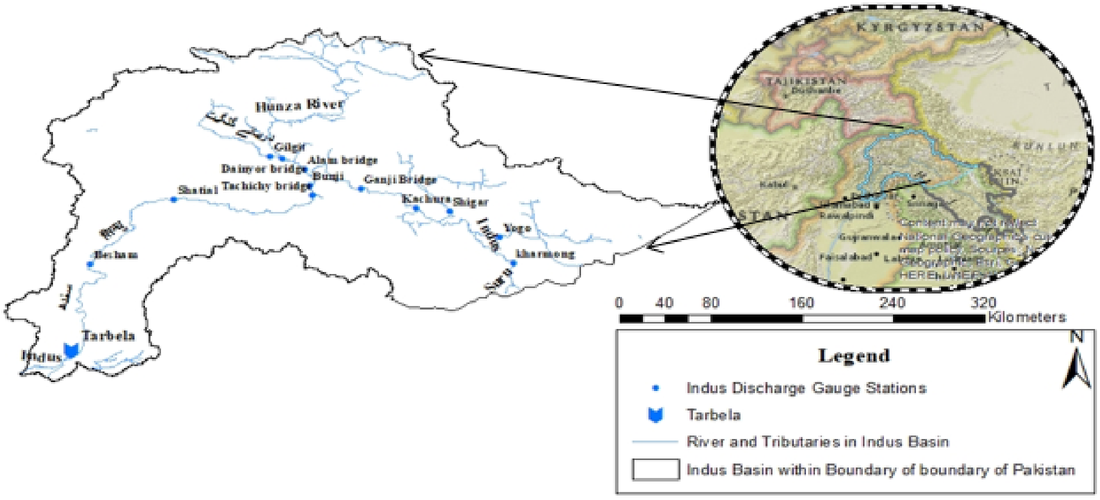


FIGURE 3.1: Location of 1st Study Area i.e. Upper Indus Basin (UIB) in Pakistan, its Boundaries and River System

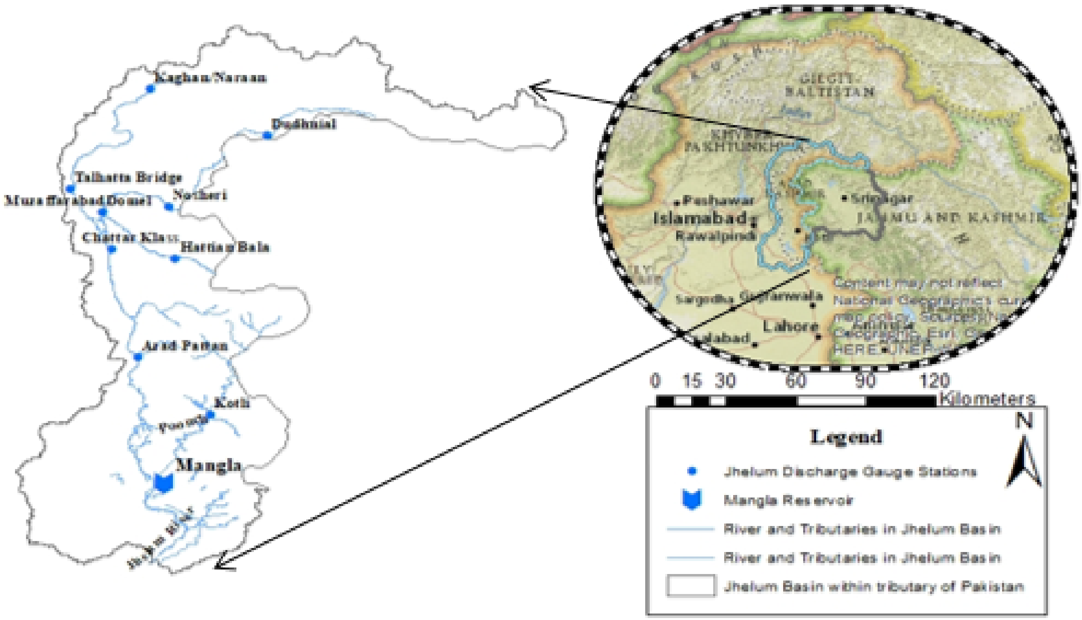


FIGURE 3.2: Location of 2nd Study Area i.e. Upper Jhelum Basin (UJB) in Pakistan, its Boundaries and River System

3.2 Data Collection

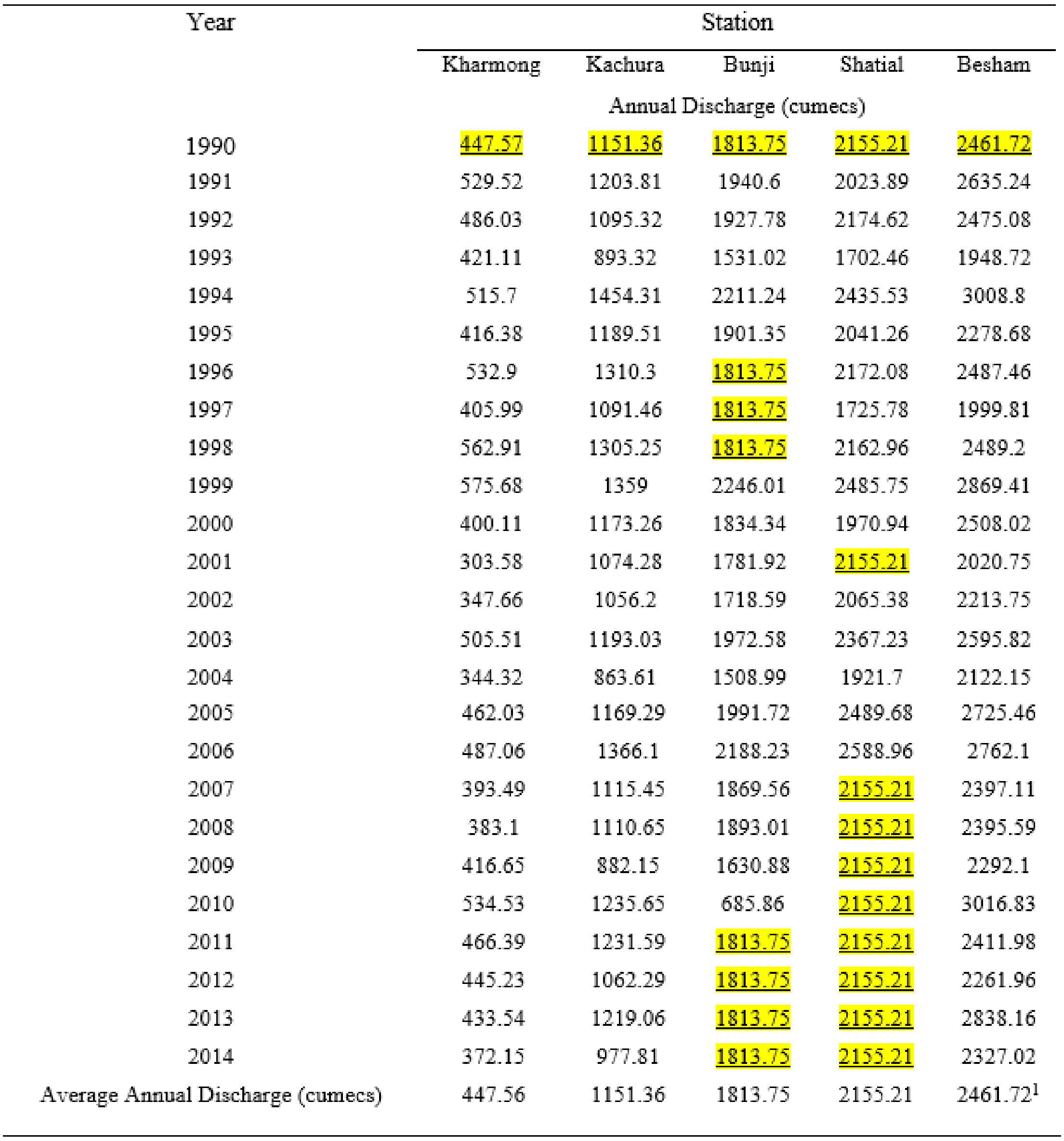
This study makes use of two types of datasets, the stream flows data and the Topographic data. The source, collection and processing prior to analysis of both these datasets is discussed in the following articles.

3.2.1 Stream Flows Data

The daily stream flow data for the period of 1990 2014 was acquired from Surface Water Hydrology Project sub division of Water and Power Development Authority (WAPDA), Sunny View Complex Lahore, Pakistan for the five stream gauging stations namely, Kharmong, Kachura, Bunji, Shatial and Besham, located within the 1st study area, as shown in Figure 3.1. While four stream gauging stations namely, Hattian Bala, Domel, Chattar Klass and Azad Pattan, located within the 2nd study area,as shown in Figure 3.2, the stream gauge stations of Hattian Bala and Chattar Klass were installed and operational in 1997 so the data for the period from 1990-1996 obtained from nearly installed stream gauge stations namely Chinari and Kohala, respectively. Average annual flows were then calculated using this data at each of the gauging stations. Table 3.1 shows the annual discharge at each of above five stations for Indus River, derived from daily discharge data. Table 3.2 shows the annual discharge at each of above four stations for Jhelum River, derived from daily discharge data.

Figure 3.3 shows the yearly variation in stream flows over the five gauging stations at Indus River under discussion namely, Kharmong, Kachura, Bunji, Shatial and Besham while Figure 3.4 shows the yearly variations in stream flows over the four gauging stations at Jhelum River under discussion namely, Hattian Balla, Domel, Chattar Klass and Azad Pattan.

TABLE 3.1: Average Annual Discharge at the Five Gauging Stations within Indus River Study Area(Obtained from SWHP WAPDA)

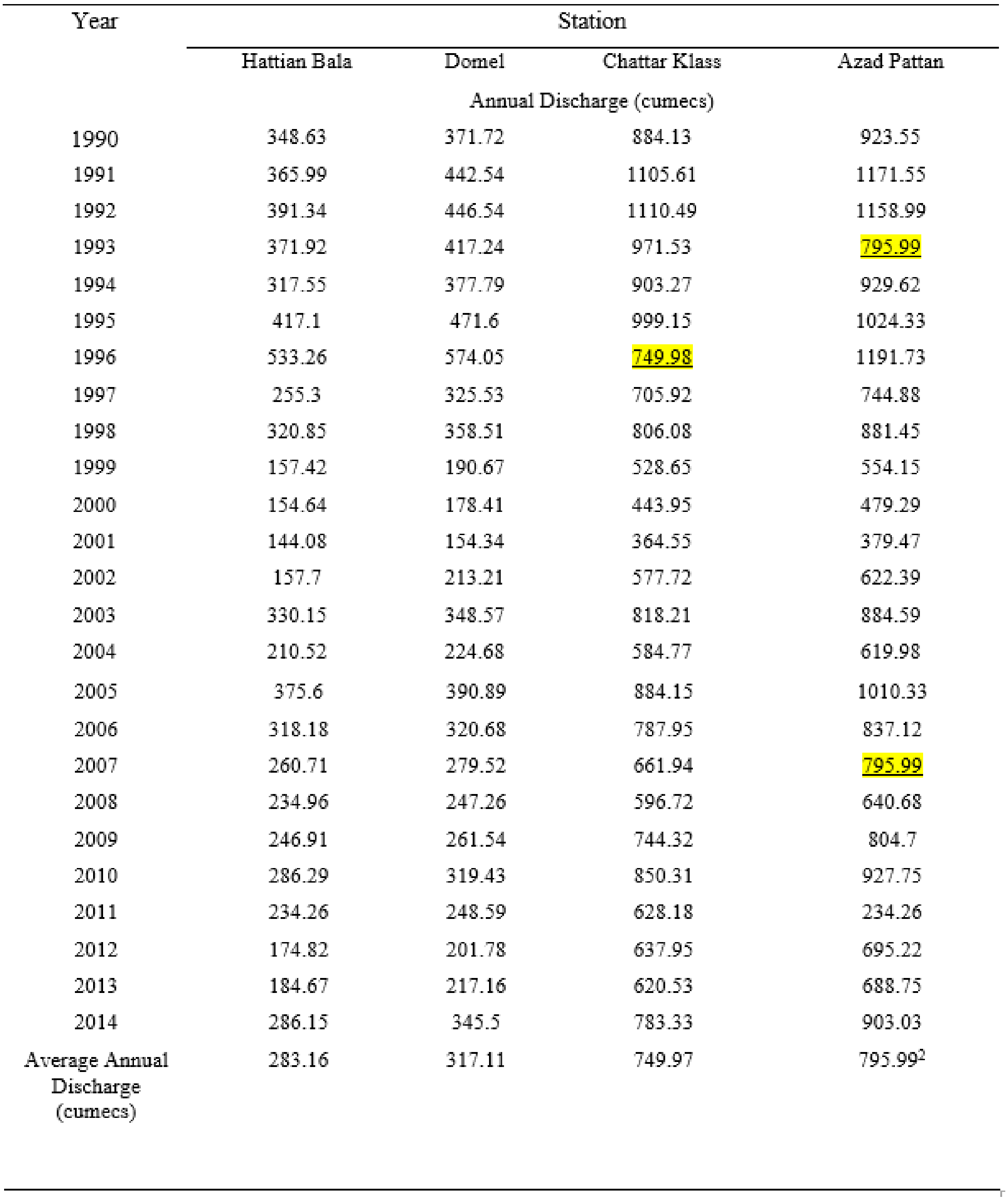


Year	Station				
	Kharmong	Kachura	Bunji	Shatial	Besham
	Annual Discharge (cumecs)				
1990	447.57	1151.36	1813.75	2155.21	2461.72
1991	529.52	1203.81	1940.6	2023.89	2635.24
1992	486.03	1095.32	1927.78	2174.62	2475.08
1993	421.11	893.32	1531.02	1702.46	1948.72
1994	515.7	1454.31	2211.24	2435.53	3008.8
1995	416.38	1189.51	1901.35	2041.26	2278.68
1996	532.9	1310.3	1813.75	2172.08	2487.46
1997	405.99	1091.46	1813.75	1725.78	1999.81
1998	562.91	1305.25	1813.75	2162.96	2489.2
1999	575.68	1359	2246.01	2485.75	2869.41
2000	400.11	1173.26	1834.34	1970.94	2508.02
2001	303.58	1074.28	1781.92	2155.21	2020.75
2002	347.66	1056.2	1718.59	2065.38	2213.75
2003	505.51	1193.03	1972.58	2367.23	2595.82
2004	344.32	863.61	1508.99	1921.7	2122.15
2005	462.03	1169.29	1991.72	2489.68	2725.46
2006	487.06	1366.1	2188.23	2588.96	2762.1
2007	393.49	1115.45	1869.56	2155.21	2397.11
2008	383.1	1110.65	1893.01	2155.21	2395.59
2009	416.65	882.15	1630.88	2155.21	2292.1
2010	534.53	1235.65	685.86	2155.21	3016.83
2011	466.39	1231.59	1813.75	2155.21	2411.98
2012	445.23	1062.29	1813.75	2155.21	2261.96
2013	433.54	1219.06	1813.75	2155.21	2838.16
2014	372.15	977.81	1813.75	2155.21	2327.02
Average Annual Discharge (cumecs)	447.56	1151.36	1813.75	2155.21	2461.72[1]

---

[0] Showing the yearly variations of discharge at 5 gauge stations in Indus River extract from daily discharge data.

Table 3.2: Average Annual Discharge at the Four Gauging Stations within Jhelum River Study Area (Obtained from SWHP WAPDA)



Year	Station			
	Hattian Bala	Domel	Chattar Klass	Azad Pattan
	Annual Discharge (cumecs)			
1990	348.63	371.72	884.13	923.55
1991	365.99	442.54	1105.61	1171.55
1992	391.34	446.54	1110.49	1158.99
1993	371.92	417.24	971.53	795.99
1994	317.55	377.79	903.27	929.62
1995	417.1	471.6	999.15	1024.33
1996	533.26	574.05	749.98	1191.73
1997	255.3	325.53	705.92	744.88
1998	320.85	358.51	806.08	881.45
1999	157.42	190.67	528.65	554.15
2000	154.64	178.41	443.95	479.29
2001	144.08	154.34	364.55	379.47
2002	157.7	213.21	577.72	622.39
2003	330.15	348.57	818.21	884.59
2004	210.52	224.68	584.77	619.98
2005	375.6	390.89	884.15	1010.33
2006	318.18	320.68	787.95	837.12
2007	260.71	279.52	661.94	795.99
2008	234.96	247.26	596.72	640.68
2009	246.91	261.54	744.32	804.7
2010	286.29	319.43	850.31	927.75
2011	234.26	248.59	628.18	234.26
2012	174.82	201.78	637.95	695.22
2013	184.67	217.16	620.53	688.75
2014	286.15	345.5	783.33	903.03
Average Annual Discharge (cumecs)	283.16	317.11	749.97	795.99[2]

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[0] Showing the yearly variations of discharge at 4 gauge stations in Jhelum River extract from daily discharge data.

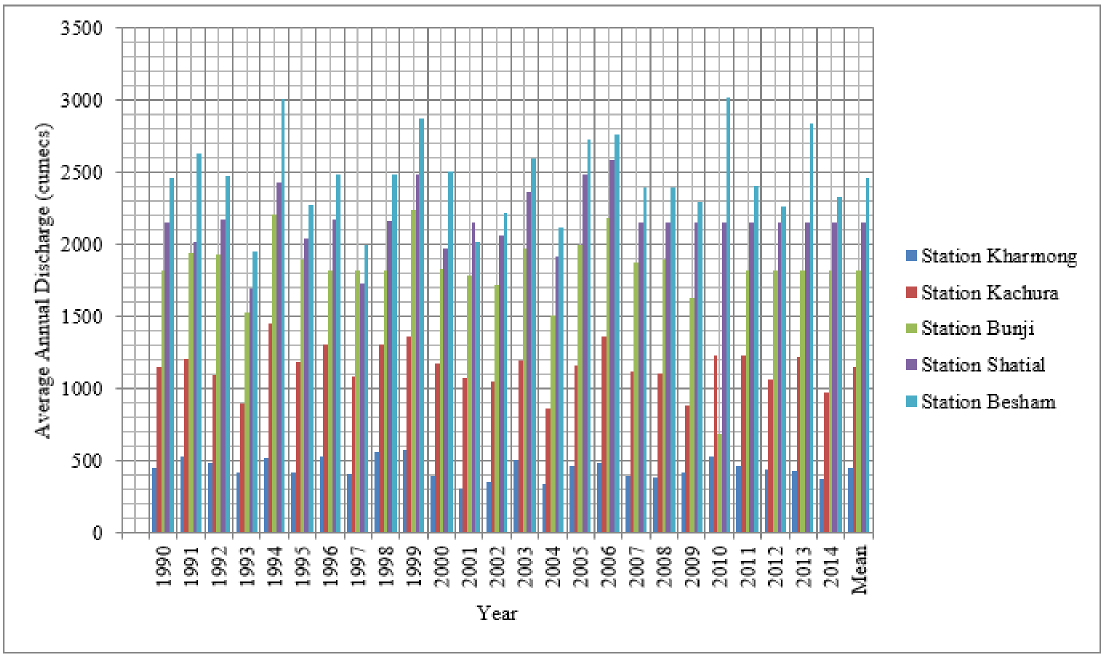


Figure 3.3: Average Annual Discharge Variations at Five Gauging Stations of Indus River

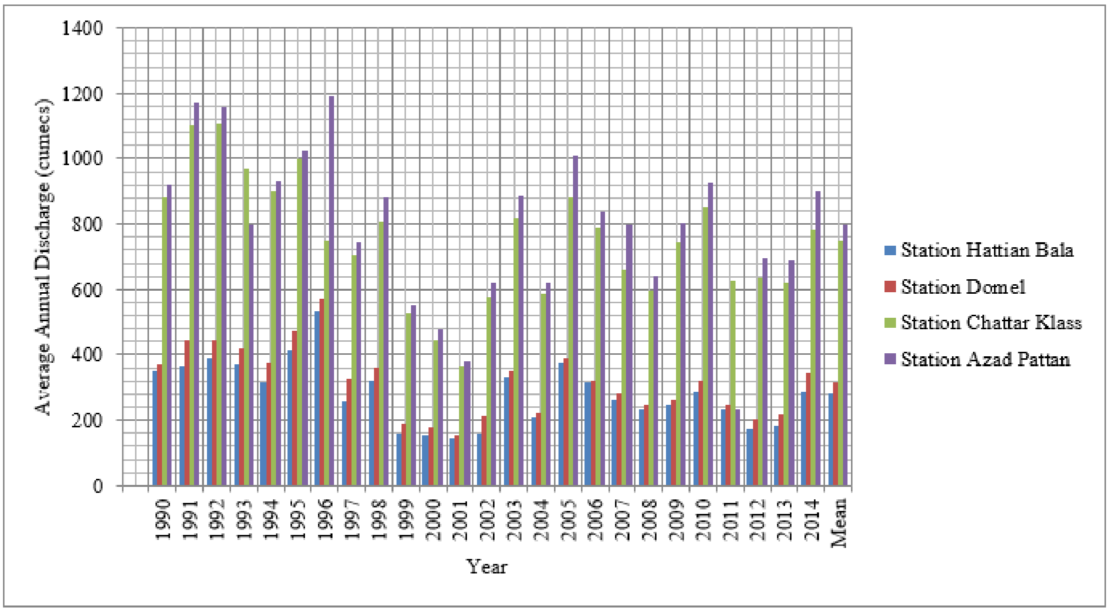


Figure 3.4: Average Annual discharge Variations at Four Gauging Stations of Jhelum River

The discharge values highlighted and Underlined in yellow in Table 3.1 and Table 3.2 were actually missing from the dataset. In order to replace these missing values with a suitable measure of central value, one needs to look into the variability of the dataset. A boxplot is a way of summarizing a set of data measured on an interval scale. The boxplot is a type of graph which is used to show shape of the distribution, variability and its central value. Boxplot is often used in exploratory data analysis (Easton and McColl). Figure 3.5 shows a boxplot of the annual stream flows data from 1990- 2014 over each of the five gauging stations of Indus River while Figure 3.6 shows boxplot of the annual stream flows data from 1990-2014 over each of the four gauging stations of Jhelum River.

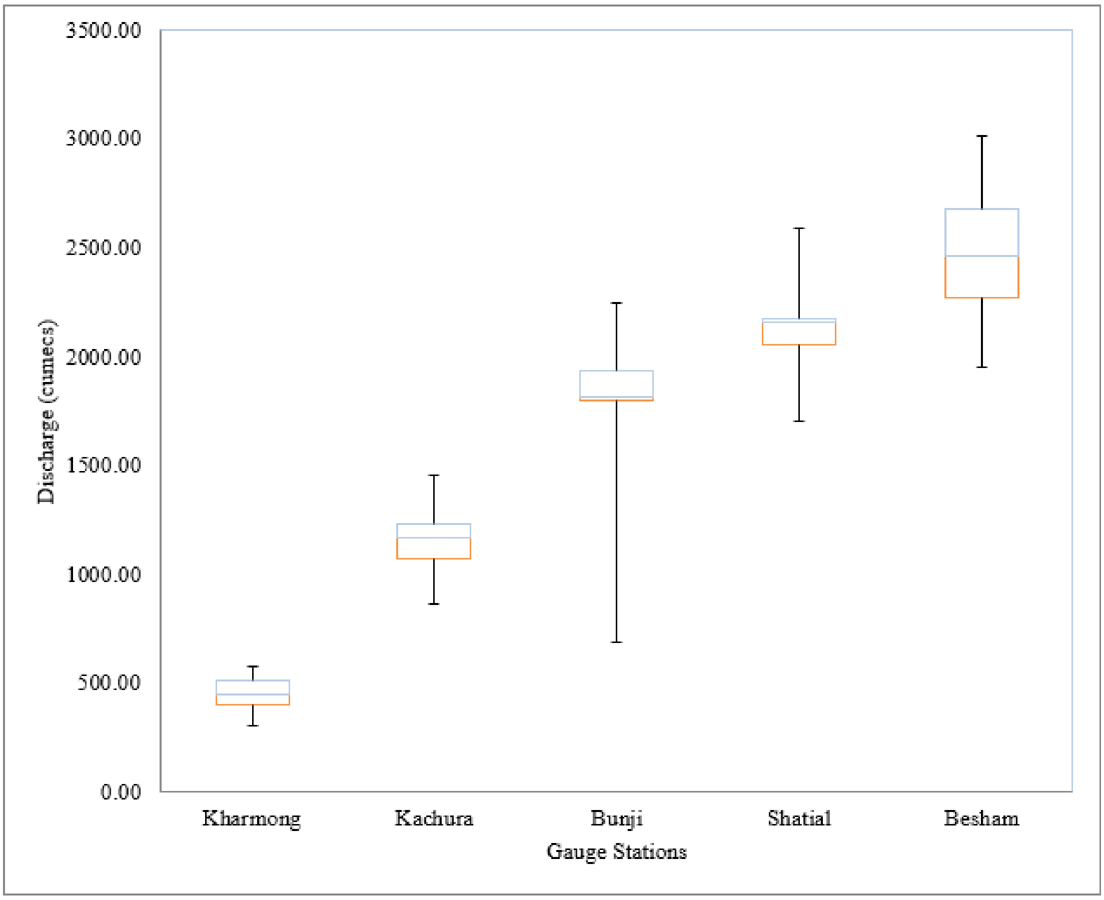


Figure 3.5: Boxplot Indicating the Variability in the Annual Stream Flow Dataset for the Indus Basin

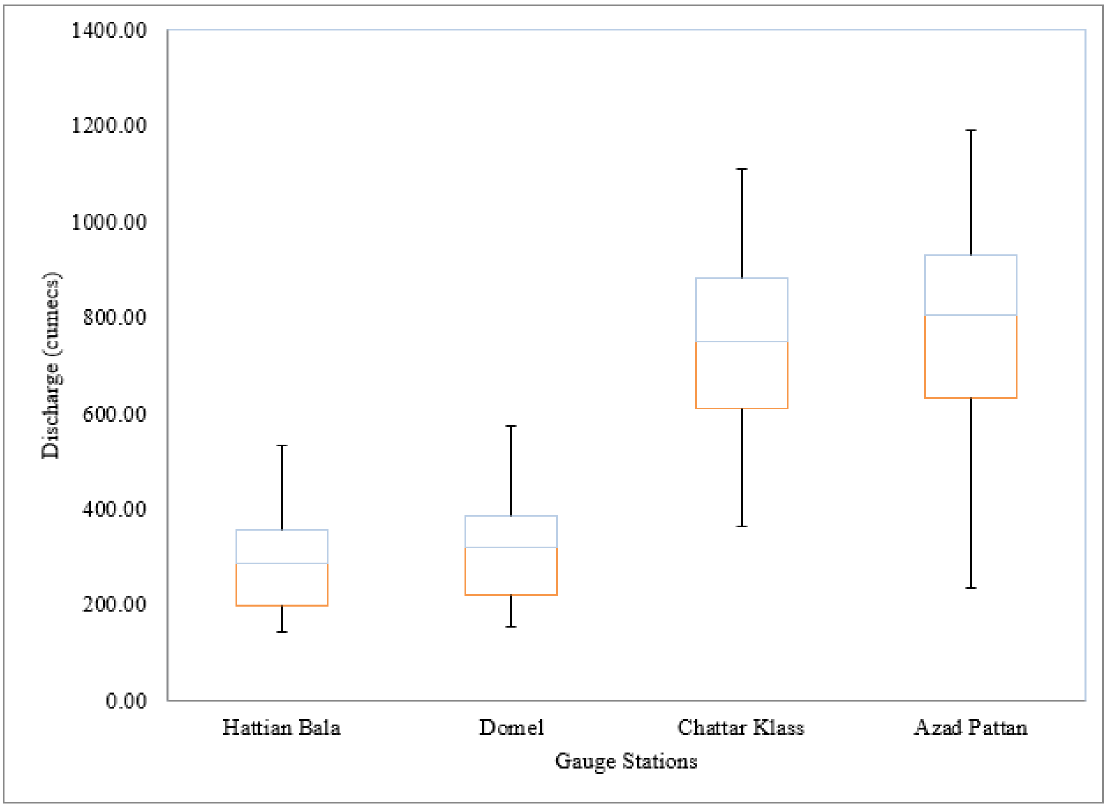
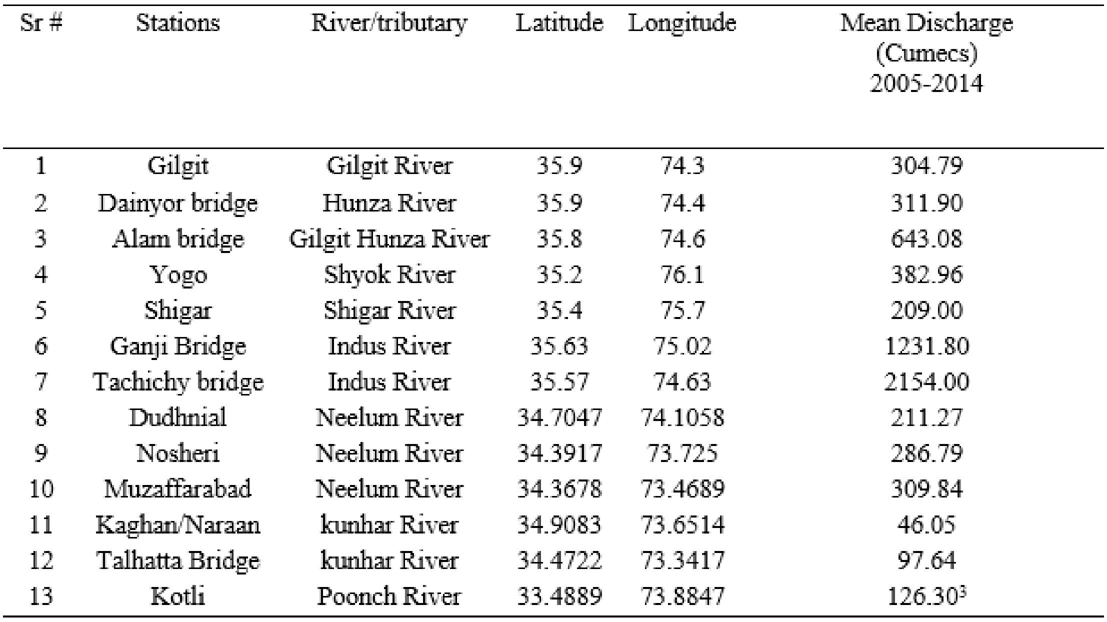


FIGURE 3.6: Boxplot Indicating the Variability in the Annual Stream Flow Dataset for the Jhelum Basin

Figure 3.5 and Figure 3.6 shows that the dataset is free of outliers which indicate the use of mean as an accurate measure of central value. Otherwise, it would have been more suitable to use median as a measure of central value for replacing the missing values in the stream flows dataset.

Beside the main river discharge data of Indus and Jhelum rivers, the discharge observed at various locations on the minor rivers contributing in main rivers are also listed below in order to evaluate the hydropower potential at minor rivers too and also taking in considerations their effect on main rivers. The discharge from 2005 to 2014 at the tributary and minor rivers of Indus and Jhelum are listed in Table 3.3.

Table 3.3: Average Annual Discharge Observed at Tributaries in Indus and Jhelum Basins (Obtained from SWHP WAPDA)



Sr #	Stations	River/tributary	Latitude	Longitude	Mean Discharge (Cumecs) 2005-2014
1	Gilgit	Gilgit River	35.9	74.3	304.79
2	Dainyor bridge	Hunza River	35.9	74.4	311.90
3	Alam bridge	Gilgit Hunza River	35.8	74.6	643.08
4	Yogo	Shyok River	35.2	76.1	382.96
5	Shigar	Shigar River	35.4	75.7	209.00
6	Ganji Bridge	Indus River	35.63	75.02	1231.80
7	Tachichy bridge	Indus River	35.57	74.63	2154.00
8	Dudhnial	Neelum River	34.7047	74.1058	211.27
9	Nosheri	Neelum River	34.3917	73.725	286.79
10	Muzaffarabad	Neelum River	34.3678	73.4689	309.84
11	Kaghan/Naraan	kunhar River	34.9083	73.6514	46.05
12	Talhatta Bridge	kunhar River	34.4722	73.3417	97.64
13	Kotli	Poonch River	33.4889	73.8847	126.30[3]

3.2.2 Topographic Data

The topographic details were obtained in the form of a Digital Elevation Model (DEM) from NASA's Shuttle Radar Topography Mission (SRTM) 90 m digital elevation data (A. et al., 2008). It is available at http://srtm.csi.cgiar.org free of cost. The website has a world map that is divided into a number of grids. DEM for single/multiple grid(s) can be download simply by selected the grids of interest and then selecting the file format. The data is available both in GeoTiff and Arc Info ASCII format. For the purpose of this study the data was downloaded in GeoTiff format. Four cells falling in the north most part of Pakistan for Indus River and four cells falling in the Northern areas of Azad Jammu and Kashmir of Pakistan for Jhelum River were selected. The data in the form of four cells was then 'Mosaicked' and 'Clipped' using ArcGIS. The DEM for Indus and Jhelum Basin obtained through SRTM are given in Figure 3.7 and Figure 3.8 respectively.

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[0] Showing the yearly variations of discharge gauge stations in Indus and Jhelum basins minor tributaries extract from daily discharge data.

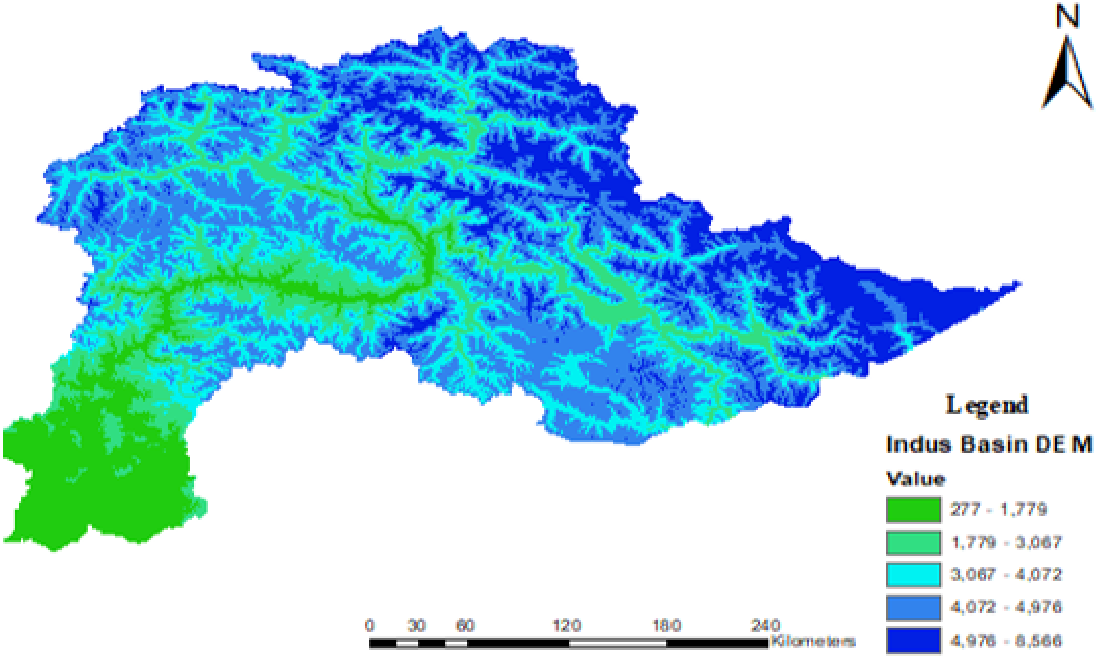


FIGURE 3.7: A Digital Elevation Model (DEM) of the Indus Basin Area obtained from STRM 90 m

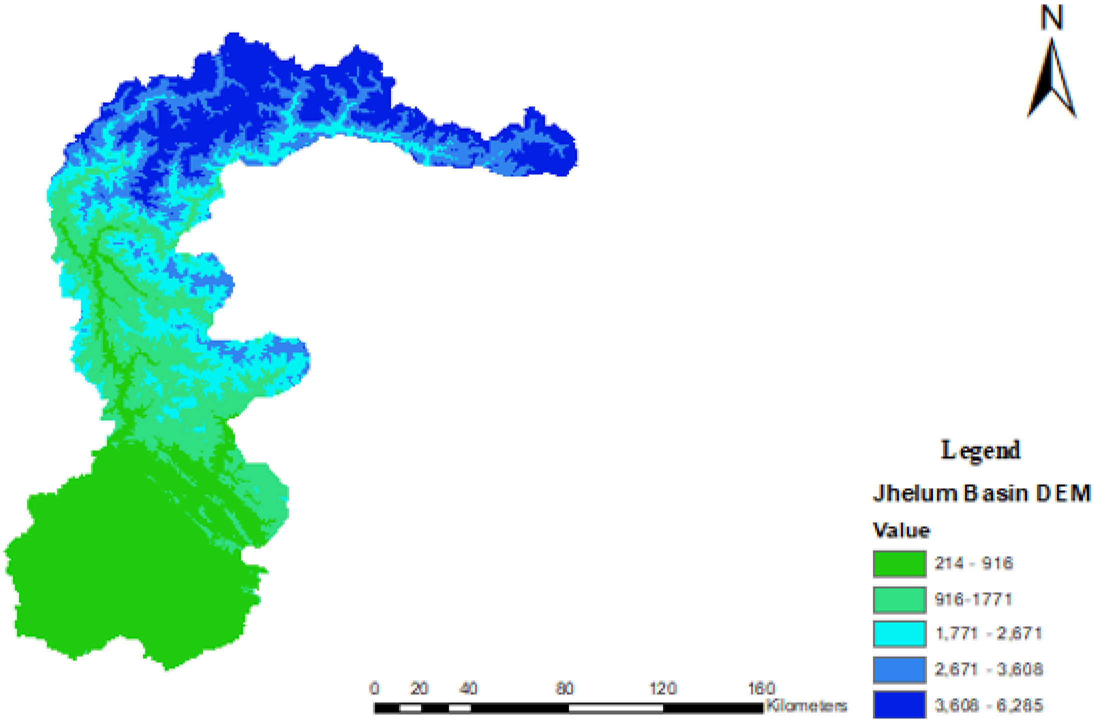


FIGURE 3.8: A Digital Elevation Model (DEM) of the Jhelum Basin Area obtained from STRM 90 m

3.3 Research Methodology

The approach for evaluating the hydropower potential of a basin presented in this thesis basically consists of preprocessing the DEM in GIS to delineate the catchment and generate the stream network. Points are then generated over the stream at a specified interval followed by the interpolation of point average annual stream flow data to obtain the stream flow values at these points. The interpolation of stream flow data is accomplished using ratio proportion technique in GIS. The elevation values at these points are extracted from the DEM to get the hydraulic head. Knowing the average annual stream and hydraulic head, the theoretical hydropower potential at these previously defined points can be easily evaluated. The following articles discuss these steps in detail.

3.3.1 DEM Preprocessing

The DEM obtained from SRTM as discussed in article 3.2.2 needs to be processed in order to generate the stream network and delineate the watershed under study, which in this case is the Upper Indus Basin (UIB) and Upper Jhelum Basin (UJB). Arc Map 10.5 shall be used for this purpose along with Arc Hydro Toolset. Arc Hydro is a set of data tools and models that operates within ArcGIS to support temporal and geospatial data analyses (Esri). Arc Hydro Tools extensions is downloadable free of cost at http://downloads.esri.com/archydro/archydro. Figure 3.9 shows the Arc Hydro Toolset in Arc Map 10.5.

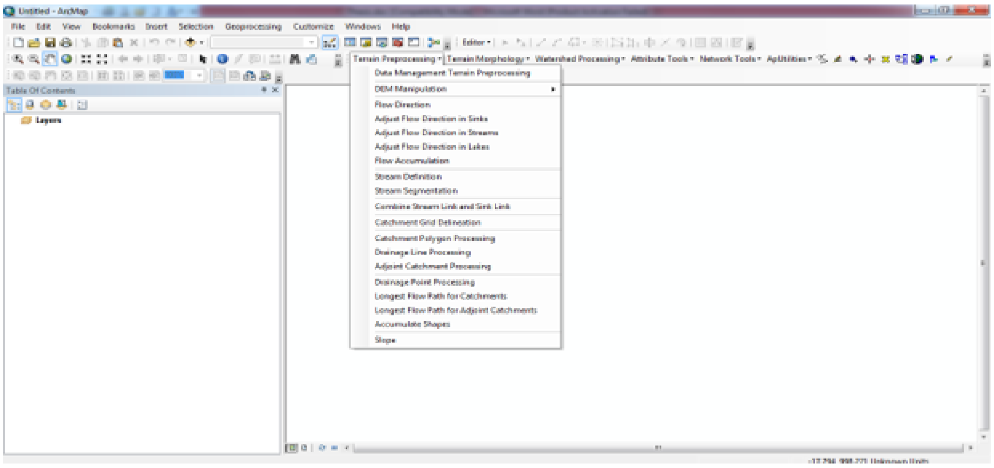
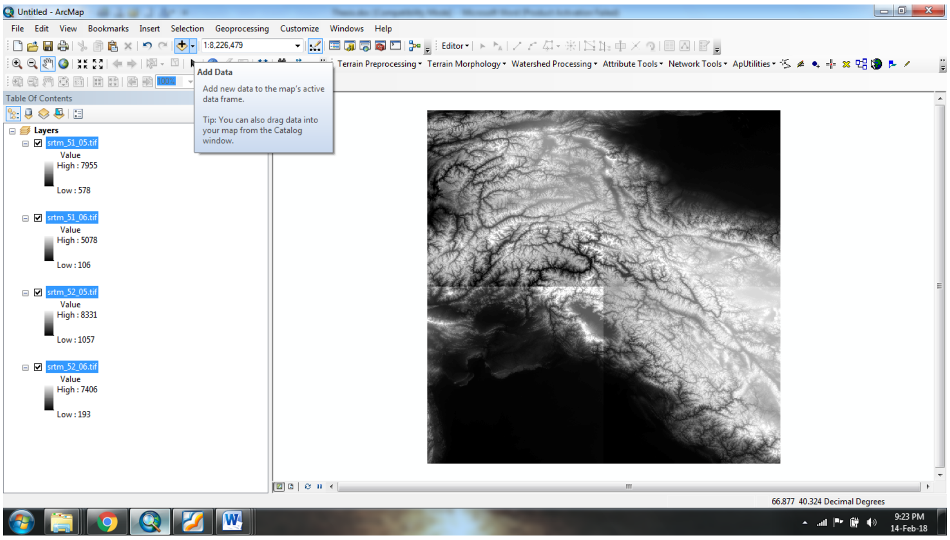


FIGURE 3.9: ArcHydro Tools in ArcMap 10.5

The steps involved in stream network generation and catchment delineation are discussed below:

3.3.2 Adding DEM to Arc Map 10.5

Firstly the four DEM tiles downloaded as discussed in article 3.2.2 need to be added to the map Arc Map 10.5. This can be done by using the Add Data tool as shown in Figure 3.10. The boundaries of the four DEM tiles are quite distinct. In order to further manipulate this DEM, the four tiles need to be mosaicked together. The Study area for both catchment area lies within the above downloaded DEM.


Add Data

Add new data to the map's active data frame.

Tip: You can also drag data into your map from the Catalog window.

FIGURE 3.10: Adding DEM to Arc Map 10.5

3.3.3 Mosaic

"Mosaic to New Raster" shall be used to generate a new raster dataset by mosaicking the original four raster datasets in Figure 3.11. This makes easy the manipulation of the DEM in the subsequent steps. This option can be found in Arc Toolbox → Data Management Tools → Raster → Raster Dataset → Mosaic To New Raster.

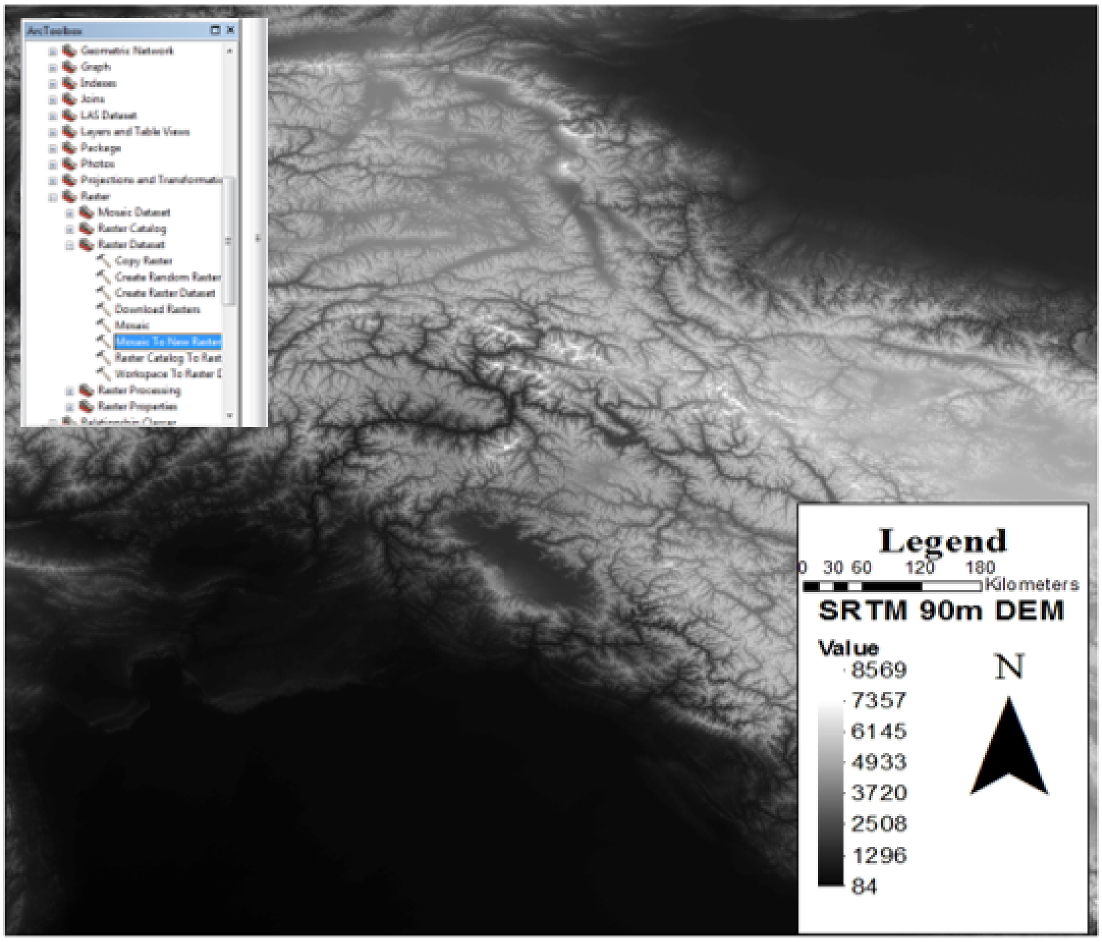


FIGURE 3.11: Mosaicked Digital Elevation Model

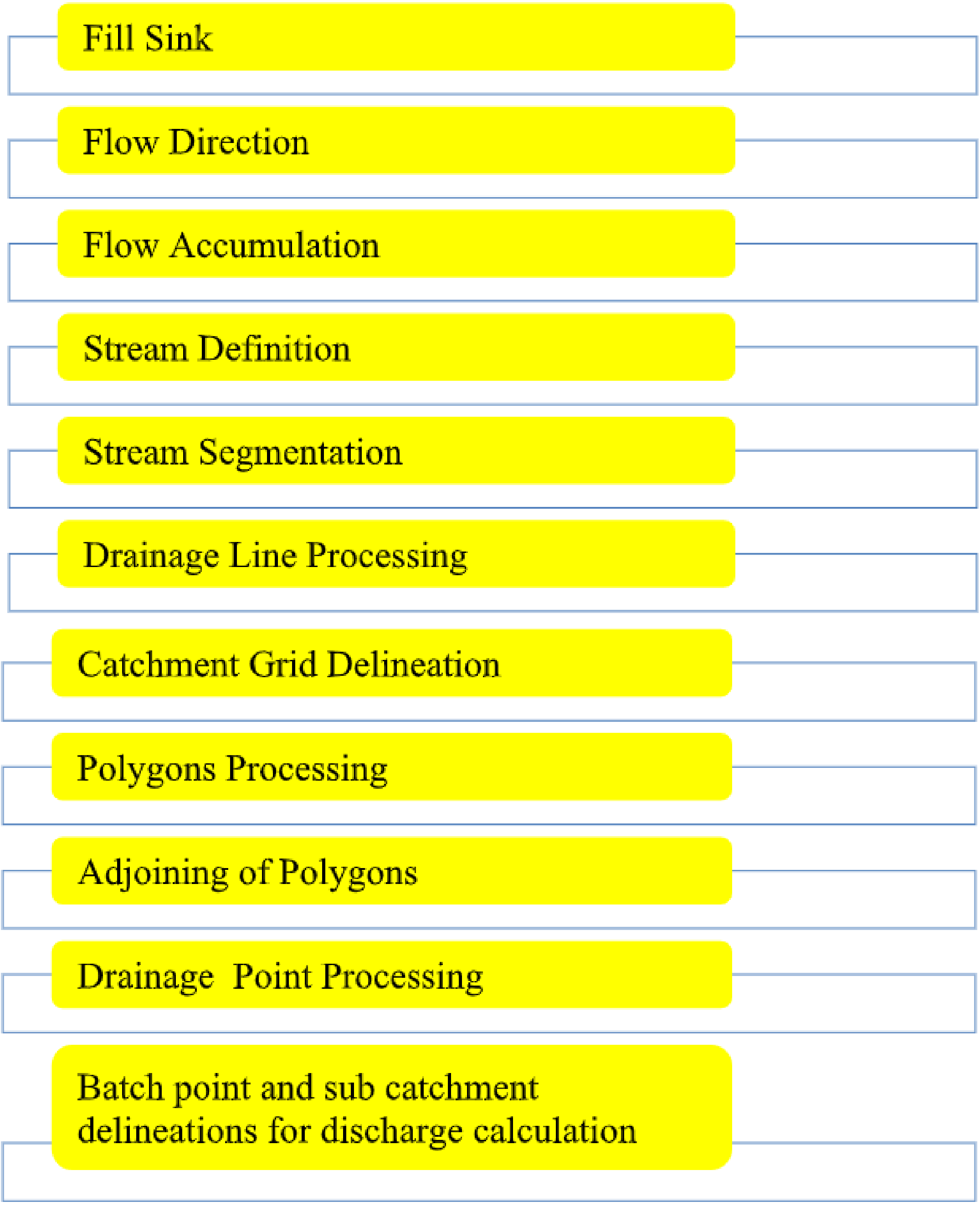


Figure 3.12: Methodology Adopted for Processing of DEM in Arc GIS

3.3.4 Fill Sinks

In order to fills the sinks in a grid fill sinks function used referred to Figure 2 in Annexure-A. Water cannot flow and trapped in the cell if cell is surrounding by a cells of a higher elevation. To overcome this problem, fill sinks function modifies the elevation value (Merwade et al., 2006).

3.3.5 Flow Direction

The flow direction function computes the flow direction for a given grid referred to Figure 3 & 4 in Annexure-A. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell (Merwade et al., 2006). The output of the Flow Direction tool is an integer raster whose values range from 1 to 128.

3.3.6 Flow Accumulation

The flow accumulation function computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid (Merwade et al., 2006) referred to Figure 5 in Annexure-A.

3.3.7 Stream Definition

This function computes a stream grid which contains a value of “1” for all the cells in the input flow accumulation grid that have a value greater than the given threshold referred to Figure 6 in Annexure-A. By default this threshold is set to 1% of the maximum flow accumulation. All other cells in the stream grid contain no data (Merwade et al., 2006).

3.3.8 Stream Segmentation

This function creates a grid of stream segments that have a unique identification. Either as a segment between two segment junctions or it may be defined a segment as a head (Merwade et al., 2006). All the cells in a particular segment have the same grid code that is specific to that segment referred to Figure 7 in Annexure-A.

3.3.9 Drainage Line Processing

In order to convert the input stream link grid into a drainage line feature class, drainage line processing function used referred to Figure 8 in Annexure-A. Each line in the feature class carries the identifier of the catchment in which it resides (Merwade et al., 2006). This generates the stream network.

3.3.10 Catchment Grid Delineation

Catchment grid delineation functions requires flow direction grid and stream segmentation grid as inputs and it classifies the entire area under consideration into a number of catchments based on the stream segments which drain into that area (Merwade et al., 2006) referred to Figure 9 in Annexure-A.

3.3.11 Catchment Polygon Processing

Catchment polygon processing function is used to converts a catchment grid into catchment polygon feature class (Merwade et al., 2006) referred to Figure 10 in Annexure-A.

3.3.12 Ad joint Catchment Processing

Adjoint catchemnt processing functions generates the aggregated upstream catchments from the “Catchment” feature class. For each catchment that is not a head catchment, a polygon representing the whole upstream area draining to its inlet point is constructed and stored in a feature class that has an “Ad joint Catchment” tag referred to Figure 11 in Annexure-A This feature class is used to speed up the point delineation process (Merwade et al., 2006).

3.3.13 Drainage Point Processing

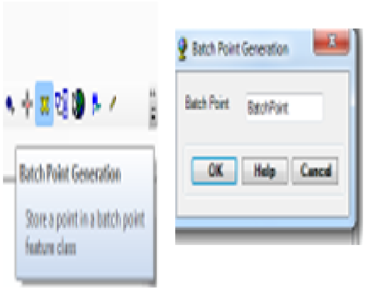
In order to generate drainage points associated with catchment drainage point processing function is used (Merwade et al., 2006) referred to Figure 12 in Annexure-A.

3.3.14 Batch Watershed Delineation

This function delineates the watershed upstream of each point in an input Batch Point feature class referred to Figure 3.13. The batch points are inserted at the requisite place for which we want to delineate watershed. For this process is given below:

Step 1

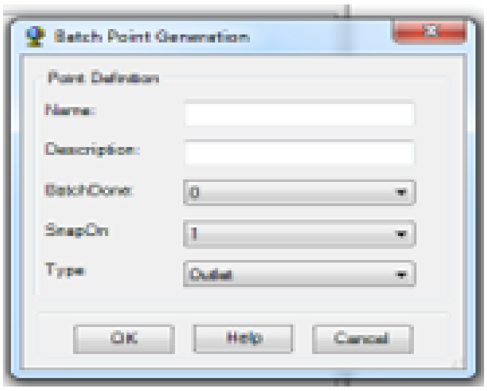
Insert the Batch point by clicking the yellow button on the upper right corner.



Batch Point: BatchPoint

Step 2

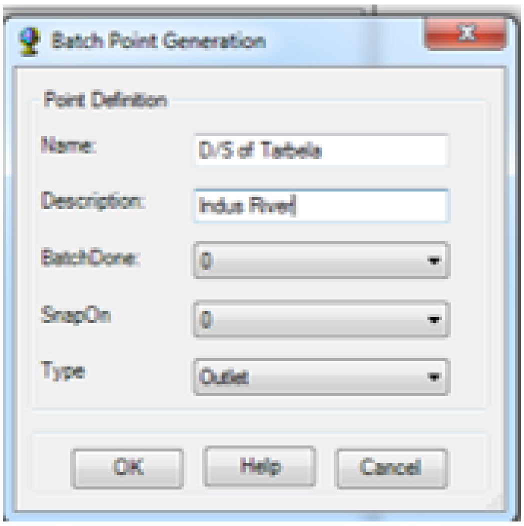
The following window will display on clicking Ok.



Name:
Description:
BatchDone: 0
SnapOn: 1
Type: Outlet

Step 3

Insert the Detail and Snap On change from 1 to 0.


Batch Point Generation

Point Definition

Name: D/S of Tarbela

Description: Indus River

BatchDone: 0

SnapOn: 0

Type: Outlet

FIGURE 3.13: Procedure to Insert the Batch Point

The Arc Hydro tools "Batch Point Generation" can also be used to interactively create the Batch Point feature class. This function was used to locate the outlet of the watershed. To activate "Batch Watershed Delineation" go to Watershed Processing Batch Watershed Delineation.

FIGURE 3.14: Batch Watershed Delineation (Upper Indus Basin)

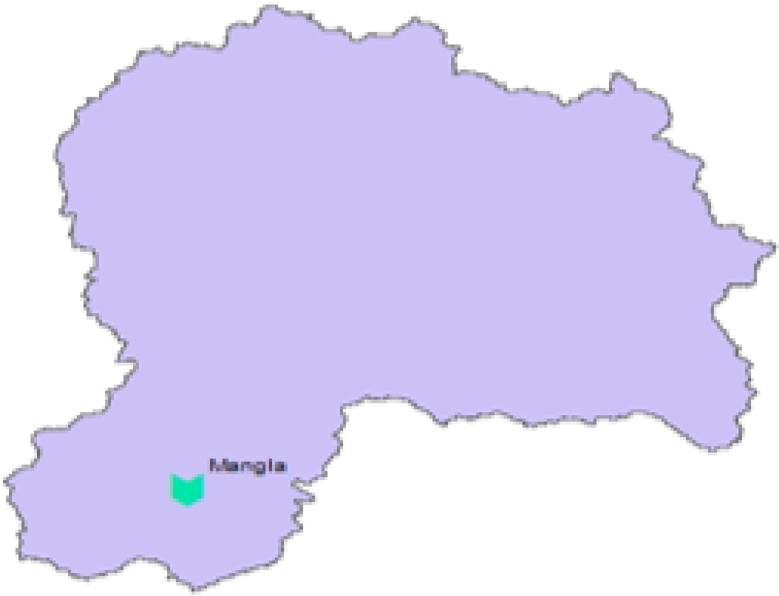


Figure 3.15: Batch Watershed Delineation (Upper Jhelum Basin)

However, some area of the watershed falls outside the boundaries of Pakistan. In order to cut this area, use the "Clip" function which can be found it ArcToolbox → Analysis Tools → Extract → Clip. This function cuts out a piece of one feature class using one or more of the features in another feature class as a cookie cutter. This is particularly useful for creating a new feature class, also referred to as study area. This study uses the Shape file of Pakistans boundary as the Clip Feature.

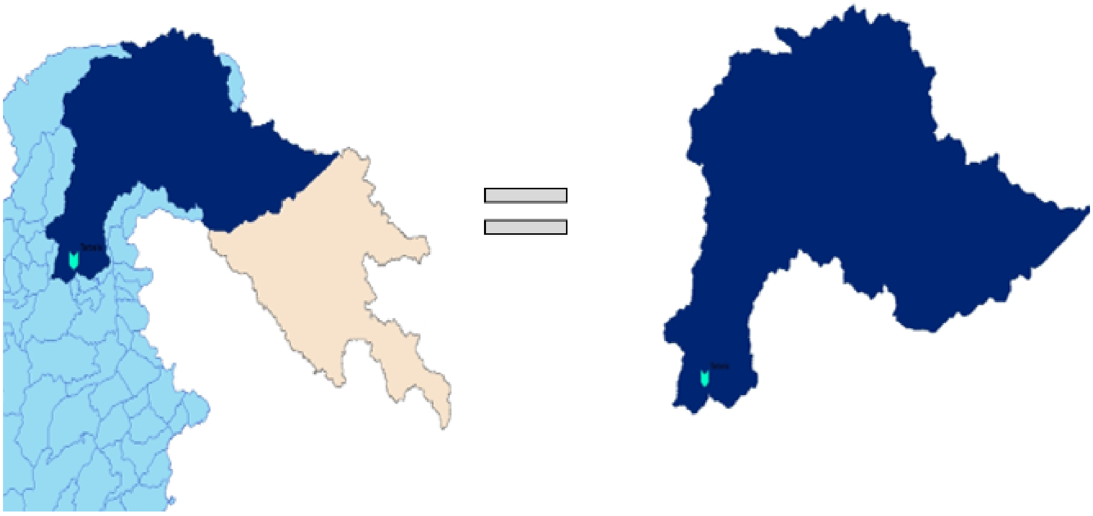


Figure 3.16: Clipping the Delineated Watershed of Upper Indus Basin (UIB)

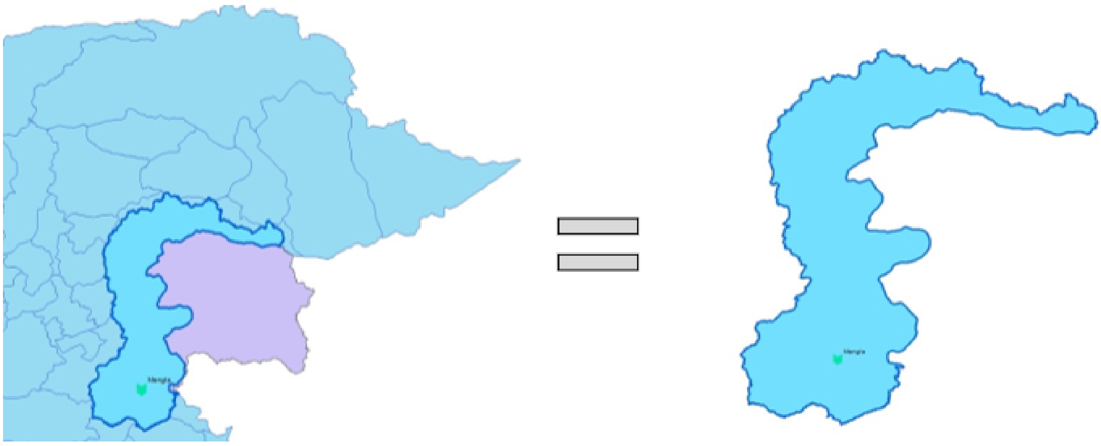


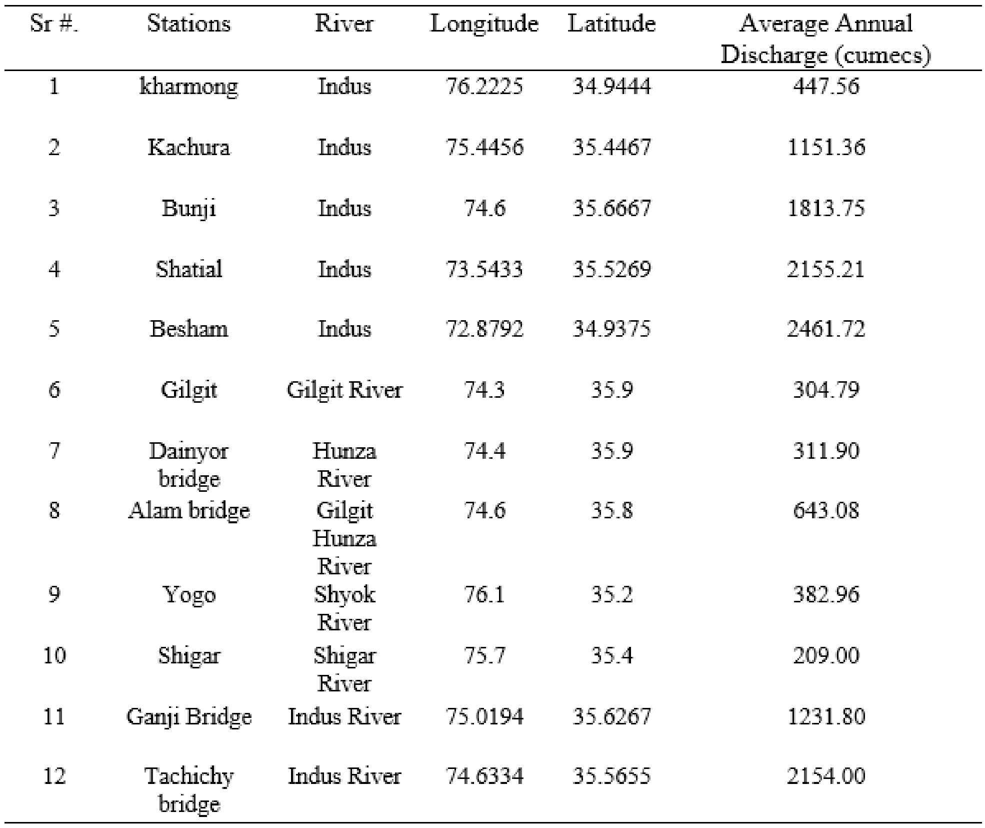
FIGURE 3.17: Clipping the Delineated Watershed of Upper Jhelum Basin (UJB)

3.4 Stream Flow Interpolation

3.4.1 Plotting and Snapping Point Data to River Reach

The aforementioned gauging stations were then located within the study areas with average annual runoff in cumecs as the attribute value. The points were located in the study areas using their geographic coordinates obtained from Google and Data provided by WAPDA. The stations along with their geographic coordinates and average annual discharge attribute are enlisted in Table 3.4 and 3.5.

Table 3.4: Stream Gauging Stations, their Geographic Coordinates and Average Annual Discharge for the Upper Indus Basin (Obtained from SWHP WAPDA)

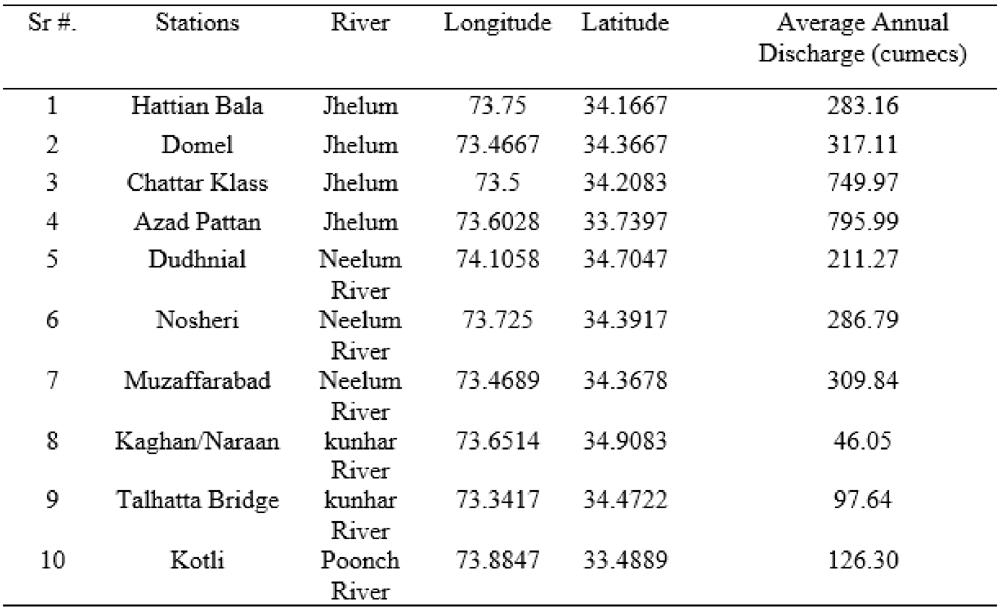


Sr #.	Stations	River	Longitude	Latitude	Average Annual Discharge (cumecs)
1	kharmong	Indus	76.2225	34.9444	447.56
2	Kachura	Indus	75.4456	35.4467	1151.36
3	Bunji	Indus	74.6	35.6667	1813.75
4	Shatial	Indus	73.5433	35.5269	2155.21
5	Besham	Indus	72.8792	34.9375	2461.72
6	Gilgit	Gilgit River	74.3	35.9	304.79
7	Dainyor bridge	Hunza River	74.4	35.9	311.90
8	Alam bridge	Gilgit Hunza River	74.6	35.8	643.08
9	Yogo	Shyok River	76.1	35.2	382.96
10	Shigar	Shigar River	75.7	35.4	209.00
11	Ganji Bridge	Indus River	75.0194	35.6267	1231.80
12	Tachichy bridge	Indus River	74.6334	35.5655	2154.00

In order to plot these points in ArcGIS, an excel sheet was prepared containing the above data and it was saved as a .csv file. By using Add Data function this file is added to ArcGIS. The points were then plotted in ArcGIS. It is worth noting that the above coordinates correspond to the city or town center and not to the representative point on the reach. Therefore, these

points do not seem to align with the river reach in ArcGIS as is evident from Figure 3.28.In order to snap these points to the river vector, go to Arc Toolbox → Analysis Tools → Proximity → Near. Choose the point layer as Input features and line (drainage line) layer as Near feature. Check the “Location” checkbox. Four new attributes will be added to the point layer namely, NEAR_FID, NEAR_DIST, NEAR_X and NEAR_Y. Open the attribute table of the point layer and click on Table Options button in the attribute table window and Export the data as a .dbf file. Add this data to the current map. Choose to display the X field and

Table 3.5: Stream Gauging Stations, their Geographic Coordinates and Average Annual Discharge for the Upper Jhelum Basin (Obtained from SWHP WAPDA)

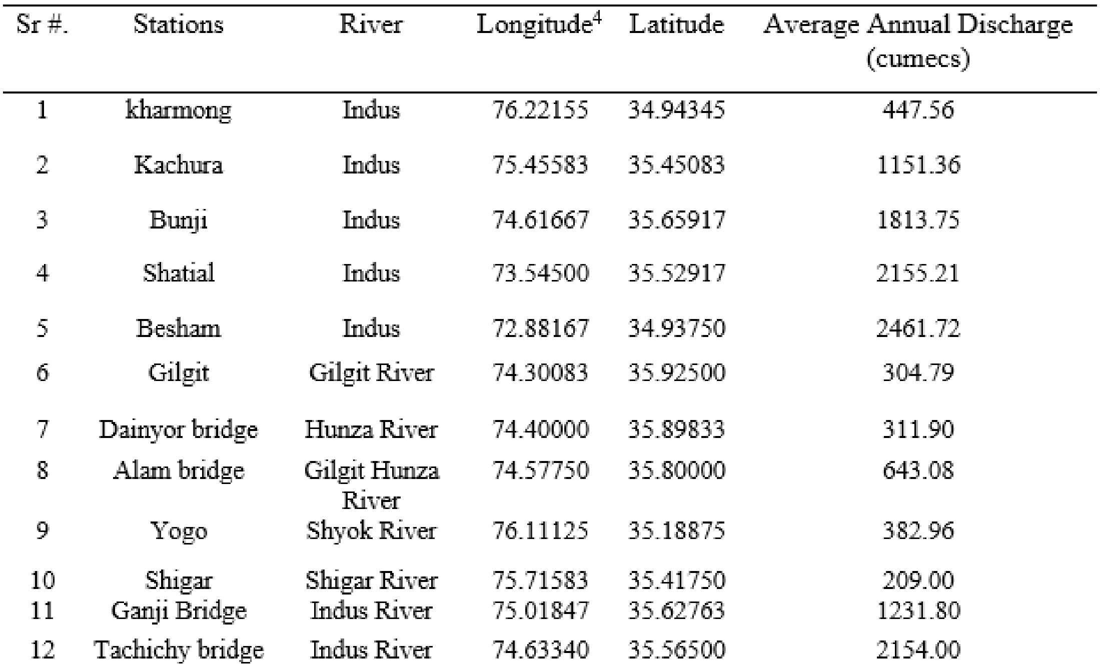


Sr #.	Stations	River	Longitude	Latitude	Average Annual Discharge (cumecs)
1	Hattian Bala	Jhelum	73.75	34.1667	283.16
2	Domel	Jhelum	73.4667	34.3667	317.11
3	Chattar Klass	Jhelum	73.5	34.2083	749.97
4	Azad Pattan	Jhelum	73.6028	33.7397	795.99
5	Dudhnial	Neelum River	74.1058	34.7047	211.27
6	Nosheri	Neelum River	73.725	34.3917	286.79
7	Muzaffarabad	Neelum River	73.4689	34.3678	309.84
8	Kaghan/Naraan	kunhar River	73.6514	34.9083	46.05
9	Talhatta Bridge	kunhar River	73.3417	34.4722	97.64
10	Kotli	Poonch River	73.8847	33.4889	126.30

Figure 3.18: Location of Gauging Station Before Snapping at Indus and Jhelum Basin

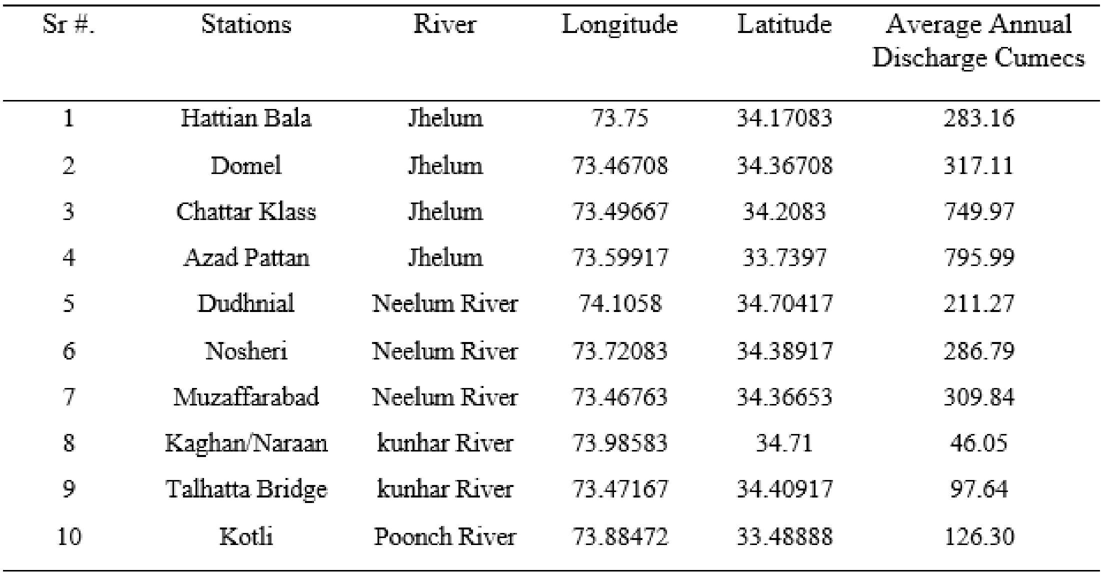
Y field as NEAR_X and NEAY_Y respectively. These attributes correspond to the snapped coordinates of the stations. From here on, these snapped coordinates shall be referred to as the coordinates of the gauging stations. The stations along with their snapped geographic coordinates and average annual discharge attribute are enlisted in Table 3.6 for Indus Basin while Table 3.7 shows station along with snapped geographic coordinates and average annual discharge for Jhelum Basin.

Table 3.6: Stream Gauging Stations, their Snapped Geographic Coordinates and Average Annual Discharge for the Upper Indus Basin



Sr #.	Stations	River	Longitude[4]	Latitude	Average Annual Discharge (cumecs)
1	kharmong	Indus	76.22155	34.94345	447.56
2	Kachura	Indus	75.45583	35.45083	1151.36
3	Bunji	Indus	74.61667	35.65917	1813.75
4	Shatial	Indus	73.54500	35.52917	2155.21
5	Besham	Indus	72.88167	34.93750	2461.72
6	Gilgit	Gilgit River	74.30083	35.92500	304.79
7	Dainyor bridge	Hunza River	74.40000	35.89833	311.90
8	Alam bridge	Gilgit Hunza River	74.57750	35.80000	643.08
9	Yogo	Shyok River	76.11125	35.18875	382.96
10	Shigar	Shigar River	75.71583	35.41750	209.00
11	Ganji Bridge	Indus River	75.01847	35.62763	1231.80
12	Tachichy bridge	Indus River	74.63340	35.56500	2154.00

Table 3.7: Stream Gauging Stations, their Snapped Geographic Coordinates and Average Annual Discharge for the Jhelum Basin



Sr #.	Stations	River	Longitude	Latitude	Average Annual Discharge Cumecs
1	Hattian Bala	Jhelum	73.75	34.17083	283.16
2	Domel	Jhelum	73.46708	34.36708	317.11
3	Chattar Klass	Jhelum	73.49667	34.2083	749.97
4	Azad Pattan	Jhelum	73.59917	33.7397	795.99
5	Dudhnial	Neelum River	74.1058	34.70417	211.27
6	Nosheri	Neelum River	73.72083	34.38917	286.79
7	Muzaffarabad	Neelum River	73.46763	34.36653	309.84
8	Kaghan/Naraan	kunhar River	73.98583	34.71	46.05
9	Talhatta Bridge	kunhar River	73.47167	34.40917	97.64
10	Kotli	Poonch River	73.88472	33.48888	126.30

---

[0] Longitude and latitude are snapped by using Arc Gis and Discharge Obtained from SWHP WAPDA.

[0] Longitude and latitude are snapped by using Arc Gis and Discharge Obtained from SWHP WAPDA.

FIGURE 3.19: Location of Snapped Gauging Station at Indus and Jhelum Basin

3.4.2 Calculation of Relative Discharge over the Entire Catchment Areas

Runoff was interpolated over the entire catchment area under consideration by using ratio proportion technique in ArcGIS. As the discharge values are required at every proposed location along the river where we want to calculate the hydropower potential. The discharge at unknown locations are calculated by interpolated the given discharge at various gauging stations (Jha, 2011). To explain it further assume “1” and “2” as two gauges installed in a

stream with Q1 and Q2 discharges as shown in figure below. Gauge “1” is installed at an upstream location in the watershed, whereas, gauge “2” is located at the downstream point. The respective sub-drainage areas of “1” and “2” are “A1” and “A2” respectively. Let there are two more points “X1” and “X2” located upstream and downstream of gauge “1” where flow is needed to be estimated. Similarly, the sub catchment areas of “X1” and “X2” are “AX1” and “AX2” respectively. The flow QX1 and QX2 at ungauged location using equations 3.1 and 3.2.

i. Estimating Flow QX1 at ‘X1’
Moving upstream from gauge ‘1’ discharge needs to be subtracted relative to the

area of sub catchment X1.

$$QX_1 = \left({}^{AX_1}/_{A_1}\right)*Q_1 \tag{3.1}$$

ii. Estimating Flow QX2 at ‘X2’

Moving downstream from gauge ‘a’, the cumulative discharge can be calculated for each proposed site using following equation.

$$QX_2 = \left({}^{AX_2}/_{A_2}\right)*Q_2 \tag{3.2}$$

FIGURE 3.20: Diagrammatic View of Approach Adopted to Evaluate Discharge at Unknown Points

Using the above mentioned approach the discharge is calculated at the requisite point at which the hydropower potential to be evaluated. The requisite points are generate by using command **“sampling”** at the distance of 5 Km along the Indus and Jhelum rivers and also at minor rivers.

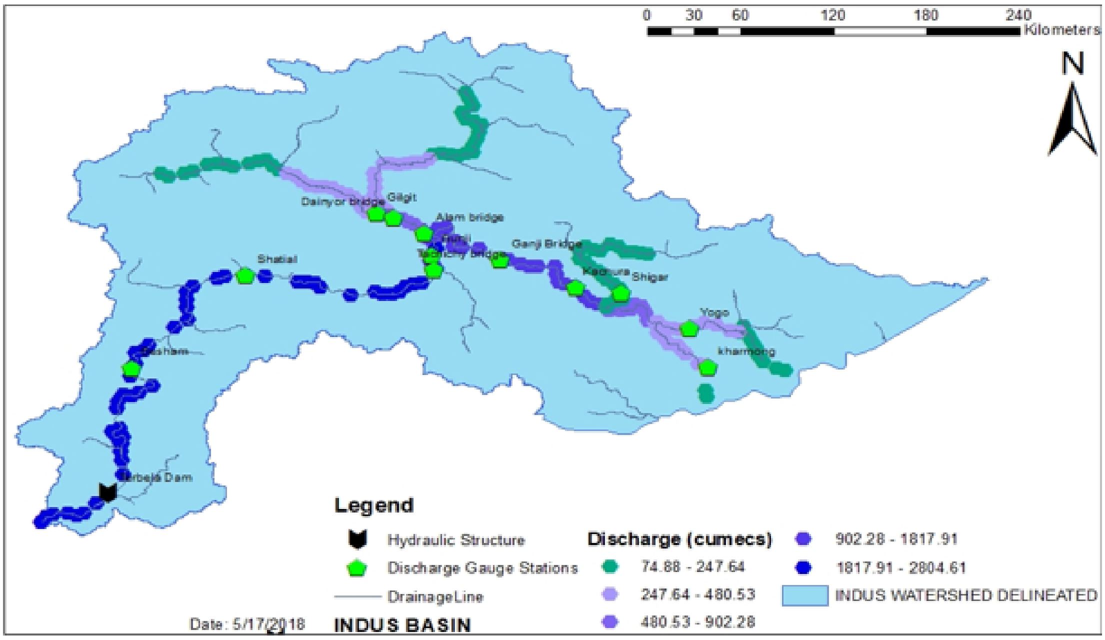


FIGURE 3.21: Discharge Interpolated over the Indus River and its Tributaries

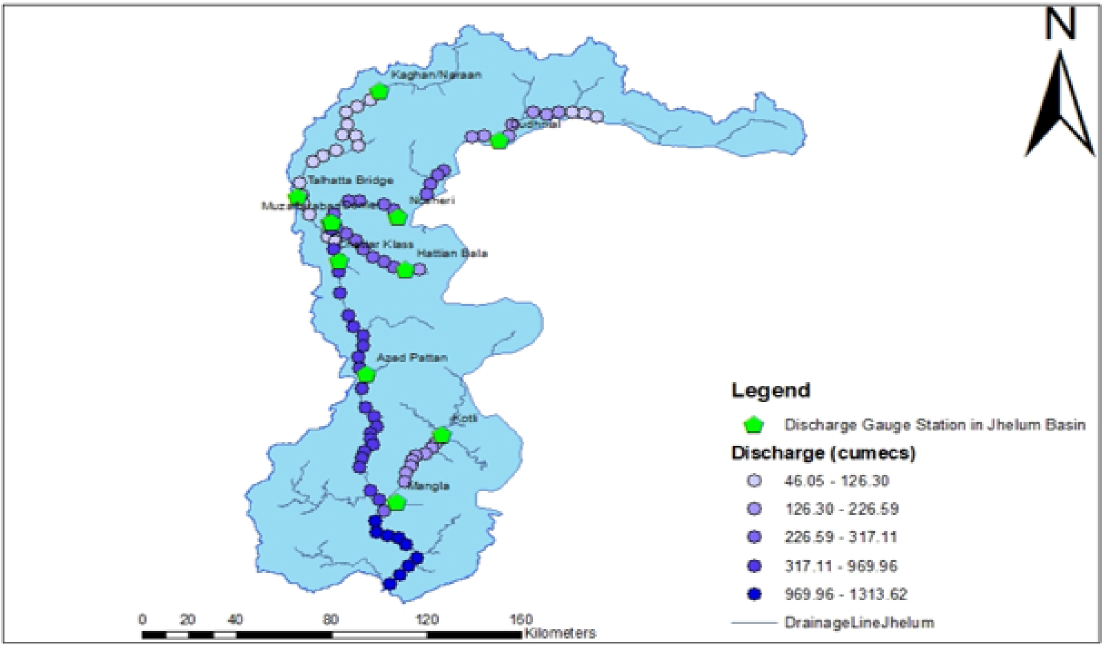


FIGURE 3.22: Discharge Interpolated over the Jhelum River and its Tributaries

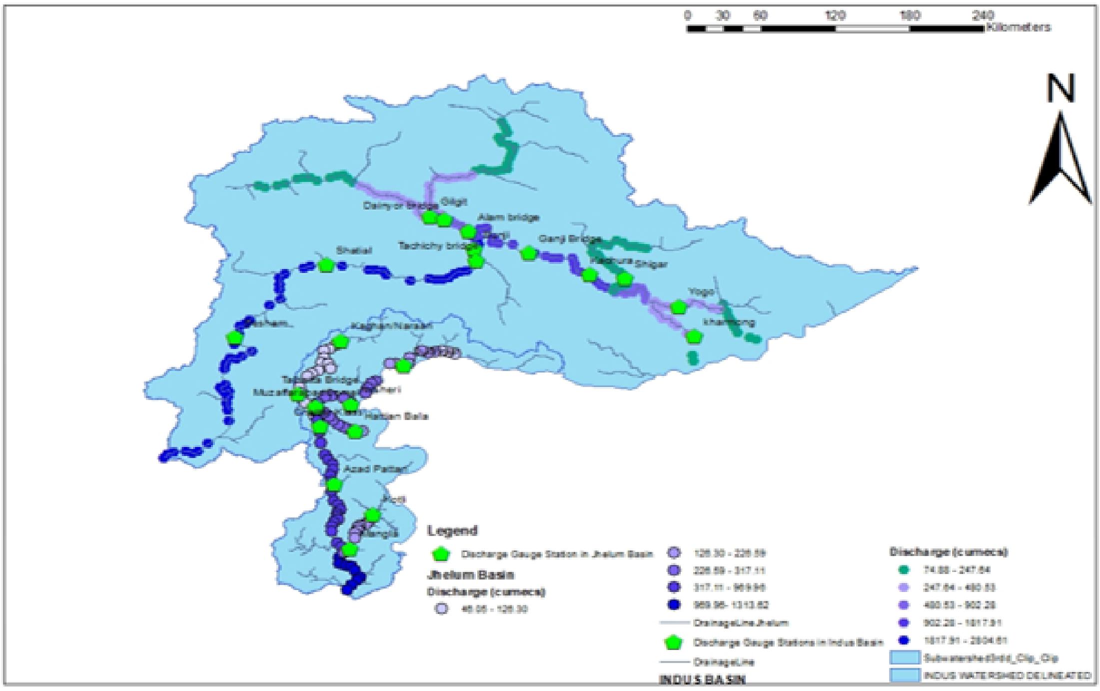


FIGURE 3.23: Discharge Interpolated over the Indus and Jhelum Basins

3.4.3 Evaluation of Hydropower Potential

As already discussed, points were constructed along the entire length along the River Indus and River Jhelum and their tributaries, starting from just downstream of Tarbela dam and Mangla Dam to the point where River Indus and River Jhelum enters the international boundaries of Pakistan at an interval of 5 km, these being the points at which the hydropower potential is to be evaluated. The runoff and elevation at these points were extracted from the DEM and interpolated runoff layer, using the “Extract Values to Points”. Head at each point was then evaluated by subtracting the elevation at each point from that of the immediately previous point (Figure 3.34) as explainable by the following equation,

$$H_N = h_{N-1} - h_N \tag{3.3}$$

where,

hN = elevation of the point under consideration

hN-1 = elevation of the immediate upstream point

HN = Head in terms of height of water column at the point under consideration

The calculation of the theoretical hydropower potential was based on the following basic equation,

$$Power\ Output = P = \rho Q g H \tag{3.4}$$

where, P = Power output in watts

ρ = Density of water = 1000 kg/m3

Q = River discharge (m3/s)

g = Acceleration due to gravity = 9.81 m3/s

H = Available head (m)

The density of water and acceleration due to gravity has been assumed to be constant. The only two variables in equation (3.4) are river discharge and available head, which vary along the length of the rivers and have already been evaluated using ArcGIS. So the power output can be easily evaluated.

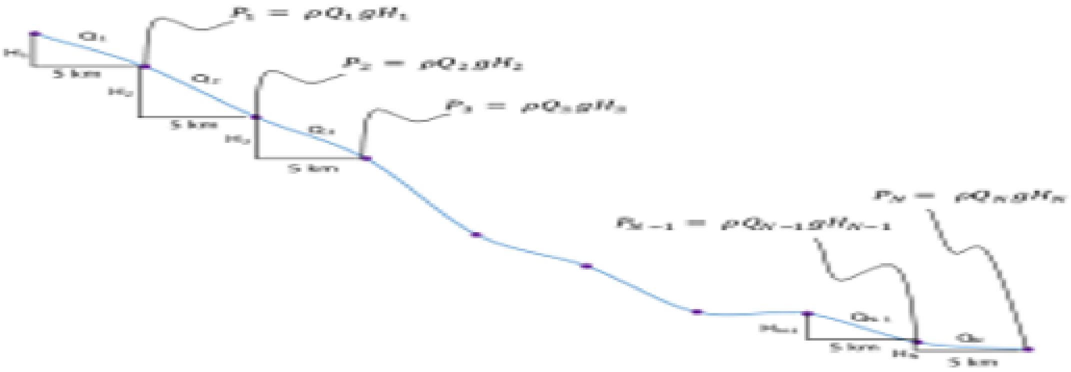


FIGURE 3.24: Diagrammatic Explanation of the Approach used for Evaluating Hydropower Potential

3.5 Summary

It can be summarized as first of all obtained the DEM and after performing steps in Arc GIS as discussed in section methodology, raster data is converted into the vector feature class file and thus the drainage lines obtained after performing drainage line processing in Arc GIS and by tool sampling in Arc GIS points at 5 Km distance are marked and hence the values are extract at the predefined points. After this the discharge is also calculated at these points too by using ratio proportion technique as discussed above so the two main parameters required for the evaluation of hydropower had been evaluated so by using the equations discussed above , hydropower can be evaluated.

Chapter 4

Results and Analysis

4.1 Background

The selected study area is discussed in previous chapter. The two main requisite parameters i.e. elevation and discharge for the evaluation of hydropower at a given points have been calculated by adopting the methodology as discussed in the previous chapter, hence the evaluation of hydropower potential in the Jhelum and Indus basins, the alternate objective of this study have been achieved. This chapter discuss the results i.e. hydropower obtained by using the methodology described in previous chapter.

4.2 Hydropower Potential in Indus Basin

The minor rivers and its tributaries are also rich in hydropower potential. The total potential for river Run-Off-River hydropower generation for Shyok River is 1023.9 MW at 19 points of interest and maximum and minimum hydropower potential are 184.085 MW and 1.74 MW respectively with an average of 53.8895 MW. The total potential for river Run-Off-River hydropower generation for Shigar River is 1141.18 MW at 23 points of interest and maximum and minimum hydropower potential are 191.30 MW and 4.105 MW respectively with an average of 45.65

MW. The total potential for river Run-Off-River hydropower generation for Hunza Gilgit River is 6510.72MW at 68 points of interest and maximum and minimum hydropower potential are 271.2235 MW and 15.0113 MW respectively with an average of 95.75 MW. The total hydropower potential at minor tributaries in Indus basin is 56.27MW. Thus the total gross hydropower generation capacity at the above mentioned minor rivers sums up to 8728MW and the average hydropower generation is 75.2414MW.

4.2.1 General Analysis of Hydropower Potential in Indus Basin

The hydropower potential is low near the upstream end of the river where it enters Pakistan, followed by a subsequent increase as it is joined by several minor rivers i.e. Shyok River, Shigar River, Hunza and Gilgit River, Astore River etc and several minor tributaries downstream. Figure 4.1 shows a large hydropower potential near the junction of the Shyok River, Shigar River and Astore River with Indus River in the vicinity of Kharmong_Kachura with values as high as 334.059 MW and an average potential of 94.64 MW. Similarly when the same discharge of rivers reaches in the vicinity of Bunji and also there is sufficient head difference is available between the vicinity of Kachura_Bunji with values as high as 1434.9644 MW and 1186.7680 MW and average potential of 527.011 MW, much of which is concentrated near the downstream end of the reach. By examining the overall Picture this is the most rich hydropower potential reach in whole Indus basin. A significant potential for hydropower generation is also observed midway in the reach from Bunji to Shatial with peak hydropower potential of as high as 1071.5625 MW and an average potential of 342.3233 MW. Similarly in the lower reach i.e. Shatial to Besham in excess of hydropower potential with an average of 581.714 MW. The Peak value in this vicinity i.e. 1587.05 MW. Points that fall D/S of Besham is also exhibit a moderate power potential ranging average up to 322.2715 MW, probably because the reach has a flatter slope as compared to the rest of the reaches, resulting in a smaller available head. The large hydropower potential is observed near Tarbela Dam, roughly 2056.498 MW, which seems consistent with the fact that Tarbela Dam is the largest earthen dam in the world and is one of the primary sources of electrical power in the country. Had Tarbela Dam been be a Run-Off-River hydropower plant it would have theoretically generated 2056.498 MW instead of its actual generating capacity of 3478 MW. The total potential for river Run-Off-River hydropower generation for Indus River is 35716.7159 MW at 100 points of interest and maximum and minimum hydropower potential are 2056.4931 MW and 11.020 MW respectively with an average of 357.1672 MW.

4.2.2 Overall Indus Basin Result Analysis

The net hydropower potential over the entire Indus Basin through Run-Off-River at the interval of 5 Km at 225 different points is 44444.72MW with maximum and minimum 2056.49 MW and 1.5454 MW respectively, with an average hydropower generation is 205.76 MW.

The Results for the spatial distribution of the hydropower potential in the Indus basin area are shown in Table 4.1 and a Figure 4.1.The yellow highlighted points are representing the above 50MW and below average i.e. 205.762 MW, the red highlighted points are above average i.e. 205.762 MW and below 1000MW hydropower potential points. The values highlighted in green corresponding to a hydropower potential greater than 1000 MW and these points are more likely to be suitable for the development of a hydropower scheme.

TABLE 4.1: Evaluation of Hydropower along the Indus River and its Tributaries at Interval of 5 Km

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
				(a) Hunza River					
1	74°49'22"E	36°44'25"N	2931	-	-	74.48	-	-	
2	74°49'5"E	36°41'51"N	2858	2931	73	74.88	53.627	46.977	
3	74°50'23"E	36°39'23"N	2747	2858	111	105.40	114.778	100.545	
4	74°51'25"E	36°36'53"N	2714	2747	33	106.41	34.451	30.179	
5	74°47'32"E	36°34'15"N	2673	2714	41	111.45	44.829	39.270	
6	74°49'8"E	36°31'55"N	2587	2673	86	111.98	94.477	82.762	
7	74°52'3"E	36°31'7"N	2548	2587	39	124.41	47.601	41.699	
8	74°53'25"E	36°29'7"N	2459	2548	89	128.66	112.336	98.406	
9	74°53'49"E	36°28'12"N	2449	2459	10	191.60	18.796	16.465	
10	74°53'35"E	36°26'36"N	2431	2449	18	194.83	34.404	30.138	
11	74°52'40"E	36°24'19"N	2411	2431	20	195.49	38.356	33.600	
12	74°51'25"E	36°21'38"N	2386	2411	25	199.52	48.933	42.865	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
13	74°51'42"E	36°19'7"N	2342	2386	44	201.08	86.796	76.034	
14	74°49'11"E	36°18'29"N	2319	2342	23	201.56	45.480	39.840	
15	74°46'30"E	36°17'55"N	2261	2319	58	202.42	115.177	100.895	
16	74°43'22"E	36°18'12"N	2152	2261	109	203.74	217.866	190.850	
17	74°40'41"E	36°18'47"N	2086	2152	66	204.29	132.275	115.873	
18	74°37'43"E	36°18'16"N	2054	2086	32	247.64	77.742	68.102	
19	74°36'14"E	36°16'19"N	2043	2054	11	256.40	27.669	24.238	
20	74°34'3"E	36°15'14"N	1980	2043	63	257.24	158.984	139.270	
21	74°31'2"E	36°15'11"N	1902	1980	78	260.87	199.616	174.863	
22	74°28'31"E	36°14'43"N	1881	1902	21	261.97	53.969	47.277	
23	74°25'40"E	36°14'16"N	1846	1881	35	264.39	90.780	79.523	
24	74°22'45"E	36°14'50"N	1791	1846	55	265.62	143.319	125.547	
25	74°20'31"E	36°14'50"N	1764	1791	27	287.78	76.226	66.774	
26	74°17'19"E	36°10'57"N	1670	1764	94	294.12	271.224	237.592	
27	74°17'43"E	36°8'30"N	1618	1670	52	295.53	150.757	132.063	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
28	74°17'30"E	36°5'25"N	1571	1618	47	297.18	137.022	120.031	
29	74°17'13"E	36°2'30"N	1526	1571	45	304.59	134.465	117.791	
30	74°18'25"E	36°0'10"N	1491	1526	35	306.13	105.113	92.079	
31	74°19'57"E	35°58'3"N	1463	1491	28	306.60	84.217	73.774	
32	74°22'0"E	35°56'41"N	1437	1463	26	307.23	78.364	68.647	
33	74°22'26"E	35°55'49.47"N	1424	1437	13	311.00	39.673	34.754	**Dainyour**
						Subtotal	**3069.32**	**2688.72**	
(b) Gilgit River									
1	72°59'57"E	36°10'54"N	2621	-	-	25.55	-	-	
2	73°3'2"E	36°11'1"N	2601	2621	20	76.51	15.011	13.150	
3	73°5'39"E	36°9'55"N	2514	2601	87	79.12	67.527	59.153	
4	73°11'15"E	36°10'54"N	2391	2514	123	84.76	102.274	89.592	
5	73°14'17"E	36°11'49"N	2370	2391	21	85.97	17.711	15.515	
6	73°19'32"E	36°14'19"N	2334	2370	36	114.7	40.507	35.485	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
7	73°22'37"E	36°14'50"N	2222	2334	112	115.81	127.243	111.465	
8	73°25'32"E	36°14'26"N	2157	2222	65	175.52	111.920	98.042	
9	73°28'20"E	36°13'24"N	2131	2157	26	179.43	45.765	40.091	
10	73°33'55"E	36°14'43"N	2055	2131	76	188.76	140.732	123.281	
11	73°36'50"E	36°15'38"N	2043	2055	12	190.09	22.377	19.603	
12	73°39'45"E	36°16'6"N	1976	2043	67	194.73	127.990	112.119	
13	73°41'58"E	36°13'59"N	1921	1976	55	196.1	105.806	92.686	
14	73°44'11"E	36°12'21"N	1866	1921	55	197.53	106.577	93.362	
15	73°47'0"E	36°11'2"N	1843	1866	23	274.45	61.924	54.246	
16	73°49'51"E	36°9'58"N	1828	1843	15	276.05	40.621	35.584	
17	73°52'1"E	36°8'1"N	1805	1828	23	281.64	63.546	55.667	
18	73°54'30"E	36°6'22"N	1788	1805	17	293.51	48.949	42.879	
19	73°57'26"E	36°5'57"N	1772	1788	16	294.96	46.297	40.556	
20	73°59'48"E	36°5'51"N	1724	1772	48	296.21	139.479	122.184	
21	74°2'46"E	36°5'21"N	1698	1724	26	304.94	77.778	68.134	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
22	74°5'22"E	36°3'54"N	1691	1698	7	305.99	21.012	18.407	
23	74°8'3"E	36°2'51"N	1640	1691	51	309.13	154.661	135.483	
24	74°10'13"E	36°1'35"N	1594	1640	46	311.64	140.631	123.192	
25	74°12'26"E	36°0'3"N	1566	1594	28	312.41	85.813	75.172	
26	74°12'44"E	35°57'44"N	1512	1566	54	313.14	165.883	145.313	
27	74°14'28"E	35°56'2"N	1482	1512	30	313.84	92.363	80.910	
28	74°17'24"E	35°55'28"N	1465	1482	17	329.06	54.877	48.073	
29	74°20'18"E	35°55'32"N	1444	1465	21	330.22	68.029	59.593	
						Subtotal	**2293.3**	**2008.934**	

(c) Gilgit-Hunza River

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
1	74°20'18"E	35°55'32"N	1444	-	-	-	-	-	
2	74°22'4"E	35°54'45"N	1424	1444	20	641.58	125.878	110.269	
3	74°24'24"E	35°53'24"N	1396	1424	28	644.54	177.042	155.089	
4	74°27'2"E	35°53'22"N	1375	1396	21	645.18	132.914	116.432	
5	74°29'5"E	35°52'9"N	1350	1375	25	657.27	161.195	141.207	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
6	74°31'10"E	35°51'16"N	1339	1350	11	658.4	71.048	62.238	
7	74°33'31"E	35°49'31"N	1306	1339	33	660.26	213.746	187.241	
8	74°34'29"E	35°47'5"N	1292	1306	14	661.29	90.822	79.560	
9	74°35'30.12"E	35°46'14.988"N	1265	1292	27	662.39	175.447	153.692	**Alam bridge**
						Subtotal	**1148.1**	**1005.729**	
				(d) Hunza River Tributary					
1	74°57'18"E	36°30'2"N	2555	-	-	25.554	-	-	
2	74°54'30"E	36°29'51"N	2494	2555	61	76.511	45.785	40.108	
						Subtotal	**45.785**	**40.108**	
				(e) Indus River					
1	76°12'50"E	34°45'0"N	2543	-	-	139.49	-	-	
2	76°12'9"E	34°47'44"N	2524	2543	19	153.61	28.631	25.081	
3	76°13'25"E	34°55'24"N	2493	2524	31	353.86	107.612	94.268	
4	76°13'18"E	34°56'36"N	2484	2493	9	447.57	39.516	34.616	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
5	76°12'26"E	34°57'41"N	2479	2484	5	448.49	21.998	19.271	
6	76°9'49"E	34°58'5"N	2419	2479	60	451.89	265.982	233.001	
7	76°5'35"E	35°1'54"N	2366	2419	53	454.87	236.501	207.174	
8	76°3'46"E	35°3'30"N	2349	2366	17	459.3	76.597	67.099	
9	76°2'23"E	35°5'20"N	2337	2349	12	461.09	54.280	47.549	
10	75°59'25"E	35°5'37"N	2321	2337	16	469.66	73.718	64.577	
11	75°58'0"E	35°8'4"N	2314	2321	7	475.1	32.625	28.580	
12	75°55'36"E	35°9'44"N	2311	2314	3	480.53	14.142	12.388	
13	75°54'51"E	35°13'43"N	2289	2311	22	888.4	191.734	167.959	
14	75°52'17"E	35°14'31"N	2285	2289	4	889.35	34.898	30.571	
15	75°51'26"E	35°17'26"N	2282	2285	3	891.65	26.241	22.987	
16	75°50'14"E	35°20'11"N	2244	2282	38	896.13	334.059	292.636	
17	75°47'43"E	35°20'45"N	2231	2244	13	897.24	114.425	100.236	
18	75°46'14"E	35°18'31"N	2216	2231	15	898.06	132.150	115.763	
19	75°43'9"E	35°18'7"N	2202	2216	14	899.68	123.562	108.240	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
20	75°40'59"E	35°18'55"N	2191	2202	11	901.3	97.259	85.199	
21	75°38'31"E	35°18'28"N	2187	2191	4	902.28	35.405	31.015	
22	75°37'40"E	35°19'23"N	2186	2187	1	1124.16	11.028	9.661	
23	75°34'59"E	35°20'52"N	2182	2186	4	1124.16	44.112	38.642	
24	75°32'25"E	35°21'53"N	2176	2182	6	1129.46	66.480	58.236	
25	75°30'25"E	35°23'57"N	2175	2176	1	1131.23	11.097	9.721	
26	75°27'20"E	35°27'9"N	2158	2175	17	1151.36	192.012	168.203	
27	75°26'15"E	35°27'43"N	2157	2158	1	1152.84	11.309	9.907	
28	75°23'27"E	35°28'31"N	2096	2157	61	1156.11	691.828	606.041	
29	75°21'30"E	35°29'15"N	2077	2096	19	1166.24	217.375	190.421	
30	75°20'39"E	35°32'14"N	2025	2077	52	1171.05	597.376	523.301	
31	75°19'54"E	35°35'12"N	2011	2025	14	1174.96	161.369	141.359	
32	75°13'54"E	35°35'22"N	1978	2011	33	1198.1	387.861	339.766	
33	75°11'13"E	35°35'12"N	1915	1978	63	1211.31	748.626	655.796	
34	75°8'15"E	35°36'3"N	1866	1915	49	1213.87	583.495	511.142	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
35	75°3'41"E	35°37'49"N	1817	1866	49	1235.48	593.883	520.241	
36	75°0'43"E	35°37'36"N	1780	1817	37	1263.43	458.587	401.722	
37	74°53'41"E	35°41'53"N	1666	1780	114	1283.12	1434.964	1257.029	
38	74°47'52"E	35°42'34"N	1601	1666	65	1294.59	825.495	723.134	
39	74°44'43"E	35°42'48"N	1569	1601	32	1298.76	407.707	357.151	
40	74°45'18"E	35°45'11"N	1476	1569	93	1300.81	1186.768	1039.609	
41	74°42'20"E	35°50'20"N	1417	1476	59	1343.96	777.871	681.415	
42	74°39'25"E	35°49'35"N	1355	1417	62	1346.78	819.139	717.565	
43	74°37'25"E	35°47'25"N	1312	1355	43	1349.67	569.331	498.734	
44	74°38'51"E	35°45'32"N	1265	1312	47	1351.78	623.265	545.980	
45	74°37'25"E	35°44'34"N	1252	1265	13	1352.3	172.459	151.074	
46	74°38'57"E	35°42'13"N	1246	1252	6	2020.76	118.942	104.193	
47	74°37'21"E	35°39'49"N	1243	1246	3	2054.25	60.457	52.960	
48	74°36'47"E	35°37'25"N	1216	1243	27	1816.5	481.136	421.475	
49	74°37'52"E	35°35'15"N	1207	1216	9	1817.73	160.487	140.587	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
50	74°38'40"E	35°34'14"N	1191	1207	16	1817.91	285.339	249.957	
51	74°33'39"E	35°28'48"N	1171	1191	20	1983.39	389.141	340.888	
52	74°30'37"E	35°28'41"N	1116	1171	55	1986.03	1071.562	938.689	
53	74°28'17"E	35°27'46"N	1108	1116	8	1988.35	156.046	136.696	
54	74°26'10"E	35°25'36"N	1103	1108	5	1994.25	97.818	85.689	
55	74°23'19"E	35°24'52"N	1067	1103	36	1999.46	706.129	618.569	
56	74°20'20"E	35°24'41"N	1061	1067	6	2001.01	117.779	103.175	
57	74°17'36"E	35°25'22"N	1039	1061	22	2030.87	438.302	383.953	
58	74°9'12"E	35°24'24"N	1014	1039	25	2043.22	501.100	438.963	
59	73°58'40"E	35°27'9"N	986	1014	28	2098.7	576.471	504.989	
60	73°56'57"E	35°29'7"N	981	986	5	2099.28	102.970	90.201	
61	73°53'52"E	35°29'17"N	972	981	9	2104.02	185.764	162.729	
62	73°50'42"E	35°29'33"N	966	972	6	2122.34	124.921	109.431	
63	73°39'29"E	35°31'36"N	947	966	19	2164.21	403.387	353.367	
64	73°32'38"E	35°31'46"N	946	947	1	2155.21	21.142	18.521	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
65	73°25'26"E	35°31'39"N	914	946	32	2191.49	687.953	602.646	
66	73°22'36"E	35°30'40"N	895	914	19	2198.6	409.797	358.982	
67	73°14'13"E	35°27'35"N	864	895	31	2213.86	673.257	589.773	
68	73°11'59"E	35°25'31"N	821	864	43	2296.92	968.910	848.765	
69	73°12'14"E	35°22'26"N	803	821	18	2302.02	406.491	356.086	
70	73°11'59"E	35°19'42"N	786	803	17	2305.8	384.538	336.856	
71	73°12'40"E	35°14'59"N	749	786	37	2318.83	841.666	737.299	
72	73°7'47"E	35°11'59"N	681	749	68	2379.1	1587.050	1390.256	
73	72°59'8"E	35°4'58"N	670	681	11	2438.1	263.095	230.472	
74	72°57'15"E	35°2'54"N	662	670	8	2439.23	191.431	167.693	
75	72°54'30"E	35°2'18"N	626	662	36	2442.28	862.516	755.564	
76	72°54'10"E	34°58'1"N	595	626	31	2464.75	749.555	656.610	
77	72°52'53"E	34°56'19"N	591	595	4	2461.72	96.598	84.620	
78	72°52'58"E	34°55'37"N	586	591	5	2461.75	120.749	105.776	
79	72°52'32"E	34°53'8"N	563	586	23	2504.05	564.989	494.930	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
80	73°0'5"E	34°49'27"N	527	563	36	2507.37	885.503	775.700	
81	72°55'32"E	34°46'58"N	516	527	11	2509.95	270.849	237.263	
82	72°53'13"E	34°45'36"N	511	516	5	2530.77	124.134	108.742	
83	72°50'14"E	34°46'2"N	500	511	11	2532.74	273.308	239.418	
84	72°48'26"E	34°43'33"N	497	500	3	2537.86	74.689	65.428	
85	72°47'55"E	34°40'48"N	466	497	31	2539.88	772.403	676.625	
86	72°48'41"E	34°33'21"N	453	466	13	2558.96	326.344	285.877	
87	72°46'7"E	34°31'49"N	449	453	4	2560.69	100.481	88.022	
88	72°47'44"E	34°29'50"N	446	449	3	2561.43	75.383	66.035	
89	72°50'3"E	34°29'56"N	443	446	3	2564.4	75.470	66.112	
90	72°49'22"E	34°27'21"N	440	443	3	2565.71	75.508	66.146	
91	72°49'26"E	34°27'14"N	439	440	1	2565.71	25.168	22.049	
92	72°49'2"E	34°24'11"N	436	439	3	2566.1	75.520	66.156	
93	72°49'38"E	34°20'56"N	432	436	4	2621.47	102.866	90.111	
94	72°50'3"E	34°15'22"N	411	432	21	2640.16	543.899	476.456	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
95	72°40'43"E	34°4'19"N	335	411	76	2758.32	2056.493	1801.488	
96	72°36'21"E	34°0'33"N	322	335	13	2759.48	351.916	308.279	
97	72°33'52"E	33°59'46"N	310	322	12	2765.56	325.562	285.192	
98	72°31'2"E	34°0'38"N	303	310	7	2781.82	191.028	167.340	
99	72°25'44"E	34°0'7"N	290	303	13	2786.3	355.337	311.275	
100	72°23'8"E	33°59'17"N	288	290	2	2804.32	55.021	48.198	
101	72°21'23"E	33°57'2"N	283	288	5	2804.61	137.566	120.508	
						Subtotal	**35716.715**	**31287.843**	
(f) U/S of Kharmong minor tributary									
1	76°15'38"E	34°42'46"N	2546	-	-	7.27	-	-	
2	76°12'50"E	34°45'0"N	2543	2546	3	139.49	4.105	3.596	
						Subtotal	**4.105**	**3.596**	
(g) Shigar River									
1	75°54'56"E	35°41'27"N	3050	-	-	96.81	-	-	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
2	75°52'15"E	35°40'10"N	2982	3050	68	100.19	66.835	58.547	
3	75°49'48"E	35°40'36"N	2931	2982	51	110.75	55.409	48.539	
4	75°47'1"E	35°41'1"N	2881	2931	50	112.19	55.029	48.206	
5	75°44'20"E	35°41'1"N	2849	2881	32	114.66	35.994	31.531	
6	75°41'56"E	35°42'57"N	2748	2849	101	117.51	116.430	101.993	
7	75°38'59"E	35°43'55"N	2621	2748	127	118.71	147.897	129.558	
8	75°35'33"E	35°41'21"N	2569	2621	52	129.3	65.959	57.780	
9	75°33'12"E	35°41'46"N	2419	2569	150	130	191.295	167.574	
10	75°30'31"E	35°42'50"N	2391	2419	28	131.56	36.137	31.656	
11	75°28'42"E	35°41'14"N	2358	2391	33	132.56	42.914	37.592	
12	75°28'29"E	35°38'8"N	2354	2358	4	182.13	7.147	6.261	
13	75°30'51"E	35°37'4"N	2295	2354	59	182.57	105.670	92.567	
14	75°32'14"E	35°34'55"N	2286	2295	9	184.28	16.270	14.253	
15	75°34'42"E	35°33'25"N	2255	2286	31	188.13	57.212	50.118	
16	75°36'12"E	35°31'49"N	2245	2255	10	189.89	18.628	16.318	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
17	75°37'55"E	35°30'6"N	2237	2245	8	192.51	15.108	13.235	
18	75°40'29"E	35°28'36"N	2226	2237	11	196.83	21.240	18.606	
19	75°42'24"E	35°26'47"N	2218	2226	8	201.06	15.779	13.823	
20	75°43'16"E	35°24'45"N	2215	2218	3	208.76	6.144	5.382	
21	75°43'16"E	35°24'45"N	2208	2215	7	209	14.352	12.572	
22	75°43'16"E	35°22'23"N	2205	2208	3	209.65	6.170	5.405	
23	75°40'42"E	35°21'58"N	2202	2205	3	210.62	6.199	5.430	
24	75°38'27"E	35°20'41"N	2193	2202	9	211.56	18.679	16.362	
25	75°37'40"E	35°19'23"N	2186	2193	7	212.26	14.576	12.768	**Confluence of Shigar with Indus**
						Subtotal	**1137.07**	**996.075**	

(h) Shyok River

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
1	76°43'6"E	34°55'33"N	2673	-	-	132.23	-	-	
2	76°39'58"E	34°55'33"N	2645	2673	28	139.38	38.2849	33.538	
3	76°37'7"E	34°56'7"N	2620	2645	25	142.88	35.0413	30.696	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
4	76°32'7"E	34°58'45"N	2586	2620	34	162.07	54.0568	47.354	
5	76°30'41"E	35°1'24"N	2558	2586	28	169.48	46.5528	40.780	
6	76°29'37"E	35°4'7"N	2538	2558	20	171.42	33.6326	29.462	
7	76°28'20"E	35°6'32"N	2516	2538	22	176.56	38.1052	33.380	
8	76°27'11"E	35°9'6"N	2515	2516	1	178.24	1.7485	1.532	
9	76°24'29"E	35°9'45"N	2480	2515	35	179.8	61.7343	54.079	
10	76°23'41"E	35°10'23"N	2479	2480	1	339.26	3.3281	2.915	
11	76°20'50"E	35°10'32"N	2469	2479	10	340.48	33.4011	29.259	
12	76°16'12"E	35°12'49"N	2459	2469	10	350.46	34.3801	30.117	
13	76°11'46"E	35°13'36"N	2451	2459	8	375.59	29.4763	25.821	
14	76°7'51"E	35°12'23"N	2425	2451	26	381.23	97.2365	85.179	
15	76°6'4"E	35°10'36"N	2376	2425	49	382.96	184.0850	161.258	
16	76°3'21"E	35°11'15"N	2344	2376	32	386.24	121.2485	106.214	
17	76°0'42"E	35°11'41"N	2321	2344	23	388.1	87.5670	76.709	
18	75°58'0"E	35°12'2"N	2318	2321	3	390.12	11.4812	10.058	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydro electricity (x10^10 Whyr)	Remarks
19	75°55'43"E	35°13'58"N	2293	2318	25	395.55	97.0086	84.980	
20	75°54'51"E	35°13'43"N	2289	2293	4	395.8	15.5312	13.605	
						Subtotal	**1023.90**	**896.937**	
(i) Shyok Minor tributary									
1	76°24'29"E	35°14'49"N	2545	-	-	159.46	-	-	
2	76°25'33"E	35°12'32"N	2505	2545	40	157.92	1.549	1.357	
3	76°24'46"E	35°10'15"N	2483	2505	22	157.53	1.545	1.354	
4	76°23'41"E	35°10'23"N	2479	2483	4	339.26	3.328	2.915	
						Subtotal	**6.423**	**5.626**	
						Grand Total	**44,444.7179**	**38933.573**	

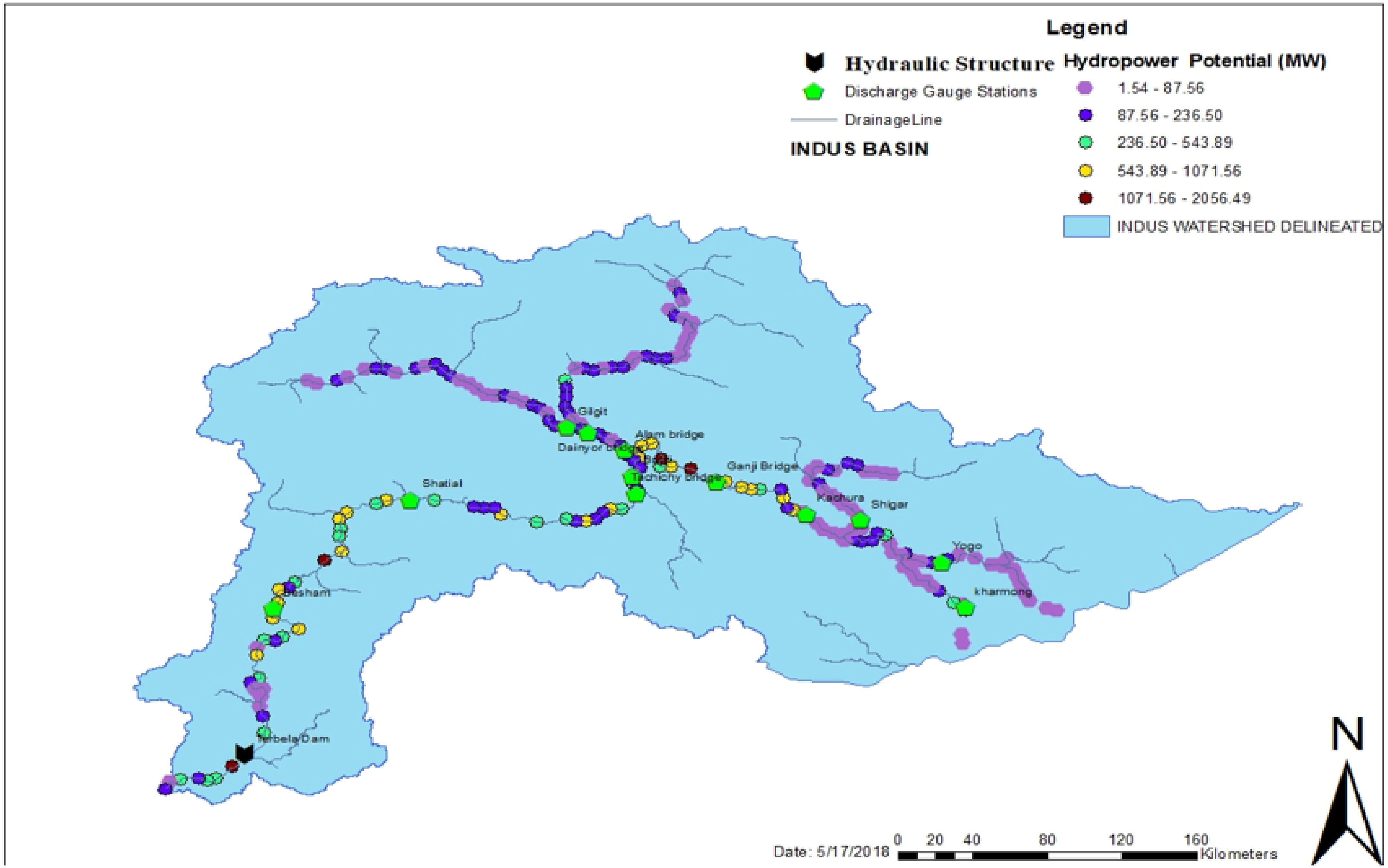


Figure 4.1: Arc GIS Evaluated Points for the Generation of Hydropower in Indus Basin

4.3 Hydropower Potential in Jhelum Basin

4.3.1 Hydropower Potential at Neelum, Kunhar and Pounch River in Jhelum Basin

The hydropower potential is low near the upstream end of the Jhelum River where it enters Pakistan, followed by a subsequent increase as it is joined by several minor rivers i.e. Neelum River, Kunhar River, Poonch River etc and several minor tributaries downstream. Figure 4.2 shows a large hydropower potential near the junction of the Neelum River and Kunhar River with Jhelum River in the vicinity of Mangla dam with values as high as 858.403 MW. Similarly for the Neelum River it is clear from figure that it starts from Pakistan boundary and approx. after 65Km it enters in Indian Held Kashmir tertiary so it become less effective in Jhelum Basin . While the total 22 points generated at Neelum River with gross Hydropower generation of 2844.41MW and maximum and minimum hydropower potential of 330.37 MW and 2.87 MW respectively, and an average hydropower potential of 129.28MW. The gross hydropower potential in the Kunhar River is 1512.322MW and maximum and minimum hydropower potential is 159.196 MW and 9.036 MW respectively, and an average hydropower potential of 75.616 MW. The Poonch River also explicit the hydropower potential of gross hydropower generation of 609.34MW, and maximum and minimum hydropower generation potential is 180.522 MW and 13.094 MW respectively, and an average hydropower generation potential from Run-Off-River is 55.397 MW. The combine hydropower potential from above mentioned three Run-Off-River is 4965.802MW.

4.3.2 Hydropower Potential at Jhelum River in Jhelum Basin

The Jhelum River show different type of behavior at different localities explained below:

By examining the overall picture of whole Jhelum basin it is clear that sufficient hydropower potential is available in the vicinity of River Jhelum. Upstream Hattian Bala gauge station there is gross hydropower generation capacity from river Run-Off-River is 1359.78MW and maximum and minimum hydropower generation potential is 159.196MW and 9.036 MW respectively, and an average hydropower generation potential is 71.567 MW. Similarly Downstream of Chattar Klass and Domel gauge station there is gross hydropower generation capacity from Run-Off-River is 2900.303 MW and maximum and minimum hydropower generation potential is 285.868 MW and 7.499 MW respectively, and an average hydropower generation potential is 126.100 MW. Downstream of Azad Pattan gauge station the gross hydropower potential from Run-Off-River is 1242.845 MW and maximum and minimum hydropower generation potential is 309.141 MW and 16.425 MW respectively, and an average hydropower potential is 88.775 MW. Downstream of Mangla Reservoir there is hydropower potential from Run-Off-River generation is 1410.696MW, and maximum and minimum hydropower potential is 858.403 MW and 12.774 MW respectively and an average hydropower potential is 156.744 MW. The one points of interest for hydropower potential observed near Mangla Dam is from Poonch River with hydropower potential of 858.403 MW. Had Mangal Dam been be a Run-Off-River hydropower plant it would have theoretically generated approx 858.403 MW instead of its actual generating capacity of 1150 MW.

4.3.3 Overall Result Analysis in Jhelum Basin

The net generation of hydropower from Run-Off-River Jhelum is 5144.063 MW and an average hydropower generation from river run off is 119.629 MW. The net hydropower potential over the entire Jhelum Basin through river run off at the interval of 5 Km at 102 different points is 10109.85MW with maximum and minimum 858.40 MW and 2.87 MW respectively, with an average hydropower generation is 105.31 MW.

The results for the spatial distribution of the hydropower potential in the Jhelum basin area are shown in Table 4.2 and a Figure 4.2.The yellow highlighted points are representing the above 50MW and below average i.e. 105.311MW hydropower potential points. The values highlighted in red corresponding to a hydropower potential greater than average hydropower potential in the vicinity i.e. 105.311 MW and below 500MW and these points are more likely to be suitable for the development of a hydropower scheme. The value heighted with green corresponding to highest Run-Off-River potential point i.e. 854.403 MW.

TABLE 4.2: Evaluation of Hydropower along the Jhelum River and its Tributaries

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
(a) Neelum River									
1	74°31'11"E	34°47'18"N	2365	-	-	89.07	-	-	
2	74°28'14"E	34°48'9"N	2095	2365	270	93.97	248.91	218.04	
3	74°25'32"E	34°48'55"N	2044	2095	51	97.22	48.64	42.61	
4	74°22'35"E	34°49'23"N	2007	2044	37	98.96	35.92	31.46	
5	74°19'46"E	34°49'11"N	1983	2007	24	148.55	34.97	30.64	
6	74°16'45"E	34°48'44"N	1921	1983	62	151.79	92.32	80.87	
7	74°13'53"E	34°49'24"N	1874	1921	47	155.26	71.59	62.71	
8	74°8'56"E	34°46'20"N	1836	1874	38	205.01	76.42	66.95	
9	74°8'13"E	34°43'21"N	1818	1836	18	206.97	36.55	32.01	
10	74°2'42"E	34°43'23"N	1737	1818	81	216.86	172.32	150.95	
11	73°59'58"E	34°43'12"N	1608	1737	129	226.59	286.75	251.19	
12	73°55'43"E	34°36'28"N	1416	-	-	245.24			

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
13	73°53'37"E	34°34'45"N	1357	1416	59	247.58	143.29	125.53	
14	73°52'4"E	34°33'37"N	1308	1357	49	247.58	119.01	104.25	
15	73°50'23"E	34°31'32"N	1263	1308	45	286.15	126.32	110.66	
16	73°49'34"E	34°28'51"N	1179	1263	84	290.68	239.53	209.83	
17	73°43'56"E	34°22'41"N	1033	-	-	310.53			
18	73°43'14.88"E	34°23'25.08"N	970	1033	63	289.19	178.73	156.57	
19	73°42'10"E	34°24'57"N	968	970	2	289.19	5.67	4.97	
20	73°39'54"E	34°26'35"N	967	968	1	292.21	2.87	2.51	
21	73°34'23"E	34°27'24"N	856	967	111	303.39	330.37	289.40	
22	73°31'54"E	34°27'14"N	780	856	76	313.75	233.92	204.92	
23	73°28'33"E	34°24'1"N	708	780	72	309.84	218.85	191.71	
24	73°28'2"E	34°21'14"N	666	708	42	312.64	128.81	112.84	
25	73°28'14.88"E	34°21'14"N	664	666	2	629.75	12.36	10.82	
						Subtotal	**2844.11**	**2491.44**	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
(b) Kunhar River									
1	73°43'1"E	34°56'40"N	2497	-	-	38.34	-	-	
2	73°38'55.32"E	34°54'32.76"N	2435	2497	62	46.05	28.009	24.535	
3	73°38'50"E	34°54'5"N	2410	2435	25	46.09	11.304	9.902	
4	73°36'42"E	34°52'16"N	2338	2410	72	48.33	34.142	29.909	
5	73°33'48"E	34°50'46"N	2298	2338	40	54.32	21.315	18.672	
6	73°31'14"E	34°49'23"N	2142	2298	156	55.84	85.465	74.867	
7	73°31'27"E	34°46'16"N	2006	2142	136	59.21	79.007	69.210	
8	73°30'29"E	34°43'36"N	1760	2006	246	61.70	148.917	130.451	
9	73°33'23"E	34°43'29"N	1659	1760	101	62.59	62.016	54.326	
10	73°34'7"E	34°41'2"N	1501	1659	158	72.22	111.950	98.068	
11	73°28'53"E	34°39'45"N	1432	1501	69	79.13	53.564	46.922	
12	73°25'59"E	34°38'34"N	1232	1432	200	81.14	159.196	139.455	
13	73°23'51"E	34°37'10"N	1122	1232	110	88.32	95.313	83.494	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
14	73°20'44"E	34°31'43"N	1039	1122	83	93.26	75.939	66.522	
15	73°21'10"E	34°28'43"N	890	1039	149	97.64	142.719	125.022	
16	73°21'36"E	34°26'28"N	845	890	45	98.53	43.497	38.103	
17	73°22'53"E	34°23'54"N	825	845	20	99.22	19.467	17.053	
18	73°22'53"E	34°23'54"N	816	825	9	102.34	9.036	7.916	
19	73°26'57"E	34°18'20"N	780	816	36	106.88	37.749	33.068	
20	73°28'38"E	34°17'22"N	650	780	130	110.70	141.178	123.672	
21	73°28'20"E	34°15'27"N	629	650	21	740.45	152.540	133.625	
						Subtotal	**1512.322**	**1324.7939**	
				(c) Jhelum River					
1	73°52'42"E	34°7'19"N	1059	-	-	128.15			
2	73°47'50"E	34°10'13"N	951	1059	108	222.88	236.138	206.857	
3	73°42'13"E	34°11'0"N	888	951	63	291.07	179.894	157.587	
4	73°39'49"E	34°12'9"N	879	888	9	294.14	25.970	22.750	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
5	73°37'20"E	34°13'21"N	807	879	72	301.20	212.747	186.366	
6	73°35'4"E	34°15'24"N	785	807	22	306.83	66.222	58.011	
7	73°33'26"E	34°17'30"N	745	785	40	310.26	121.747	106.651	
8	73°31'20"E	34°19'16"N	733	745	12	311.68	36.692	32.142	
9	73°29'4"E	34°20'40"N	708	733	25	316.53	77.631	68.005	
10	73°28'11"E	34°21'15"N	668	708	40	317.11	124.434	109.004	
11	73°28'2"E	34°21'14"N	664	668	4	629.74	24.711	21.647	
12	73°27'49"E	34°20'25"N	650	664	14	630.50	86.593	75.856	
13	73°28'20"E	34°15'27"N	629	650	21	740.45	152.540	133.625	
14	73°29'37"E	34°12'45"N	619	629	10	751.07	73.681	64.544	
15	73°29'30"E	34°9'50"N	616	619	3	755.84	22.244	19.486	
16	73°29'54"E	34°4'24"N	582	616	34	762.40	254.291	222.759	
17	73°31'46"E	33°58'52"N	581	582	1	764.38	7.499	6.569	
18	73°32'55"E	33°56'16"N	543	581	38	766.85	285.868	250.420	
19	73°35'11"E	33°54'2"N	534	543	9	785.16	69.323	60.727	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
20	73°35'6"E	33°51'20"N	511	534	23	786.24	177.401	155.403	
21	73°34'5"E	33°48'30"N	478	511	33	787.37	254.896	223.289	
22	73°34'25"E	33°45'51"N	463	478	15	788.73	116.062	101.671	
23	73°36'11"E	33°43'50"N	452	463	11	795.99	85.895	75.244	
24	73°34'48"E	33°40'56"N	434	452	18	800.93	141.430	123.893	
25	73°35'45"E	33°36'10"N	422	434	12	808.51	95.178	83.376	
26	73°37'35"E	33°33'57"N	384	422	38	829.28	309.141	270.807	
27	73°38'16"E	33°31'30"N	368	384	16	830.93	130.423	114.251	
28	73°36'54"E	33°29'50"N	361	368	7	833.93	57.266	50.165	
29	73°36'52"E	33°28'25"N	359	361	2	837.15	16.425	14.388	
30	73°37'15"E	33°27'0"N	353	359	6	845.10	49.743	43.575	
31	73°35'29"E	33°25'18"N	342	353	11	846.90	91.390	80.057	
32	73°34'43"E	33°23'42"N	339	342	3	848.10	24.960	21.865	
33	73°34'23"E	33°21'19"N	337	339	2	856.88	16.812	14.727	
34	73°36'46"E	33°15'24"N	341	347	6	866.92	51.027	44.700	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
35	73°38'47"E	33°13'21"N	335	341	6	969.96	57.092	50.012	
36	73°37'57"E	33°8'8"N	263	335	72	1215.31	858.403	751.961	
37	73°38'6"E	33°5'16"N	254	263	9	1221.06	107.807	94.439	
38	73°40'46"E	33°4'22"N	251	254	3	1226.35	36.091	31.616	
39	73°43'16"E	33°3'45"N	240	251	11	1229.07	132.629	116.183	
40	73°44'47"E	33°2'5"N	234	240	6	1235.34	72.712	63.696	
41	73°47'14"E	32°58'46"N	223	234	11	1287.40	138.924	121.697	
42	73°45'26"E	32°56'58"N	221	223	2	1303.87	25.582	22.410	
43	73°43'23"E	32°54'45"N	219	221	2	1313.62	25.773	22.577	
44	73°41'8"E	32°52'32"N	218	219	1	1302.11	12.774	11.190	
						Subtotal	**5144.063**	**4506.1992**	
				(d) Poonch River					
1	73°52'32"E	33°30'5"N	550	-	-	124.70	-	-	
2	73°53'4.92"E	33°29'20.04"	506	550	44	126.30	54.516	47.756	

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upstream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
		N							
3	73°52'42"E	33°28'17"N	506	550	44	162.35	70.077	61.388	
4	73°51'25"E	33°27'18"N	468	506	38	164.02	61.144	53.563	
5	73°50'44"E	33°26'12"N	451	468	17	169.59	28.283	24.776	
6	73°49'19"E	33°24'36"N	422	451	29	188.53	53.636	46.985	
7	73°47'8"E	33°24'11"N	415	422	7	190.68	13.094	11.471	
8	73°46'17"E	33°23'1"N	384	415	31	191.95	58.376	51.137	
9	73°46'2"E	33°21'47"N	364	384	20	196.09	38.474	33.703	
10	73°44'47"E	33°19'59"N	346	364	18	200.55	35.413	31.022	
11	73°44'42"E	33°17'38"N	338	346	8	201.66	15.827	13.864	
12	73°39'50"E	33°10'25"N	263	338	75	245.35	180.522	158.137	
						Subtotal	**609.364**	**533.80273**	
						Grand Total	**10109.85**	**8856.232**	

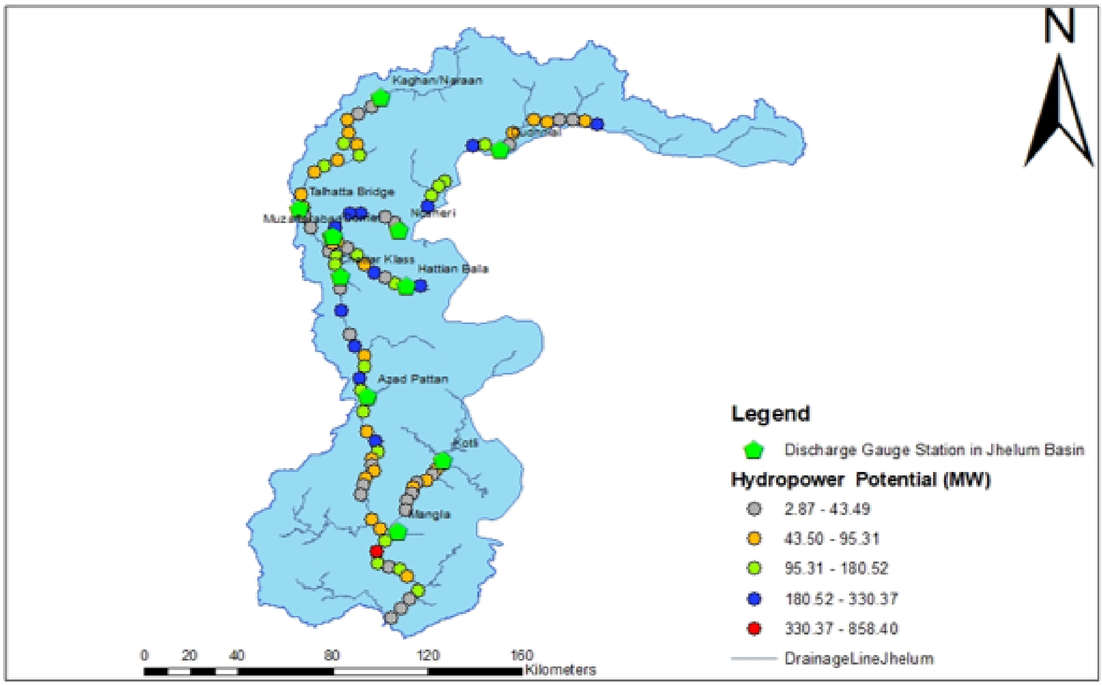


FIGURE 4.2: Arc GIS Evaluated Points for the Generation of Hydropower in Jhelum Basin

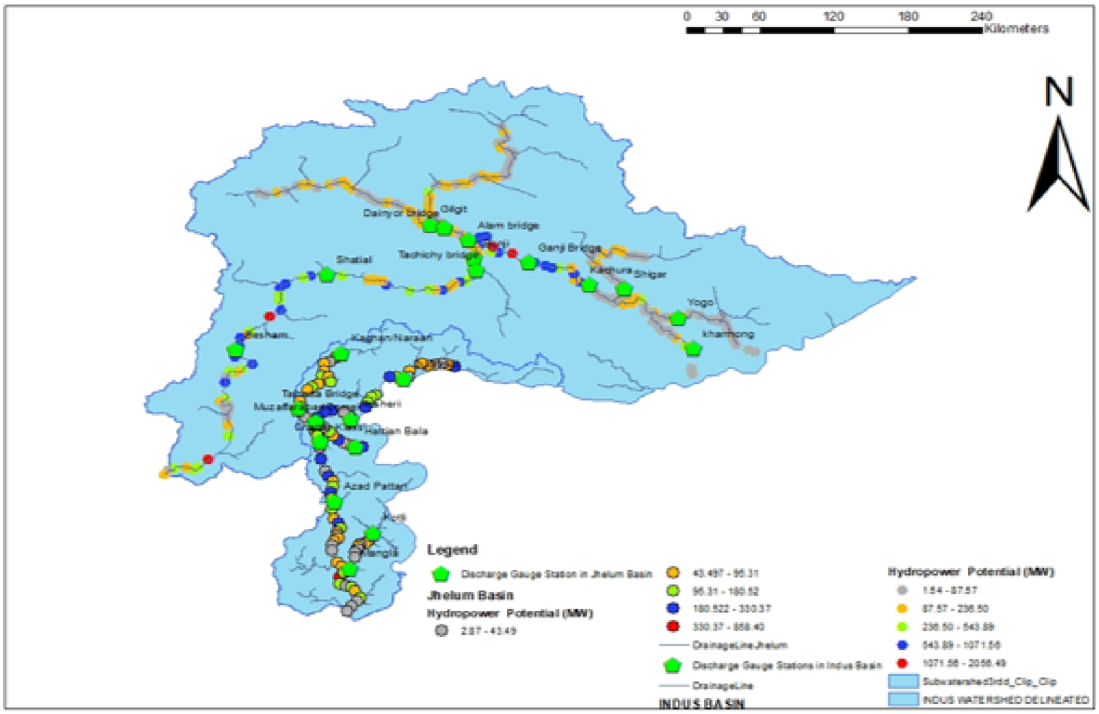


FIGURE 4.3: Arc GIS Evaluated Points for the Generation of Hydropower in Indus and Jhelum Basin

4.4 Comparison Between Indus and Jhelum Basin

Indus Basin is located between the longitudes of 7215’00”E to 77^{0}50’00”E and latitudes of 33^{0}50’00”N to 3705’00”N which is a portion of the Upper Indus Basin (UIB), falling within the boundaries of Pakistan. Hindukush-Karakorum-Himalaya (HKH) region constitutes a large part of the basin. The total Indus Basin area at the point of selection of Batch Point was determined to have a nearly 151211 km^2, much of which approx 52.49 % i.e. 79372 km^2 falls within the northernmost administrative territory of Pakistan, Gilgit-Baltistan. The basin is basically the catchment area of the Indus River, upstream of the Tarbela Reservoir which is country largest reservoir. Along the way, Indus River is joined by many small and large River and tributaries, most prominent of which are Shyok River, Shigar River, Hunza River, Gilgit River and Astore River.

The length of Largest River of Indus Basin within the territory of Pakistan is Indus River itself, approx. length 795 KM. The River is joined by Shyok River of approx. length 137 KM. The Shigar River of approx. length 129 KM joined Indus River. The Hunza and Gilgit Rivers of approx. length 417 KM also met Indus River. The minor tributaries of approx. length 51KM also join Indus River.

Upper Jhelum River Basin (UJB) the longitudes of 73^{0}00’00”E to 76^{0}00’00”E and latitudes of 33^{0}00’00”N to 35^{0}15’00”N situated in the north of Pakistan. The Jhelum River, along with Poonch, Neelum, Kunhar and Kanshi Rivers, the major streams of the Jhelum River, drain the southern slope of the Greater Himalayas and the northern slope of the Pir Punjal Mountains are located in Jammu and Kashmir. The total Jhelum Basin area at the point of selection of Batch Point was determined to have a nearly 36002 km^2, much of which approx. 48.56 % i.e. 17484 km^2 falls within the northernmost administrative territory of Pakistan, Azad Jammu &Kashmir. The basin is basically the catchment area of the Jhelum River, upstream of the Mangla reservoir which is the country second largest reservoir. Along the way, Jhelum River is joined by many small and large tributaries, most prominent of which are Neelum/Kishan Ganga River, Kunhar River, Poonch River and Kanshi River etc.

The length of Largest River of Jhelum Basin within the territory of Pakistan is Jhelum River itself, approx. length 296 KM. The River is joined by Kunhar River of approx. length 120 KM. The Neelum River of approx. length 146 KM joined Jhelum River. The Poonch River of approx. length 66 KM also met Jhelum River.

4.5 Summary

The result analysis shows that there is a vast hydropower potential in Jhelum and Indus basins that can be developed by erecting Run-Off-River schemes. The result shows that the hydropower potential in Indus basin is approx. 4 times that of Jhelum basin. The main reasons for this huge difference of feasible sites between Indus and Jhelum are elevations and discharge variations.

It is clear from below graphic representation of parameters. The maximum elevation value in Jhelum basin is 6285m while the maximum elevation value in Indus value is 8566m. Similarly, the minimum value in Jhelum basin is 214 m and the minimum elevation value in Indus value is 277 m. Thus, it shows that Indus basin is at high elevation relative with Jhelum basin. Similarly analysis of discharge shows that maximum annual average discharge in Jhelum basin is 795.99 cumecs at Azad Pattan discharge gauge station and the maximum annual average discharge in Indus basin is 2461.72 cumecs at Besham discharge gauge station. Thus, elevation and discharge both parameters analysis shows that Indus Basin is much more gifted for developing a hydropower schemes as compared with Jhelum basin. It will be economical to install several point of hydropower scheme with common Power Station.

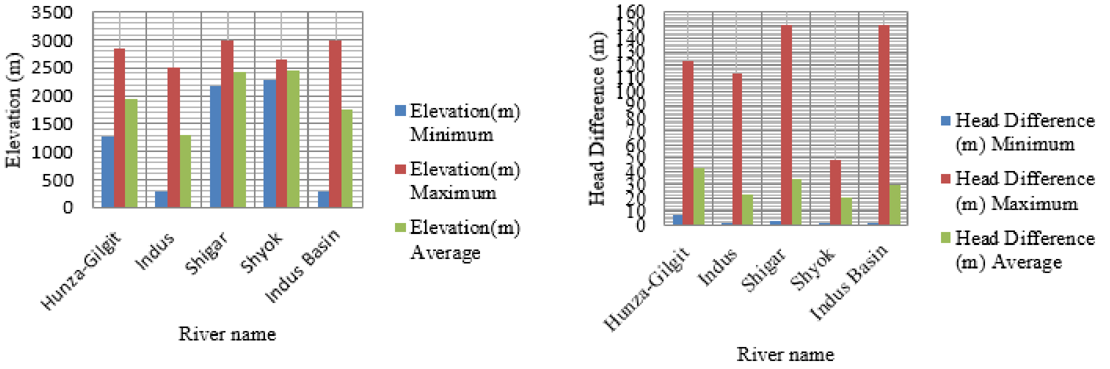


Figure a: Comparison of elevations of Indus Basin

Figure b: Comparison of Head Difference of Indus Basin

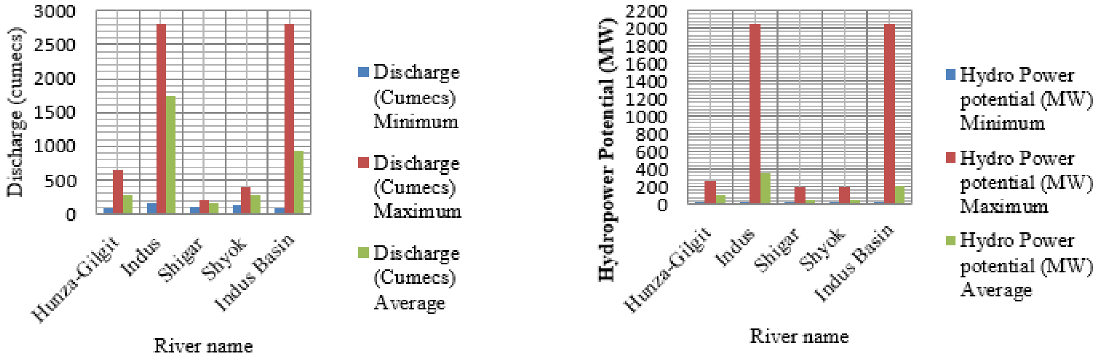


Figure c: Comparison of Discharge of Indus Basin

Figure d: Comparison of Hydropower Potential of Indus Basin

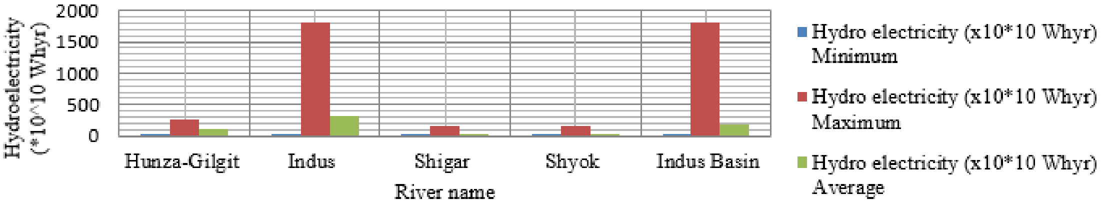


Figure e: Comparison of hydroelectricity of Indus Basin

FIGURE 4.4: (a-e): Indus Basin Characteristics Comparison

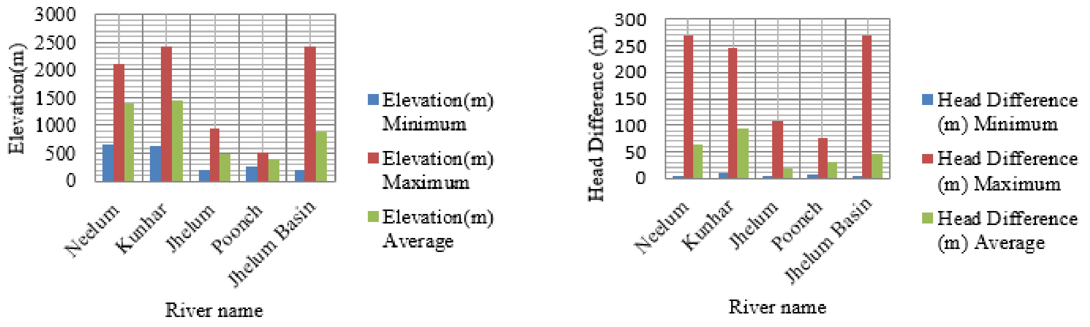


Figure a: Comparison of elevations of Jhelum Basin

Figure b: Comparison of Head Difference of Jhelum Basin

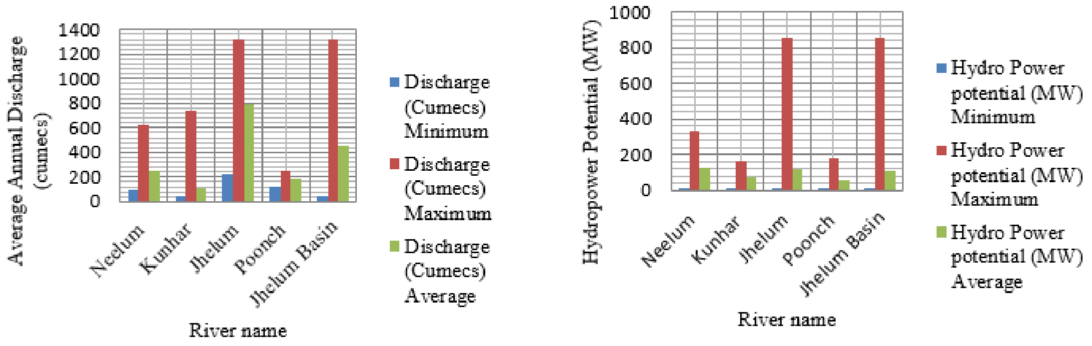


Figure c: Comparison of Discharge of Jhelum Basin

Figure d: Comparison of Hydropower Potential of Jhelum Basin

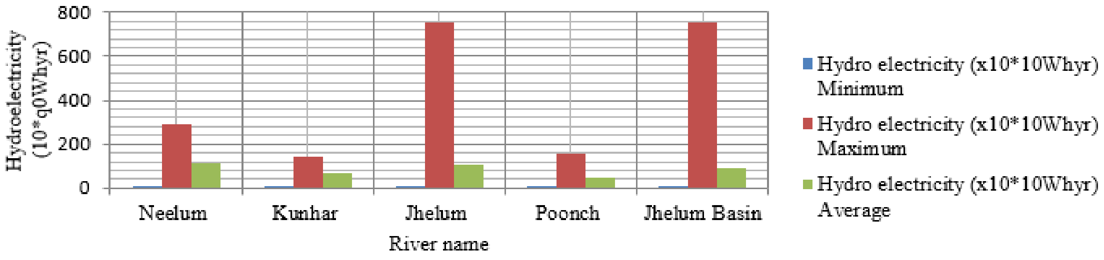


Figure e: Comparison of hydroelectricity of Jhelum Basin

FIGURE 4.5: (a-e): Jhelum Basin Characteristics Comparison

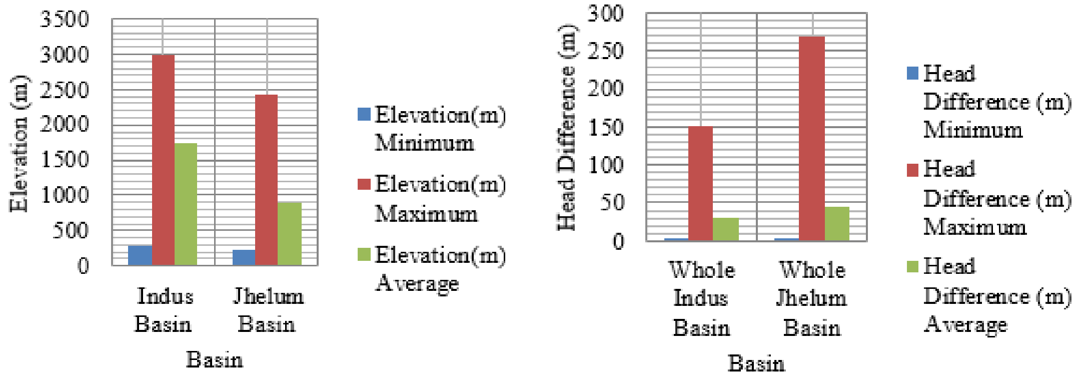


Figure a: Comparison of elevation of Jhelum and Indus Basin.

Figure b: Comparison of Head Difference (m) of Jhelum and Indus Basin.

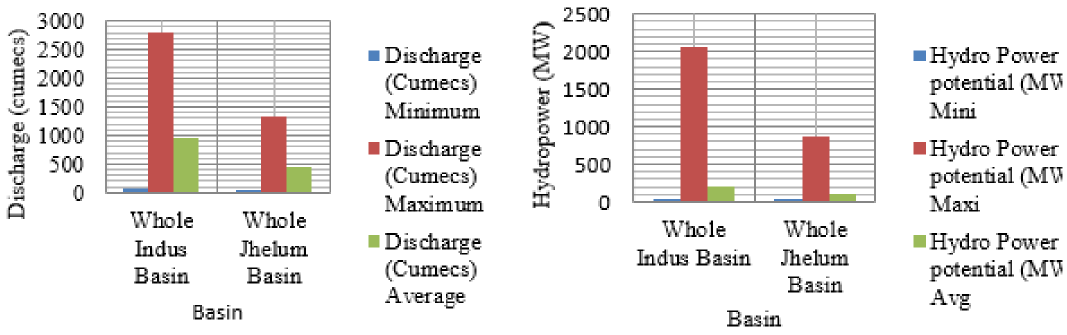


Figure c: Comparison of Discharge (cumecs) of Jhelum and Indus Basin.

Figure d: Comparison of Hydropower Potential (MW) of Jhelum and Indus Basin.

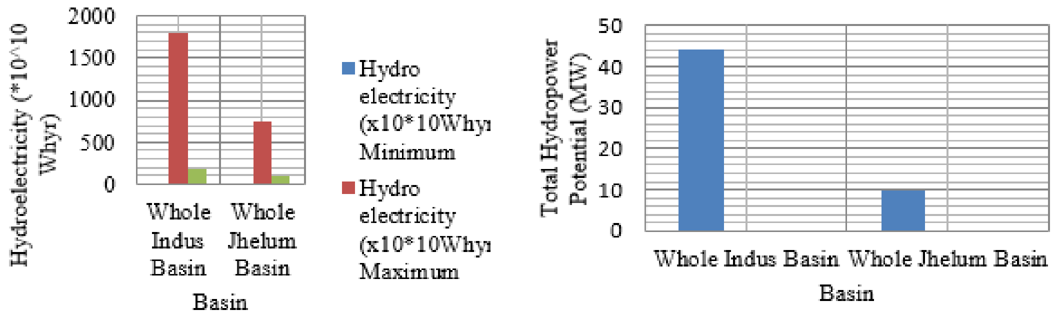


Figure e: Comparison of Hydroelectricity (*10^10 Whryr) of Jhelum and Indus Basin.

Figure f: Total Hydropower Potential (MW) in Jhelum and Indus Basin.

FIGURE 4.6: (a-f): Comparison between Indus and Jhelum Basin.

Chapter 5

Conclusions and Recommendations

5.1 Summary

The evaluation of feasible hydropower sites, which are mostly, located in mountainous areas, needs large number of data. Especially in poorly gauged areas, hydropower sites study are difficult, time intensive as well as costly. Moreover, as in case of single storage hydropower projects, in which the site is predefined, while in case of Run-Off-River schemes the complexity is also prevailed as the location is unknown at the stage of assessment. The obtained results highlight the ability of the developed methodology to provide the data required at the preliminary stage for the development ofRun-Off-River economically. The shortlisting sites detail geological and geotechnical studies can be conducted efficiently. ArcGIS 10.5 along with Arc Hydro toolset proved to be efficient, highly effective and remarkably user-friendly software for rapid identification of potential hydropower sites for Run-Off-River development, which could have otherwise been a very cumbersome job, not to mention the susceptibility of the results to errors due to the lack of topographical data. It can be concluded that the Indus Basin and Jhelum Basin possesses an abundant potential for hydropower generation, as evident from the results. This study presents a very efficient approach for evaluating the hydropower potential associated with a catchment area and spotting such sites within the catchment, during the preliminary stages. Even establishments like Run-Off-River development, which do not require any reservoir and generate power directly from the flowing stream, can generate a massive amount of electrical energy in these areas, thus alleviating the energy shortfall currently being faced by Pakistan. The study is also conducted for the sub-catchments in order to develop a spatial distribution map identifying potential areas for small and large scale hydropower developments e.g. for Shatial, Shyok, Gilgit, Hunza etc for Indus basin and Neelum, Kunhar, Poonch etc for the Jhelum Basin.

5.2 Conclusions

The overall purpose of the research study is to provide feasible and economical hydropower sites in Jhelum and Indus basins. After detail result analysis of the study the conclusions are listed below:

- The total hydropower potential of the Upper Indus Basin amounts to 44,444 MW, based on the 5km interval at 225 points established for the purpose of this study.
- The total hydropower potential of the Upper Jhelum Basin amounts to 10,100 MW, based on the 5km interval at 102 points established for the purpose of this study.
- The total hydropower potential within Indus and Jhelum Basins as a result of this study comes out to be 54,544 MW by constructing hydropower schemes at 327 points.

The detail study has been carried out for all the sites mentioned in results and analysis section but keeping in view the current electricity shortage situation of country, the following 50 sites can immediately explored through detailed survey and feasibility as the total calculated hydropower potential through these sites of interest is approximately 31990.84 MW. The 50 sites are tabulated in Table 5.1. The most of the point of interest lies on the Indus River so there is no issue of accessibility as the Karakorum highway N-35and N-15 almost moves along with Indus River. The pictorial view of the 50 sites for first preference is given in Figure 5.1.

- The range of hydropower capacity will range between 2,056.493 MW and 273.308 MW.
- There are 45 point of interest in Indus Basin from which 29,889 MW can be generated while 2,101 MW can be generated by setting 5 hydropower schemes in Jhelum Basin.
- Total 31,990 MW can be added into National Grid by setting the 50 hydropower schemes collectively.

Thus taking a wisely steps by erecting hydropower schemes at the above mentioned 50 sites the gross theoretically hydropower potential approx. 31,990 MW can be generated and as already discussed net average demand is 21,000 MW and hence currently entire demand can be met through hydropower and thus economic sector of country can be boost by relying minimum on fossil fuel operated plants.

This study can help the decision-making authorities such as Water and Power Development Authority (WAPDA) of Pakistan to make quick and sound decisions in the best interest of the country's economy and shed some light on the vast reserves of renewable energy available in much neglected Indus and Jhelum Basin areas of Pakistan.

5.3 Future Recommendations

A detailed feasibility study is recommended to determine the cost factor involved with developed of such a hydropower scheme as well as the risks involved in its construction. The type of the development is another important factor that needs to be determined and can result in a better economy. Climate change is also another important factor that must be taken into account by considering its effect on hydro-meteorological parameters and evaluating the hydropower potential for various future climate change scenarios to which Pakistan may be subjected to especially discharge analysis. Keeping these factors in mind future following areas can be addressed:

- Associated power losses study can be conducted.
- An alternate study by obtaining 30 m resolution DEM from ASTER can be carried out and also by changing the distance at 2, 10 and 20 Km.
- For storage developments same type study can be conducted to generate power as well as storage of water.
- Further areas and basins can be evaluated.
- Detailed technical and economic feasibility assessment can be executed.
- Detailed geology and geotechnical investigations can be done for above mentioned sites.

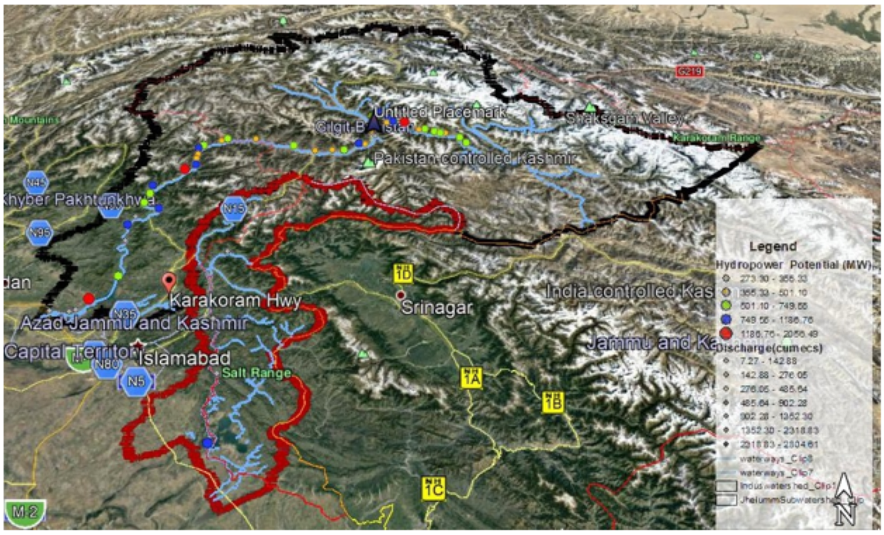


Figure 5.1: Top 50 Sites Recommended for the Development of Hydropower Schemes

Table 5.1: Top 50 Sites Recommended for Hydropower Development

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upsream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
1	72°40'43"E	34°4'19"N	335	411	76	2758.32	2056.493	1801.488	Indus River
2	73°7'47"E	35°11'59"N	681	749	68	2379.1	1587.05	1390.256	Indus River
3	74°53'41"E	35°41'53"N	1666	1780	114	1283.12	1434.964	1257.029	Indus River
4	74°45'18"E	35°45'11"N	1476	1569	93	1300.81	1186.768	1039.609	Indus River
5	74°30'37"E	35°28'41"N	1116	1171	55	1986.03	1071.562	938.689	Indus River
6	73°11'59"E	35°25'31"N	821	864	43	2296.92	968.91	848.765	Indus River
7	73°0'5"E	34°49'27"N	527	563	36	2507.37	885.503	775.7	Indus River
8	72°54'30"E	35°2'18"N	626	662	36	2442.28	862.516	755.564	Indus River
9	73°37'57"E	33°8'8"N	263	335	72	1215.31	858.403	751.961	Jhelum River
10	73°12'40"E	35°14'59"N	749	786	37	2318.83	841.666	737.299	Indus River
11	74°47'52"E	35°42'34"N	1601	1666	65	1294.59	825.495	723.134	Indus River
12	74°39'25"E	35°49'35"N	1355	1417	62	1346.78	819.139	717.565	Indus River
13	74°42'20"E	35°50'20"N	1417	1476	59	1343.96	777.871	681.415	Indus River
14	72°47'55"E	34°40'48"N	466	497	31	2539.88	772.403	676.625	Indus River

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upsream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
15	72°54'10"E	34°58'1"N	595	626	31	2464.75	749.555	656.61	Indus River
16	75°11'13"E	35°35'12"N	1915	1978	63	1211.31	748.626	655.796	Indus River
17	74°23'19"E	35°24'52"N	1067	1103	36	1999.46	706.129	618.569	Indus River
18	75°23'27"E	35°28'31"N	2096	2157	61	1156.11	691.828	606.041	Indus River
19	73°25'26"E	35°31'39"N	914	946	32	2191.49	687.953	602.646	Indus River
20	73°14'13"E	35°27'35"N	864	895	31	2213.86	673.257	589.773	Indus River
21	74°38'51"E	35°45'32"N	1265	1312	47	1351.78	623.265	545.98	Indus River
22	75°20'39"E	35°32'14"N	2025	2077	52	1171.05	597.376	523.301	Indus River
23	75°3'41"E	35°37'49"N	1817	1866	49	1235.48	593.883	520.241	Indus River
24	75°8'15"E	35°36'3"N	1866	1915	49	1213.87	583.495	511.142	Indus River
25	73°58'40"E	35°27'9"N	986	1014	28	2098.7	576.471	504.989	Indus River
26	74°37'25"E	35°47'25"N	1312	1355	43	1349.67	569.331	498.734	Indus River
27	72°52'32"E	34°53'8"N	563	586	23	2504.05	564.989	494.93	Indus River
28	72°50'3"E	34°15'22"N	411	432	21	2640.16	543.899	476.456	Indus River
29	74°9'12"E	35°24'24"N	1014	1039	25	2043.22	501.1	438.963	Indus River
30	74°36'47"E	35°37'25"N	1216	1243	27	1816.5	481.136	421.475	Indus River
31	75°0'43"E	35°37'36"N	1780	1817	37	1263.43	458.587	401.722	Indus River

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upsream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
32	74°17'36"E	35°25'22"N	1039	1061	22	2030.87	438.302	383.953	Indus River
33	73°22'36"E	35°30'40"N	895	914	19	2198.6	409.797	358.982	Indus River
34	74°44'43"E	35°42'48"N	1569	1601	32	1298.76	407.707	357.151	Indus River
35	73°12'14"E	35°22'26"N	803	821	18	2302.02	406.491	356.086	Indus River
36	73°39'29"E	35°31'36"N	947	966	19	2164.21	403.387	353.367	Indus River
37	74°33'39"E	35°28'48"N	1171	1191	20	1983.39	389.141	340.888	Indus River
38	75°13'54"E	35°35'22"N	1978	2011	33	1198.1	387.861	339.766	Indus River
39	73°11'59"E	35°19'42"N	786	803	17	2305.8	384.538	336.856	Indus River
40	72°25'44"E	34°0'7"N	290	303	13	2786.3	355.337	311.275	Indus River
41	72°36'21"E	34°0'33"N	322	335	13	2759.48	351.916	308.279	Indus River
42	75°50'14"E	35°20'11"N	2244	2282	38	896.13	334.059	292.636	Indus River
43	73°34'23"E	34°27'24"N	856	967	111	303.39	330.37	289.4	Neelum River
44	72°48'41"E	34°33'21"N	453	466	13	2558.96	326.344	285.877	Indus River
45	72°33'52"E	33°59'46"N	310	322	12	2765.56	325.562	285.192	Indus River
46	73°37'35"E	33°33'57"N	384	422	38	829.28	309.141	270.807	Jhelum River
47	73°59'58"E	34°43'12"N	1608	1737	129	226.59	286.75	251.19	Neelum River
48	73°32'55"E	33°56'16"N	543	581	38	766.85	285.868	250.42	Jhelum River

Sr No	Longitude (DMS)	Latitude (DMS)	Elevation Above Mean Sea level (AMSl) (m)	Elevation above Mean sea level (AMSL) of upsream end (m)	Head (m)	Discharge (cumecs)	Hydropower Potential (MW)	Hydroelectricity (x10^10 Whyr)	Remarks
49	74°38'40"E	35°34'14"N	1191	1207	16	1817.91	285.339	249.957	Indus River
50	72°50'14"E	34°46'2"N	500	511	11	2532.74	273.308	239.418	Indus River
						Grand Total	**31990.84MW**		

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Annexure A

Output of the DEM after performing steps mentioned in Figure 3.12. It will also guide the beginners to processes DEM in Arc GIS.

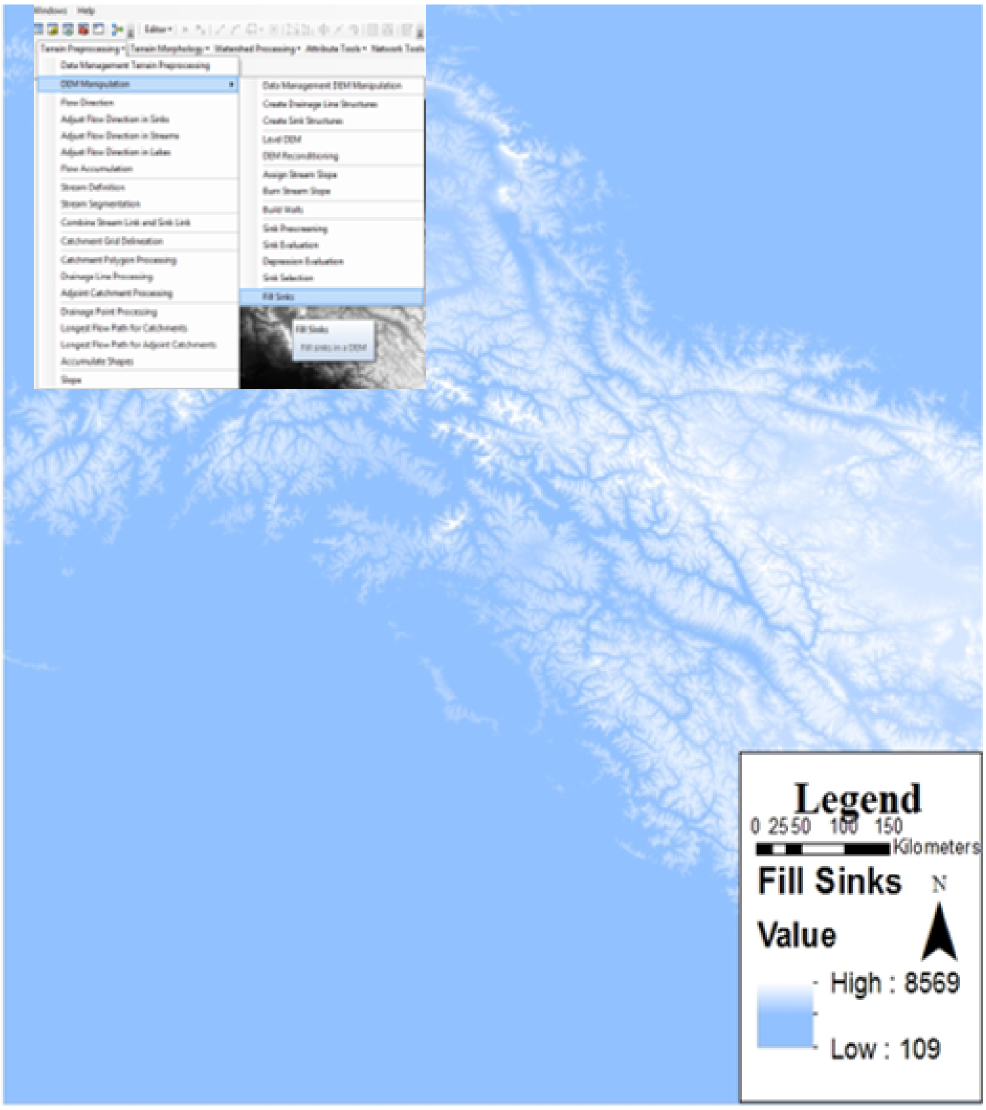

Figure 2: Fill Sinks

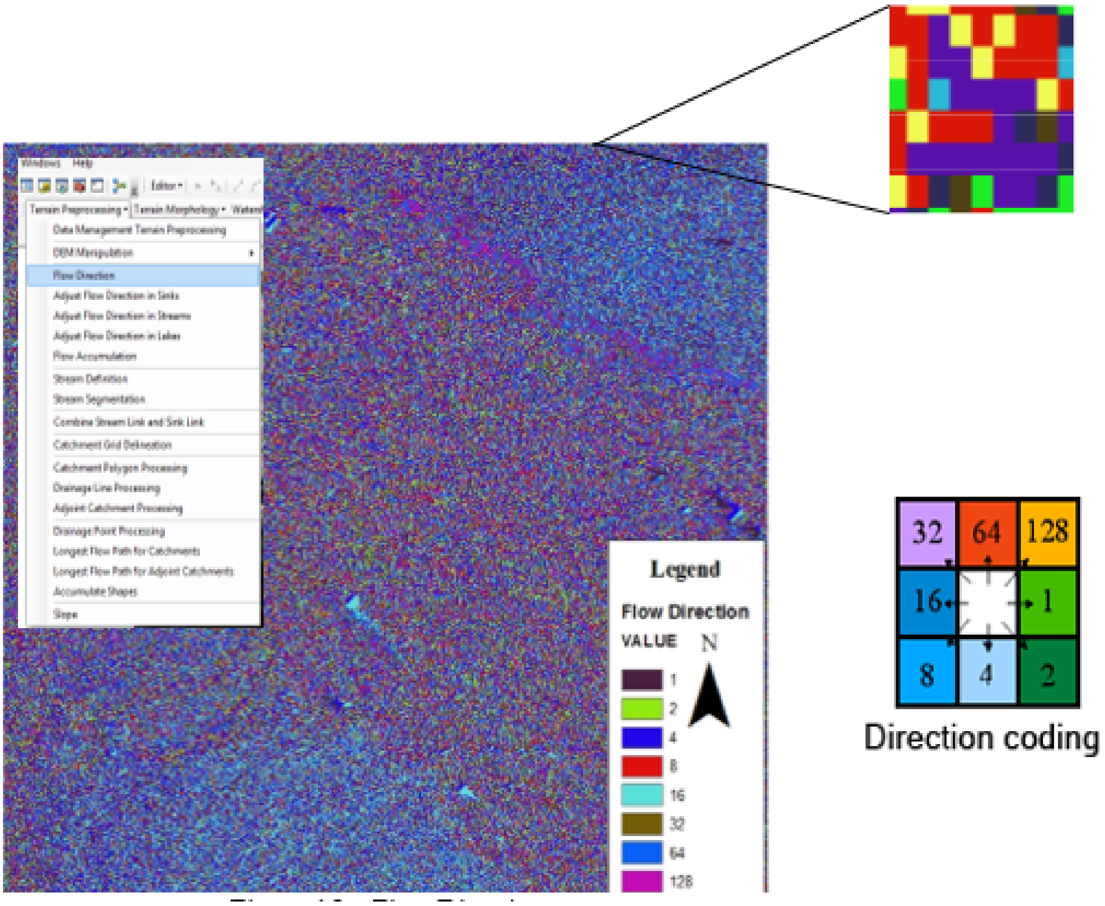

FIGURE 3: Flow Direction

Elev_Ras

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

=

Flow_Dir

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

FIGURE 4: Generation of Flow Direction raster from DEM (Source: ArcGIS Resource Center)

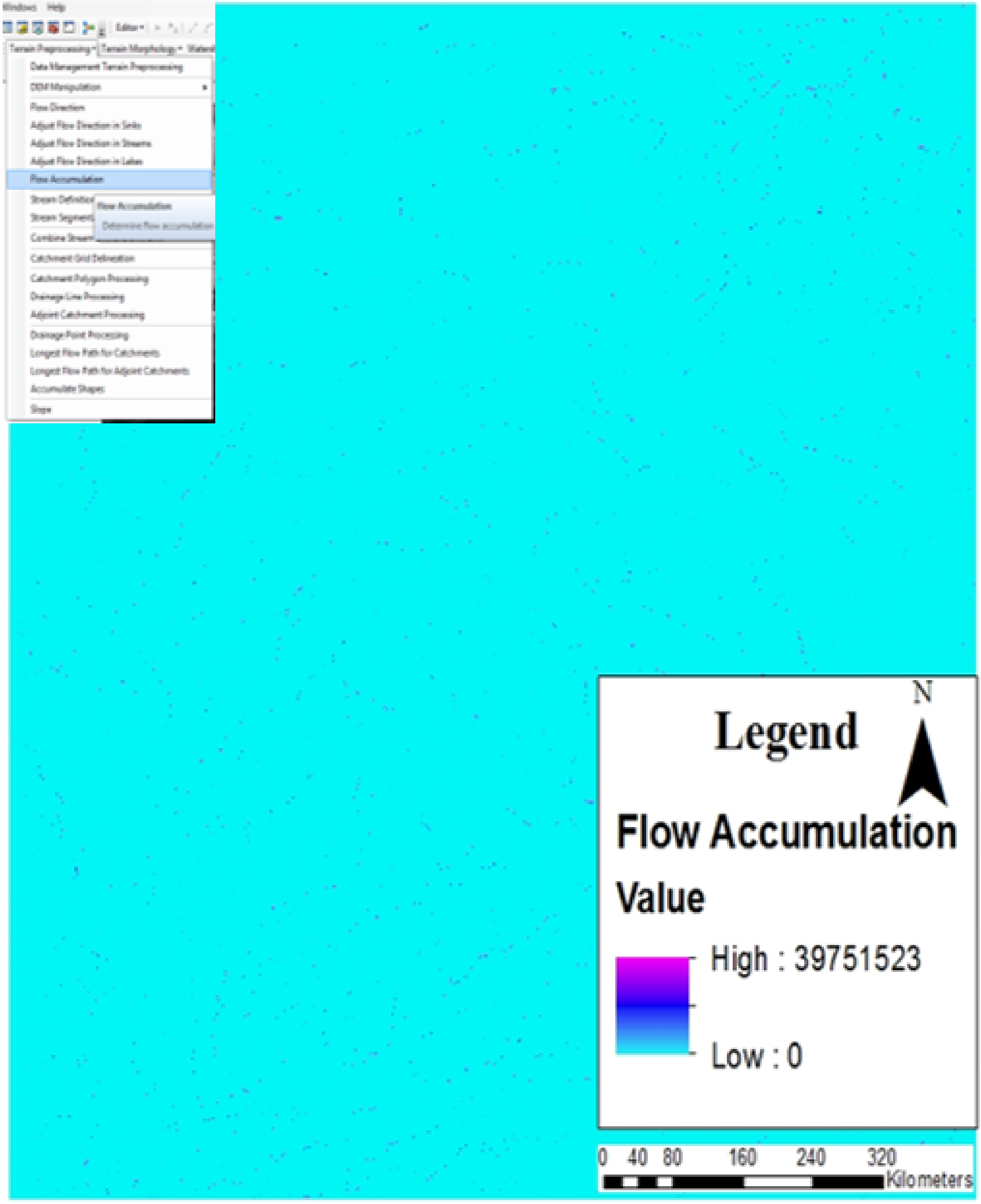

FIGURE 5: Flow Accumulation

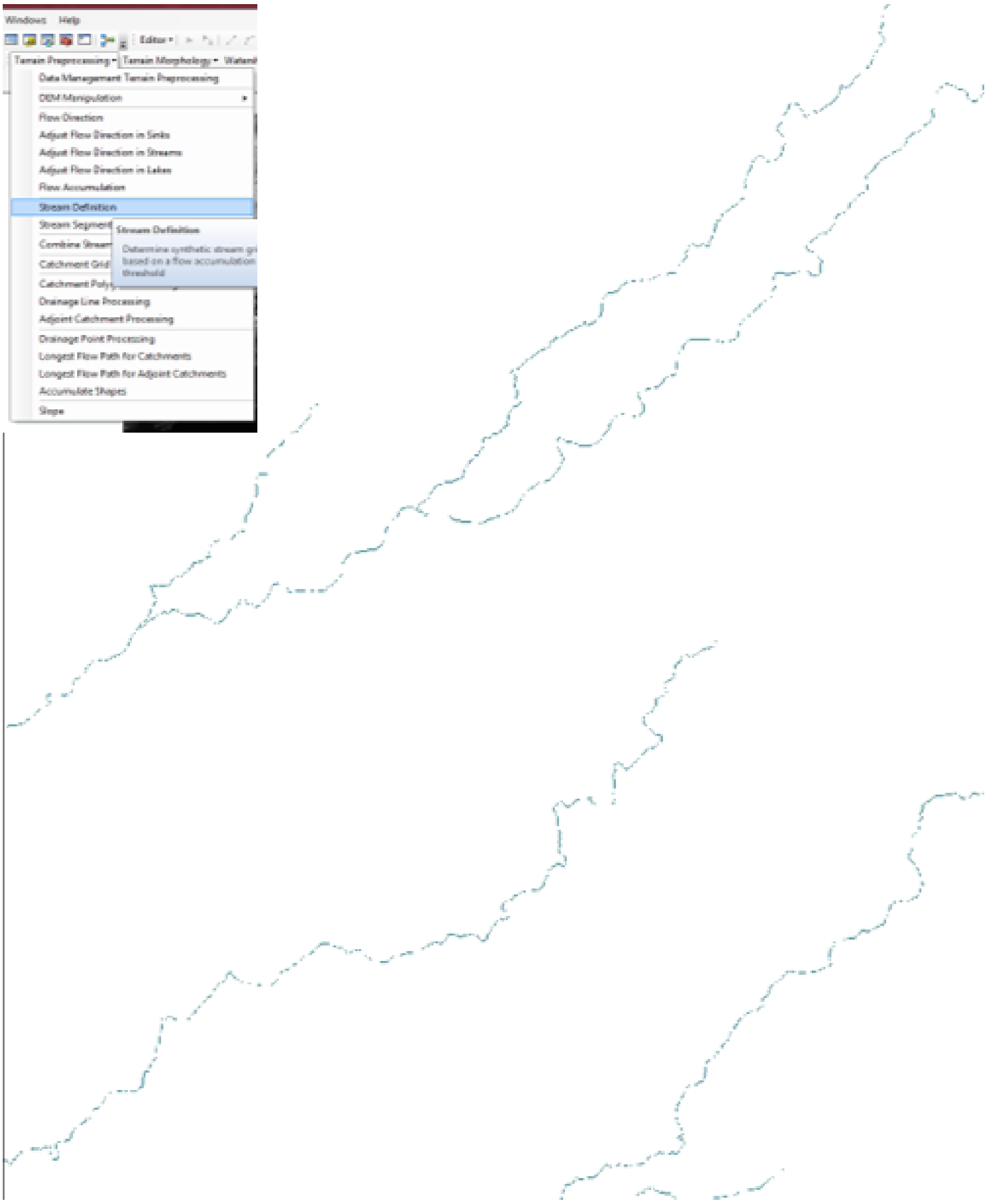

Figure 6: Stream Defination

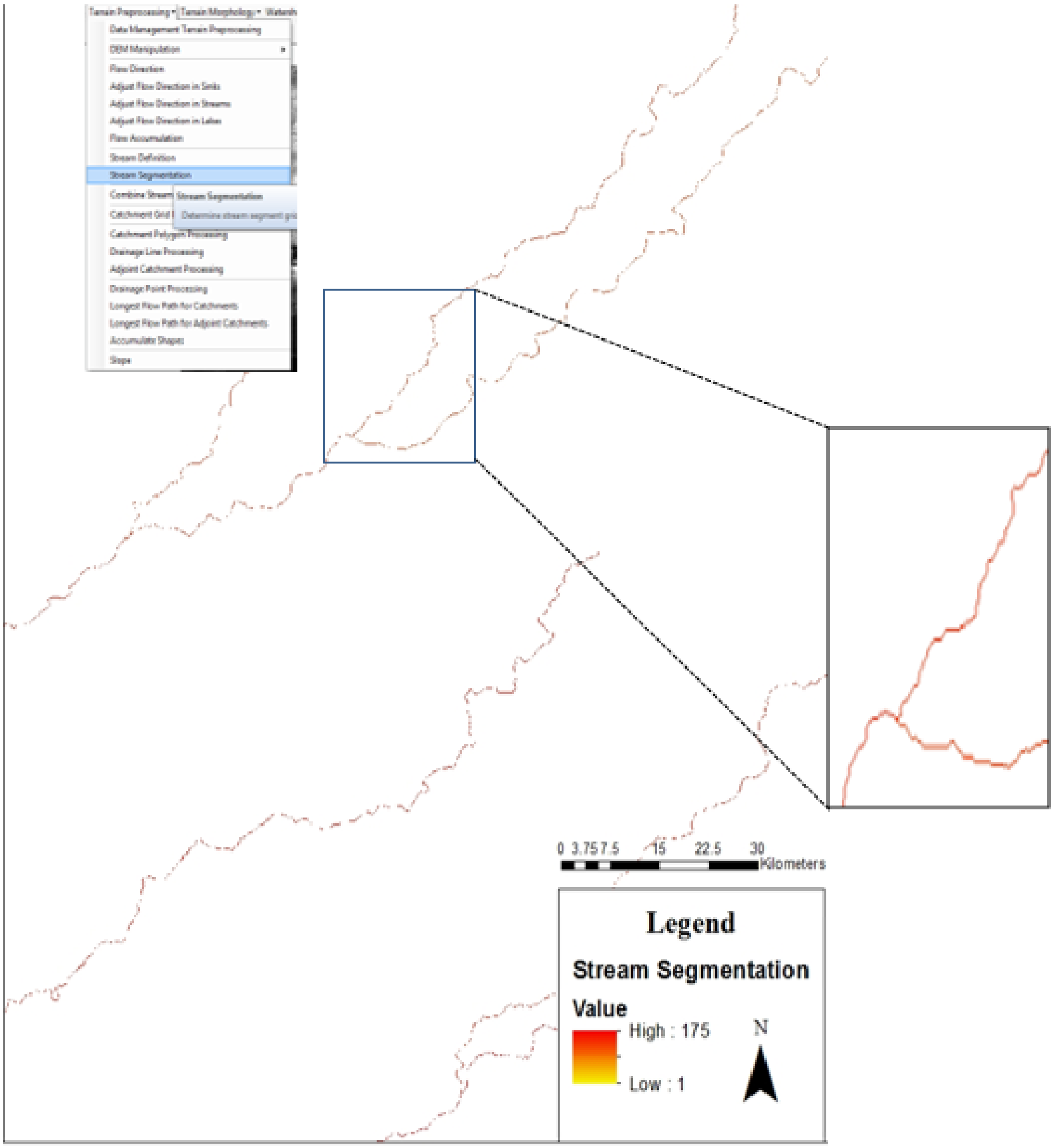

FIGURE 7: Stream Segmentation

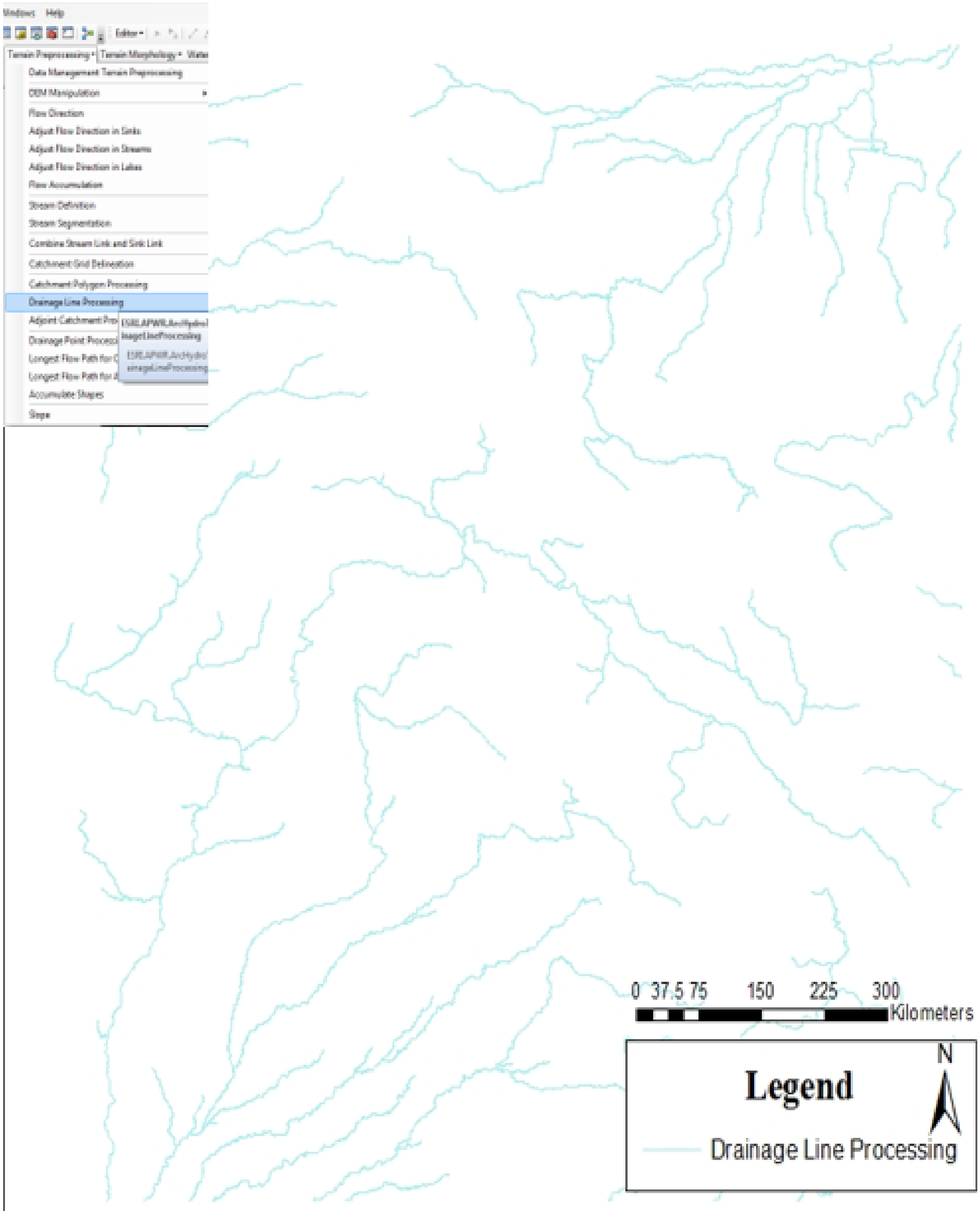

Figure 8: Drainage Line Processing

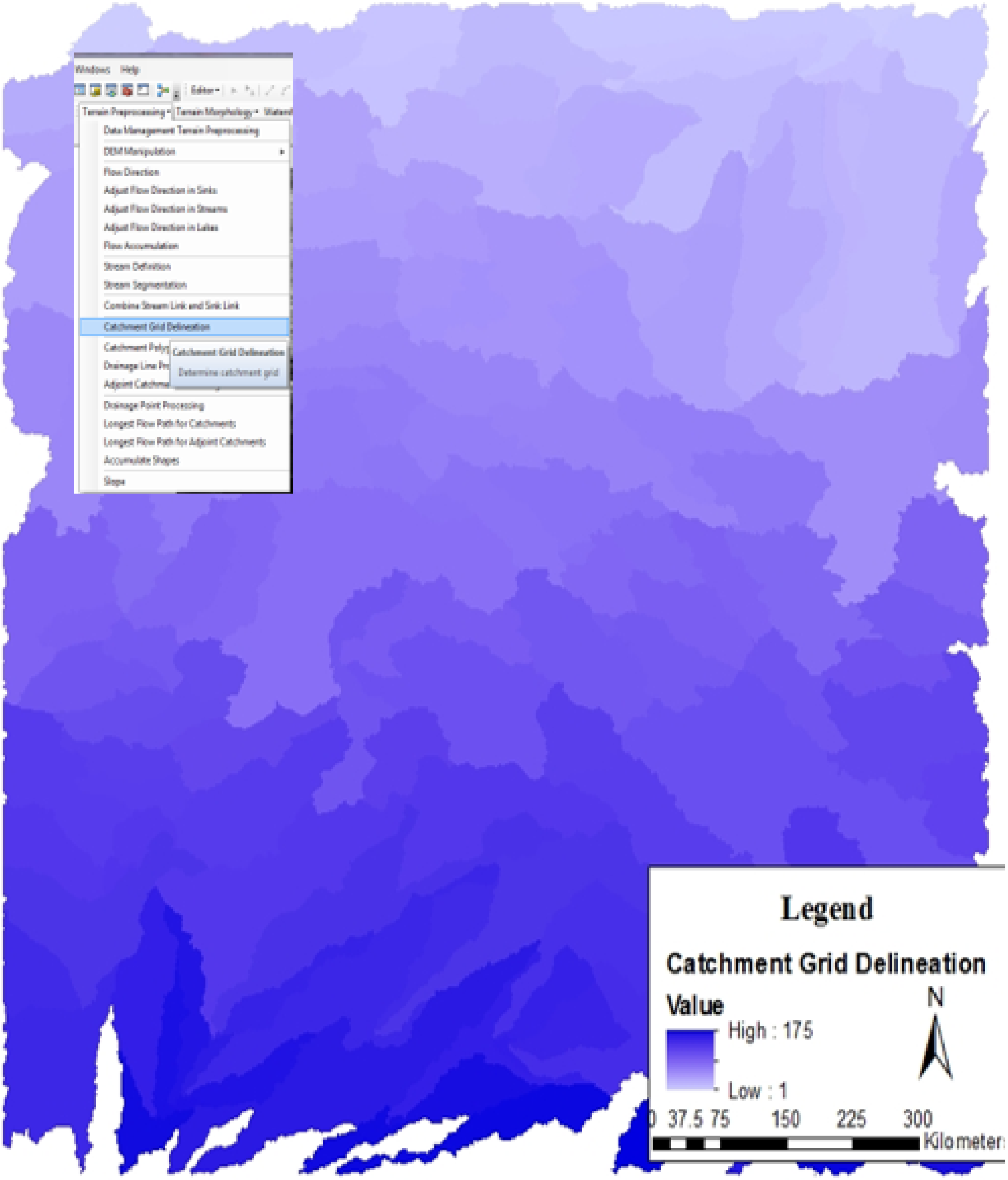

Figure 9: Catchment Grid Delineation

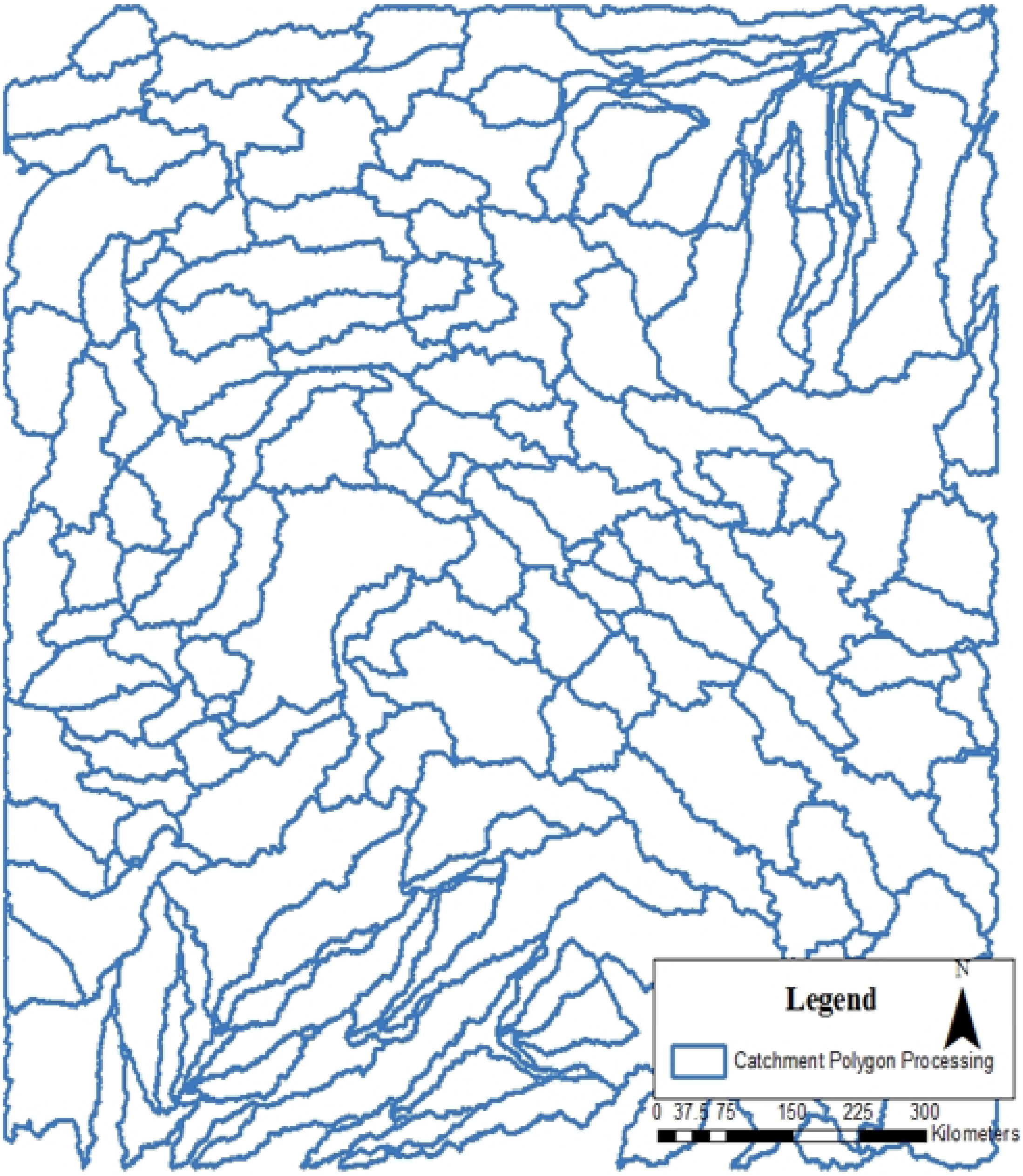

FIGURE 10: Catchment Polygon Processing

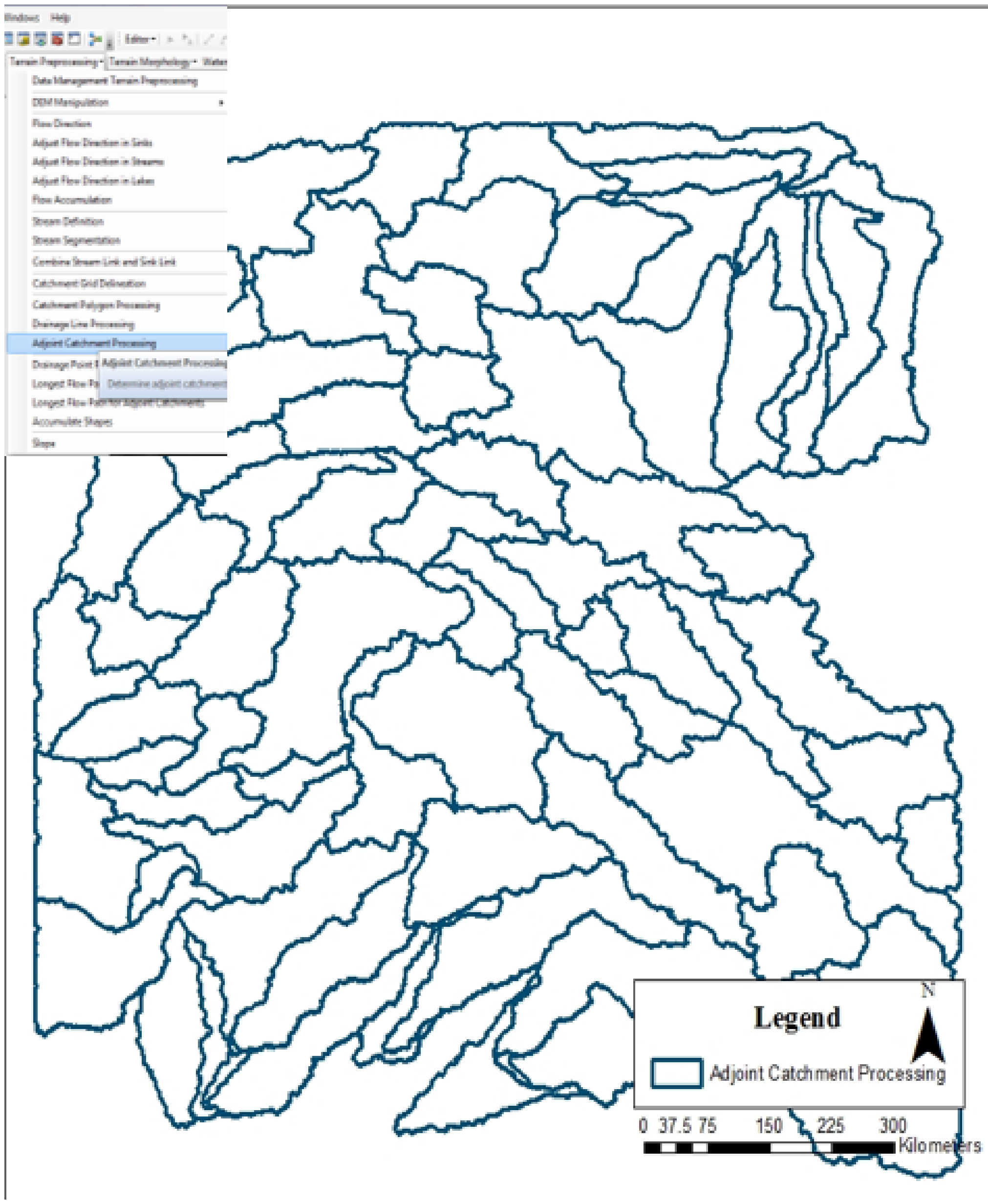

Figure 11: Adjoining of Catchment Polygon

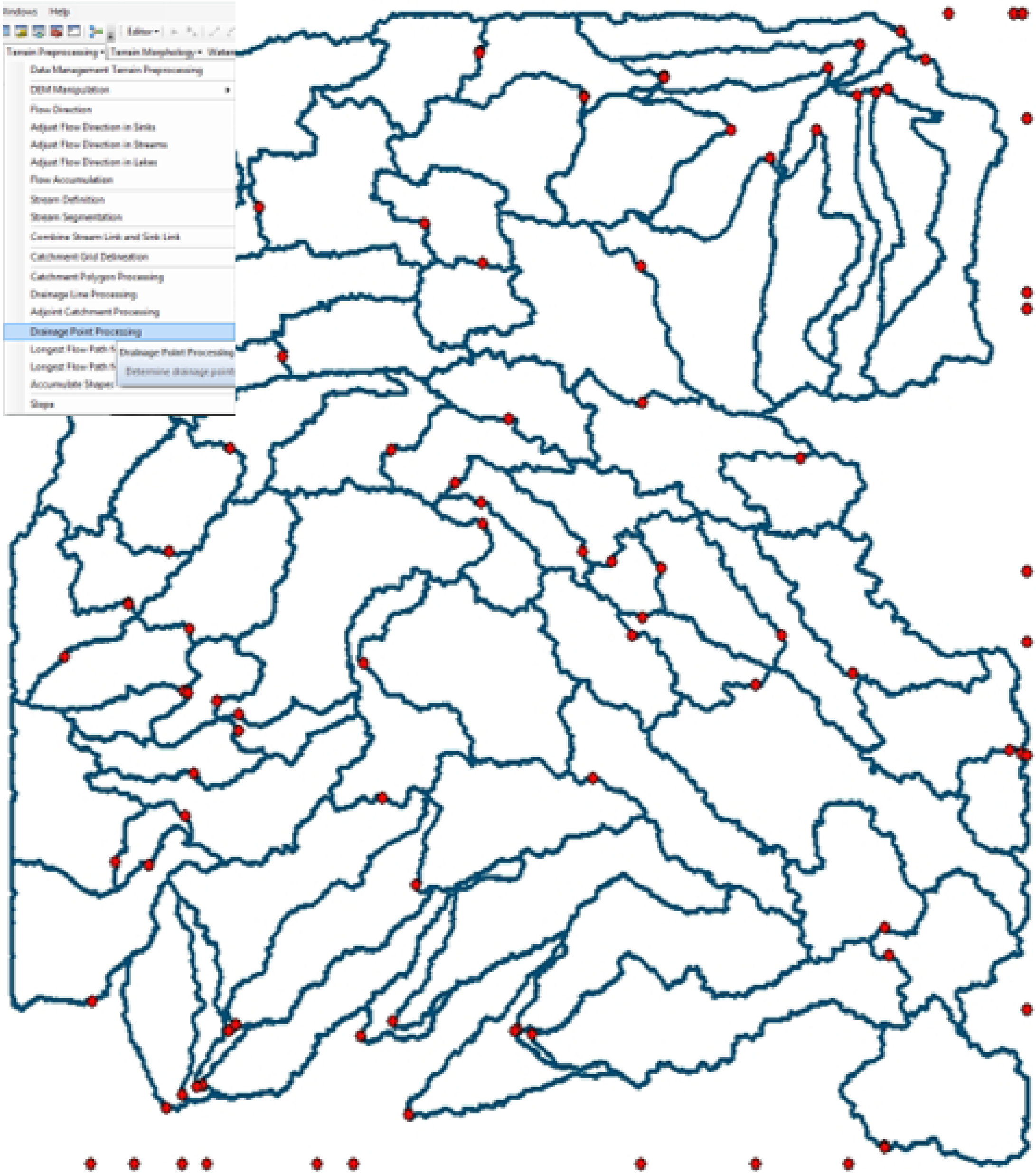

FIGURE 12: Drainage Point Processing