CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Evaluation of Hydraulic Condition of Soan River at Downstream of Chirah Station to Plan and Propose Water Turbine

by

Summer Yamin

A thesis submitted in partial fulfillment for the degree of Master of Science

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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.

CERTIFICATE OF APPROVAL

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Abstract

The important factor in the economic growth and development of any country is energy. There are various renewable energy options which include wind, solar, biomass and hydropower. Out of these, hydropower is one of the most cost-effective technology and the most widely used renewable energy production method adopted in the world. Hydropower generation on large scale by constructing large hydropower plants requires tremendous amounts of land impoundment, dams and flood control, and often they produce environmental impacts. Lack of funds to build or start the large hydroelectric power project is also one of the obstacles for developing countries. Hence, for less developed countries or the countries where large scale hydropower potential is exploited already, hydropower on a small-scale is one of the most efficient and environmental-friendly energy technologies to be considered for power generation. Pakistan suffers from massive power shortages or energy crises due to increase in population and industrial development, both asking for more electricity provision and thus owing to the large gap between supply and demand, despite having abundance of small-scale hydropower potential. According to the International Energy Agency (IEA), energy demand in Pakistan is expected three times higher at the end of 2050. So, there is need to explore a small scale hydro potential sites in our country. There are various small rivers in Pakistan which need to tap hydropower potential by installing Small Hydro Power Plants (SHPP's) to fulfill energy crises at some extant in country. Soan river is one of these rivers which needs to be explored for hydropower potential. The study focuses on evaluation of hydropower potential of Soan river near Kaak bridge using ArcGIS applied for extracting topographic data-in the form of digital elevation model (DEM) and stream flow dataset. Furthermore, suitable hydraulic turbine is also proposed for hydropower generation using standard graphs and charts. To do so, Flow data of Soan River at different stations is collected from literature review (Ashfaq et al., 2014). The flow and topography data is processed using the various spatial analyses tools in ArcGIS to delineate the catchment, generate the stream network and identify the sites for hydropower potential from study area. The head is generated by proposing weir at each identified point/sites. The height of weir is proposed by using different analysis method i.e. standard step method. By calculating head and discharge at each point, water turbine is selected from standard graphs and hydropower potential is evaluated. In Soan river basin from Chirah to Rawalpindi station, total length of almost 32km is evaluated to identify potential sites for hydropower development. The total 16 No of sites are evaluated out of which 13 hydropower potential sites are selected. Hydraulic turbines are also proposed at each selected hydropower potential site. The total hydropower potential from Chirah to Rawalpindi station of Soan River is 1713.24KW with 13 points of interest. The average power requirement of average house is 5KW. So, with an average power requirement of 5KW per house, almost 342 houses will be served from Chirah to Rawalpindi station of Soan River. The result of this examination shows about the huge hydropower potential of Soan river basin, which is usually not discovered till now. This study concludes efficiently the flows of rivers like Soan river could be managed to produce hydropower on river runoff using series of small turbines at different locations. This study also assists the decision-makers to explore hydropower potential of different small rivers in country and to install turbines to overcome energy crisis at small to medium scale locally.

Keywords: Energy Crises, Hydraulic Parameter, Hydropower, Water turbine, Soan River, Geographic Information System and Arc GIS.

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Abbreviations

ADB	Asian Development Bank
AEDB	Alternative Energy Development Board
DEM	Digital Elevation Model
GIS	Geographic Information System
IEA	International Energy Agency
IHA	International Hydropower Association
IRENA	International Renewable Energy Agency
KW	Kilo Watt
MW	Mega Watt
PCRET	Pakistan Council of Renewable Energy Technologies
PEDO	Pakhtunkhwa Energy Development Organization
PMO	Pakistan Meteorological Department
RES	Renewable Energy Source
ROR	Run of River
SHPP	Small Hydropower Power Plant
SRSP	Sarhad Resource Support Program
SRTM	Shuttle Radar Topography Mission
WAPDA	Water and Power Development Authority
WGS	World Geodetic System
WSHSR	World Small Hydropower Source Report

Chapter 1

Introduction

1.1 Background

The significant factor in the financial development and advancement of any nation is Energy. Non-renewable energy sources (coal, natural gas, fossil fuel etc.), nuclear energy and renewable (sustainable) energy sources are the three significant classification of energy for power production. The burning of fossil fuel for energy generation emits huge quantity of ozone harming substances that add to a worldwide temperature alteration. The huge costs for building new nuclear power plant are required for nuclear energy which makes them uneconomical for electricity generation. The growth of renewable energy source has attained huge consideration around the worldwide because of global warming associated with non-renewable energy source and higher investment involved in nuclear energy. The only affordable, efficient and most widely used solution of energy for electricity generation is renewable energy resource. There are various renewable energy options which include wind, solar, biomass and hydropower. Although some of sustainable energy source such as solar powered and wind gaining wide adoption but hydropower is still the most widely used one because it is the cheapest source of electricity. In addition hydropower is viewed as most significant and economical Renewable Energy Source (RES). The greater part of the electricity created from renewables originates from hydro power (83%) and the other (13%) originates from wind, sun oriented (solar), tidal geothermal energy etc [1].

Hydro power generation is one of the most productive and conventional electrical power generations. In almost 30 countries, it fills in as prime source of power generation. Practically, 25% of all out power generation of the world originates from hydro power and supply more than 1 billion people with power [2]. The advancement of hydro-power in the twentieth century was normally connected with the structure of huge dams. Several enormous hindrances of concrete, rock and earth were put across stream valleys worldwide to make tremendous artificial lakes. However, such sort of tasks (projects) likewise requires huge amount of land impoundment, dams and flood control, and frequently they also create natural effects. The disadvantages related with enormous hydro power plants are high transmission costs, natural expenses of submergence of prime land (forest, crop land etc.), shifting of families etc. Lack of funds to build the large hydro-electric power plant is also one of the main obstacles for hydropower generation in developing countries.

In the most recent decades, world electrical energy utilization has fundamentally expanded with a share that has reached at 17.7% in 2010 and is predicated to double by 2025 [3]. One of main reason of increased power demand is population, its fast increment combined with industrialization in the twentieth century brought about a tremendous power demand [4]. Pakistan is also suffering from energy crises in last couple of years due to increasing population and industrial development. The energy demand is increasing at a pace of 11 to 13% consistently every year. According to International Energy Agency (IEA), the energy demand in Pakistan is expected multiple times (three times) higher by 2050. At present, energy demand is becoming quicker than energy creation in Pakistan which increases energy crises day by day. According to Asian Development Bank (ADB), Pakistan endures power deficiency assessed at over 4200 MW during peak demand, prompting intensifying electrical failure across the country, and hence requiring power rationing. According to world small hydropower development report, The country has hydropower generation capability of over 42,000 Mega Watt. However, just 15 percent of complete hydropower potential has been utilized until this point [5]. Still, 85 percent of hydropower potential needs to be explored. The staying undiscovered potential, if appropriately utilized, can successfully fulfill power need of our country in an economical way.

Unfortunately, Pakistan is under developed country and economic condition is not such that to build a large scale hydropower projects. The other economical option to control power deficiency issue in less developed country is small hydro power generation. It is also the main prospect for future hydro advancements in developed countries, where the large-scale opportunities have either been exploited already, or would now be considered environmentally unacceptable. The other economical option to control power deficiency issue in less developed country is small hydro power generation. Small hydropower has seen fast advancement in numerous nations, making significant commitment to satisfying day by day electrical need and lessening poverty. Numerous nations around the globe have a huge capability of small hydro. In China, 19,000MW of electricity is produced from 43,000SHPPs. According to hydropower resource report, the geographic location and water resources of Pakistan is such that by installing SHPPs, 60,000MW electric power can be generated. In spite of having large available potential, only 7172MW is generated from hydropower in 2016–17 [6].

Pakistan is a developing country and economic condition is such that they cannot afford to install or start huge hydropower project or go for nuclear energy. In the light of discussion above, Small hydropower is one such cost effective solution which is quite suitable for Pakistan's energy crisis situation.

1.2 Research Motivation

Pakistan has been suffering from severe energy crisis since last couple of years and the demand of energy is also increasing at the rate of 11 to 13% every year with the increasing population and industrial development. To fulfill the energy demand, hydro power generation is one of the most efficient solutions because our country is blessed with huge hydropower potential. Unfortunately, the economic condition of country is not favorable for construction of large hydro power projects. Because, large hydro power projects requires vast amount of land impoundment, dams and flood control structure, and frequently they produce environmental effects. In Pakistan, thousands of small rivers or streams are flowing. Hence, Small hydro plants are the beneficial in term of cost and alternative solutions for Pakistan energy crisis situation. The motive of this research is to evaluate the hydropower capability of small river to overcome the energy crisis at some extent in Pakistan.

1.3 Problem Statement

Small hydro schemes are important means of renewable electricity generation and also have less environmental hazards. Small hydropower projects likewise need low starting cost, less area, shorter planning and development times, less trained labor, and lower power generation as compared with huge hydropower projects [7]. Run-of-rivers projects are usually divided into two types; low head and high head. Low head are usually appropriate for larger river that have gentle slope, whereas, the high head types are more appropriate for small rivers having steep gradient [8].

Soan River is a major tributary of Indus river, which is located in Punjab province of Pakistan. It originate in the south-western range of the Murree hills, flowing through hills, it enters the plains. Soan river is perennial river with abundance amount of water flowing every year during monsoon season. Flowing water of Soan river carries enormous amount of energy. If flow of Soan river is managed and utilized properly, the energy produced can help meet the local demand and to raise the quality of life and living standard of the people of Pothwar Plateau. Soan river is a small river with steep slope at its upstream side, it is quite suitable for high head projects. At downstream side of Soan river slope is gentle so there is need to generate head by proposing hydraulic structures to fully utilize the hydro potential.

For development of hydropower plant project, different steps are involved including the identification of attainable site areas, and the evaluation of stream flow, head, and power. The identification of hydropower sites generally requires huge share (percentage) of overall project costs [9]. Traditionally, different method used for evaluating hydropower potential are time consuming and also have a chance of high degree of inaccuracy because of human error. The traditional methods used for hydropower site selection mostly ignore the environmental and social impacts mainly focusing on engineering and economic criteria [10]. Therefore, numerous efforts have been done in order to define effective systems to support the project period (phase) of the hydropower site identification. In recent years, new approach is developed for evaluation of hydropower potential. This new approach is arising for development of remote sensing and satellite information, and their ease of information handling because of progress in GIS tool. GIS based applications have been broadly used to gauge (estimate) hydropower potential in numerous nations around the globe [9]. In spite of having extraordinary potential, GIS based innovation has been utilized to lesser extent for the assessment of the techno-conservative potential because of the complexities involved in recognizing the Run of River (RoR) hydropower sites. The run-of-river hydropower projects utilize the stream flow, and height distinction (head) in a stream reach to create power. GIS tool makes it easy to calculate flow and head of different river basin and ultimately make it easy to calculate hydro potential of run-of-river (ROR). This new approach help decision maker for identification of the most suitable hydro potential sites from study area. Thus the Problem Statement is as follows:

“For development of small hydropower projects, different steps are involved including the identification of feasible project locations, and the assessment of river flow, head, and power. The identification of hydropower sites represents a relatively high proportion of overall project costs. In recent years, GIS based applications have been widely used to estimate hydropower potentials in many countries around the world. Despite having great potential, GIS based technology has been used to lesser extent for the assessment of the hydro potential because of the complexities and advancement in this tool. So in this study, a hydro potential of Soan river over a partial length is evaluated by using GIS tool and by proposing hydraulic turbine."

1.4 Overall/Specific Research Aim

The overall aim of research program (WeR i.e. Water and Environment Research group) is to have safe, efficient and environmental friendly exploitation of water resource for hydropower. "The specific aim of MS research work is to investigate the hydraulic conditions of Soan river to explore a hydro power potential of Soan river from Chirah to Rawalpindi (over 32 km length) by proposing suitable water turbine."

This objective/aim is achieved by performing the following tasks.

1. Terrain pre-processing of Soan river basin from flow originating point to Rawalpindi station using ArcGIS to delineate the catchment and generate the stream network.
2. Identify hydropower potential sites point using ArcGIS.
3. Propose a hydraulic structure for generating head.
4. Selection of hydraulic turbine at each identified hydropower potential point.
5. Evaluate hydropower potential of Soan river basin from Chirah to Rawalpindi.

1.5 Scope of Work

The scope of work of this MS research is to conduct a site survey, measuring of head and water flow rate at different point in Soan river from Chirah to Rawalpindi (over 32 km length) by using ArcGIS, to evaluate a hydropower potential of Soan river and also propose a suitable water turbine at each selected point. The scope of work only includes hydraulic design of study area. Structural design and design of hydraulic turbine is not included in scope of work. Financial aspect of this study is also not a part of this research.

1.6 Limitation of Study

Following are the limitation of study:

1. Flow data of Soan river are available only at Chirah station and Rawalpindi station which is located at 32km downstream from Chirah station along a river.

2. Study area is only limited to Chirah station to Rawalpindi station of Soan river.

3. Study is only limited to hydraulic design of study area.

4. Structural design and design of hydraulic turbine is not included in study.

5. Financial aspect of this study is also not a part of this research.

1.7 Thesis Outline

The thesis has been so sorted out so that after studying this it gives reader a road map and sense of direction about how to evaluate hydraulic condition of rivers. After studying this thesis, researcher and professional of different field specially civil engineers and water resource engineers get knowledge on how to assess hydroelectricity capacity of a run-of-river (ROR) using the ArcGIS and also know the importance of small hydro to overcome the energy crises around the globe. The outline of MS thesis consists of major five chapters. These are:

Chapter 1 includes the background and importance of small scale hydropower scheme to overcome the energy crises, research motivation, problem statement overall or specific project aims, scope of work and report outline. This chapter aware reader why there is 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 comprises of working principle of hydropower system, importance of hydropower resource, current situation of power generation in Pakistan, hydropower development in Pakistan, turbine selection criteria and role of ARCGIS in hydropower development. Moreover, it reviews the previous studies conducted by different researchers on Soan River of Pakistan.

Chapter 3 consists of study area of research, data collection, software modeling of study area, selection criteria for identification of hydropower sites, calculation of discharge and head at identified hydropower potential point, and finally evaluation of hydropower potential.

Chapter 4 presents the results and analysis of this study to the readers and discusses their implications.

Chapter 5 concludes the thesis and recommendations are suggested for competent authorities.

Annexure A shows the extracted value of manning constant after comparison the standard imagery available in literature review.

Annexure B shows the calculation to find depth and bottom width at each selected hydropower sites.

Annexure C shows the cross section of river at each selected hydropower potential sites.

Annexure D shows the backwater length calculations at each selected hydropower potential sites.

Annexure E shows the imaginary of site survey conducted for research.

Annexure F shows the calculations of verification of flow data at Rawalpindi station.

Chapter 2

Literature Review

2.1 Background

In this chapter, the literature review related to hydropower is discussed in detail. The past and current status of small scale hydropower development around the globe is discussed in detail. This chapter also briefs the readers about the current situations of the energy sector of Pakistan and discusses the problems faced by this sector. The different techniques or method used for evaluating hydropower potential around the world are also explained in detail. Moreover, role of ArcGIS in water resource engineering especially for hydropower development is also discussed in detail. Different studies conducted on Soan River and turbine selection criteria according to different researchers are also explained in detail.

2.2 Hydropower

2.2.1 Introduction

The word "hydro" is a latin word which mean water, so hydropower is a power or energy which is generated from flowing water or falling water from rivers or streams. It is one of most efficient and well established electrical power generation because of renewable in nature and least green house gas emission [11]. Hydropower is also most reliable and cost effective renewable energy source [12]. In all over the world, the greater part of the electricity created from renewables originates from hydro power (83%) and the other (13%) originates from wind, sun oriented (solar), tidal geothermal energy etc. [1]. In almost 30 nations, Hydropower fills in as prime source of power generation. Practically, 25% of all out power generation of the world originates from hydro power [2]. Hydropower development is the most important development activity that provides multiple benefits and helps as an effective agent for the rapid economic growth of any country.

2.2.2 History of Hydropower

The development of hydropower started 2000 years earlier, when water wheels were being used by ancient Greeks to grind grain. The most noteworthy year in hydropower history was in 1831 when the essential electric generator was envisioned by Michael Faraday. The development of generator layed the establishment for us to make sense of how to produce power with hydro practically 50 years after the fact, in 1878. The first main hydroelectric force plant situated in Appleton, Wisconsin started to create power in 1882. The power output was at about 12.5kW. Very nearly 7 years after the fact in 1889, outright number of hydroelectric force plant only in the US had reached to almost 190. These power plants obtained a huge amount of commercial attention in the 19th century and were constructed rapidly in appropriate zones everywhere around the globe. In 1936, greatest hydroelectric force plant, the Hoover Dam was started working and generated 1345 MW, later extended to 2080 MW from the spilling water in the Colorado River. Hydropower's become the most important source of power around the world in the mid of 1900's.

Three Gorges Dam in China was constructed in 2008. Currently, the greatest force plant is also three Gorges dam, delivering 22500 Mega Watt. Hydropower is considered as a main source of electricity. About 25% of global electricity is generate from hydropower [2]. There are right around 30 significant hydroelectricity projects with 2000 Mega Watt limit being worked on around the world. Most of these hydro power plants are located in China.

2.2.3 Background to Hydropower Generation

The main principle of hydropower is to utilize the energy stored in flowing water when it falls from a height. The flow of water is stopped at high altitude river by constructing dams or weirs and water is pond up behind the dams or weirs. The water stored behind the dams or weir contain huge amount of potential energy. At downstream side of weir, turbine is installed which ultimately connected with electrical generator. Then stored water behind the weir is allowed to fall from the height through pipes. The falling water from weir generates pressure that rotates the shaft of turbine which is installed just downstream side of weir. When the shaft of turbine rotate, the generator coils also rotates rapidly as a result electricity is generated.

Hydropower generation is a function of head and discharge. Head is a difference of elevation between two points i.e. elevation at just above a weir to elevation where turbine is installed. Power generation is directly related with head and discharge. If more head and discharge is available in a river, more power can be generated and vice versa. Power outputs generated from turbine will always slightly less than power input because of turbine and system inefficiencies [13]. The different turbines have different efficiencies. Mostly turbines have an efficiency of 81 to 95 percent. The generators have an efficiency of almost 92 percent [14].

2.2.4 Types of Hydropower

Hydropower schemes are classified as three different kind [15] as shown in Figure 2.1.

(a) Storage schemes (b) Run of river schemes (c) Pumped storage schemes

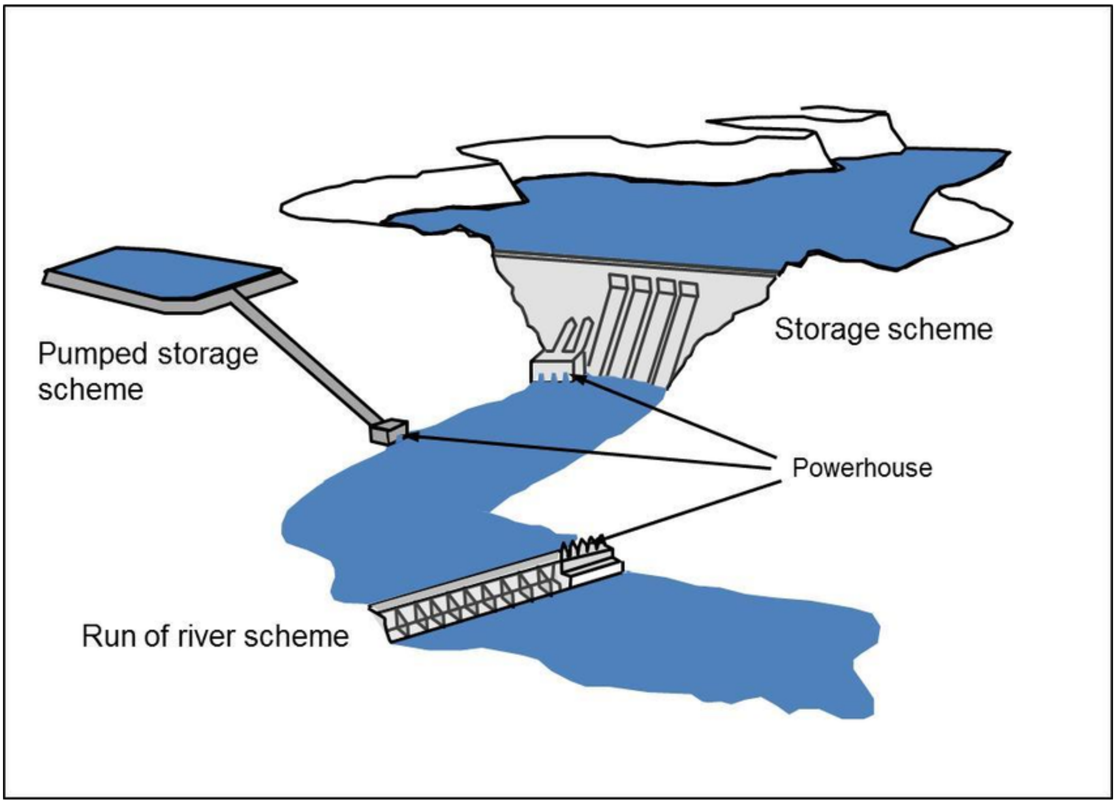

FIGURE 2.1: Diagram Illustrating the Main Types of Hydropower Schemes [15]

(a) Storage Schemes

Storage schemes have a dam that seizes the water in a reservoir that run the power plant. Storage schemes by and large have higher environmental and social expenses than pumped storage or run of river schemes because more land is immersed and the natural stream flow is upset.

(b) Run of River (ROR) Schemes

Run of river schemes have either no storage by any means, or a restricted measure of storage, referred to as pond age. Run of river plants change the flow of a stream less significantly then storage schemes. They are commonly considered to have a lower natural effect than storage schemes [16]. Run of river plants are significant for rivers with an adequate high least dry climate flow or those controlled by an a lot bigger reservoir or lake upstream.

(c) Pumped Storage Schemes

Pumped storage schemes gives peak load supply, harnessing water which is cycled between a lower and upper reservoir by pumps which utilize surplus energy from the framework at times of low demand. At the point when power request is high, water is discharged back to the lower reservior through turbine to create power. This type of hydropower can adjust load contrasts on power grids more successfully than advancements (e.g. thermal power stations) that commonly supply base load [17].

2.2.5 Hydropower Potential of Pakistan

The country has a total power generation capacity of over 34 GW by December, 2018 [18]. In 2018, the country has a power generation limit of 33, 840 Mega Watt. Hydel, nuclear and thermal are the principle source of power generation in Pakistan. According to Water and Power Development Authority (WAPDA), there is gross hydropower potential of 60,000 MW in Pakistan, out of which only 7172MW has been developed so far [19]. The vast undiscovered hydropower potential sites are in Gilgit-Baltistan. Some of undiscovered site are also located in Azad Kashmir and Punjab. The total installed capacity of the hydropower stations in the country is about 7172 MW, out of which 4303 MW is in Khyber Pukhtunkhwa (KPK), 133 MW is in Gilgit-Baltistan, 1697 MW in Punjab, 1039 MW in AJK [20]. Out of the main 20 countries which put in new hydro limit during 2018, Pakistan with the new introduced limit of 2487 MW, has been positioned third behind China and Brazil which are positioned first and second individually [21]. Figure 2.2 shows the shares of conventional energy source for power generation in Pakistan and graphical representation of Province/area wise hydro power generation in Pakistan.

During the year 2018, Pakistan has effectively finished three postponed mega hydropower projects with cumulative generation capacity of 2487 MW [23]. The new projects incorporate 108 MW-Golen Gol hydropower venture, 1410 MW Tarbela fourth Extension and the 969 MW Neelum Jhelum hydropower projects. The all out introduced generation capacity of hydroelectric power in Pakistan surged to 9389 MW from 6902 MW, enrolling an expansion of 36 percent in only one year.

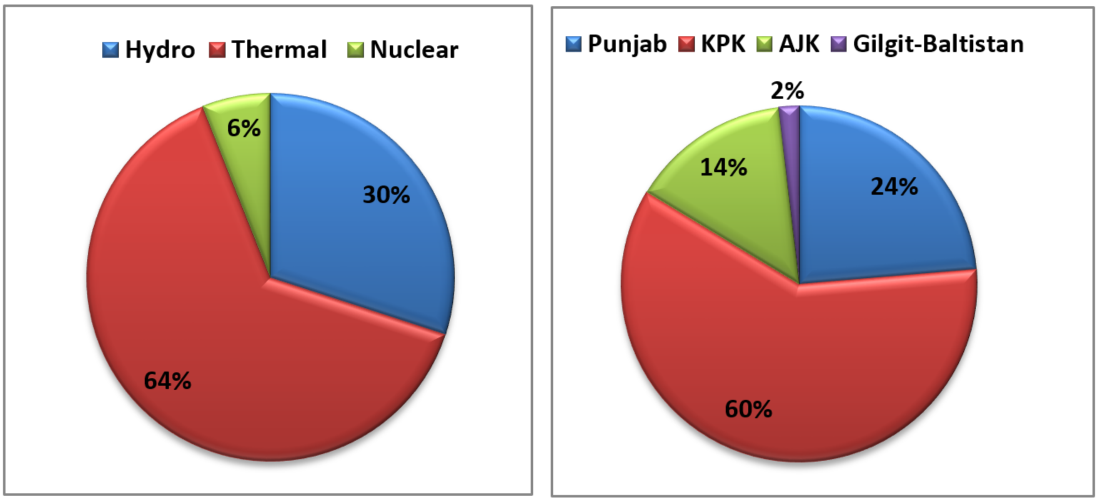

FIGURE 2.2: Shares of Conventional Energy Source for Power Generation and Percentage of Hydropower Generation in Pakistan ([22]

It is additionally worth to mention here that from 1958 to 2017 in 59 years of its beginning WAPDA could manage to take its hydel generation to 6902 MW. At various canals and barrages in Punjab, around 330 potential canal sites with an all out limit of 7291 Mega Watt were distinguished. Out of these, 8 projects with limit of 1698 MW are in activity, one site is under execution in the public sector by WAPDA, while 5 tasks with a limit of 24 MW on canal falls are under development in public sector by Govt. of Punjab. Around 142 project sites with an all out limit of 24736 MW were recognized in Khyber-Pukhtoonkhwa (KPK) having high, medium and little head. Out of these, 19 projects are in activity with a complete limit of 3767MW, 27 destinations are under execution in the public sector, though 10 sites are under implementation in the private division. In Azad Jammu and Kashmir, around 68 hydropower destinations with an absolute capability of 6450 MW have been identified to high, medium and little heads. Out of these 68 hydropower sites, 9 sites with a limit of 1036 MW are in activity, 23 sites are under implementation in the public sector and 22 sites are in the private sector. Around 278 project sited with an all out limit of 21125 MW were recognized in Gilgit-Baltistan having high, medium and little heads. Out of these, 98 projects are in operation with the absolute limit of 133MW, 31 projects are being handled/implement under the public sector through NAPWD and one in the private sector.

TABLE 2.1: Comparative Summary of the Hydro Projects in Various Stages of Implementation in various Regions of Pakistan [21].

Name of Province	Projects in Operation (MW)	Public Sector Project (MW)	Private Sector Project (MW)	Project with feasibility Study (MW)
KPK	4303	635	84	201
Punjab	1697	96	Nil	3752.17
AJ&K	1039	973.8	828.7	468.2
Northern Areas	133	18	Nil	576.5
Sindh	Nil	Nil	Nil	49.5
Baluchistan	Nil	Nil	Nil	0.5
Total	7172	1722.8	912.7	5047.87

2.2.6 Small Scale Hydropower

To meet the energy requirement, small scale hydropower plants (less than 1000 KW) play an immense task. Enormous investment is also not required for installation of small scale hydropower plants. Small hydro systems are preferable on small rivers by generating small head. Micro scale hydro system is also best from an ecological perspective. In small scale hydropower system, flow patterns at downstream are not disturbed and hence, there is no chances of flooding of valleys upstream [23]. Micro scale hydropower is a latest innovation that can be effectively worked and kept up [5]. To serve houses that are near a small river, micro hydro power plants are economical and best choice [24]. Small scale hydropower plants is also the best choice for future hydro advancement in developed countries, where the huge hydropower have been explored earlier or would now be considered environmental inappropriate. The drawback of Run-of-River (ROR) scheme is that water is not persisted from stormy to dry season [23]. Small Hydro Power Plants (SHPPs) is classified into small, mini, micro and pico on the basis of electricity generation [22]. Every country has own definition of small hydro. In most of countries, the highest range of Small Hydro Power Plant (SHPP) is 10 to 30MW. The hydro power plants with highest range less than 100kW are considered as micro hydro plants in most of countries [22]. In Pakistan, the hydropower plants with power generation capacity less than 50 MW is considered as small hydropower plants [5]. The classifications of hydro plants according to their power generation capacities in the different countries of world are listed in Table 2.2.

TABLE 2.2: Different Definitions used for Small Hydro Plants [25].

Country	Micro Hydro (KW)	Mini-Hydro (KW)	Small-Hydro (MW)	Large hydro (MW)
USA	<100	100-1000	1-30	>30
UK	100	101-1000	1-15	>15
China	-	500	0.5-25	>25
Turkey	1-100	101-1000	1-30	>10
Brazil	100	101-1000	1-30	>30
Other	100	1000	10	>10

2.2.7 Overview of Small Hydropower Worldwide

In one hundred and forty eight nations or region around the world, small hydropower plants with a limit of ten Mega watt exist. Worlds Small Hydropower Development Report (WSHDR) [5] in 2013 reported that total small scale hydropower potential is almost 173GW. The greater than half of the total small hydropower potential is situated in Asia. In Europe and America, almost 33 percent of total small hydropower potential is located. In 2011 and 2012, only 76 Giga Watt of small scale hydropower installed capacity is assessed. The total small hydropower potential in Eastern Africa is 6262 Mega Watt. The developed small scale hydropower potential (less than 10MW) in Eastern Africa is only 210 MW. In Eastern Africa, the highest small hydropotential is found in Kenya

(3000MW) and Ethiopia (1500MW). The total estimated small hydropower potential inMiddle Africa is almost 330 Mega Watt. Currently, only 77 Mega Watt is developed so far in Middle Africa. The total estimated small hydropower potential in Northern Africa is 183 Mega Watt. The developed small hydropower potential in Northern Africa is 156 Mega Watt. The estimated small hydropower potential in Southern Africa is 384 MW. The developed small scale hydropower potential in Southern Africa is only 44 Mega Watt. The estimated small hydropower potential in Western Africa is 743 MW. Currently, only 82 MW has been created so far. In Western Africa, the greatest small hydropower potential is found in Tago (145 MW). Figure 2.3 shows the worldwide dispersion of small hydropower asset potential (less than 10 MW). World Small Hydropower Development Report (WSHDR) [5] reported that 65 percent of total world's small hydropower is situated in Asia. World Small Hydropower Development Report (WSHDR) [5] also reported that 29 percent of total small hydropower is situated in Europe and America, almost 5 percent is found in Africa and almost 1 percent is found in Oceania. The graphical representation of small hydropower potential at each continent is shown in figure 2.3.

The total small hydropower potential in Caribbean is 253 MW. The created small hydropower potential in Caribbean is 125 MW. In Caribbean, the highest small hydropower potential is found in Jamaica (64 MW) and Cuba (63 MW). The total small hydropower potential in Central America is 4117 MW. The created small hydropower potential in Central America is 598 MW. In Central America region, the greatest potential is located in Mexico (3251 MW). The total small hydropower potential in South America is 9466 MW. The created small hydropower potential in South America is 1734 MW. In South America region, the highest potential is found in Chile (7002 MW). The created potential of small hydropower up to 10 MW in Northern America is 7845 MW. The total small potential of Central Asia is 4881 MW. The developed small hydropower potential in Central Asia is only 185 MW so far.

In Central Asia, the greatest potential is found in Kazakhstan (2706 MW). The total small hydropower potential in Eastern Asia is 75314 MW. The created small

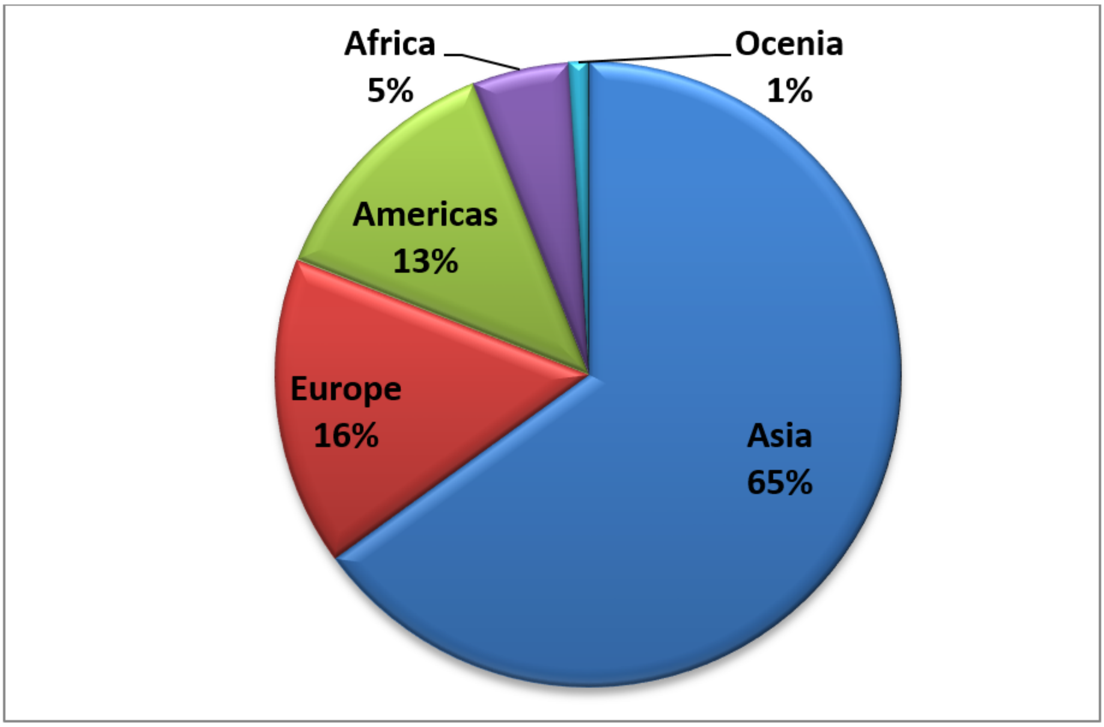

FIGURE 2.3: Global Distribution of Small Hydropower Resource Potential up to a Capacity of 10MW [5].

hydropower potential in Eastern Asia is 40486 MW. In Eastern Asia, more than 63402 MW of small hydropower potential is located in China. The total small hydropower potential in Southern Asia is 18078 MW. The created small hydropower potential in Southern Asia is 3564 MW. The worldwide greatest small hydropotential is located in Eastern Asia followed by South Asia. The total small hydro power potential in Western Asia is 7755 MW. Currently, in Western Asia only 490 MW is created. In Western Asia, the greatest small hydropower potential is located in Turkey. The total small hydropower potential in Eastern Europe is 3496 MW. Currently, in Eastern Europe only 2736 MW is created. In Eastern Europe, the greatest small hydropower potential is found in Russian federation (1301 MW). The total small hydropower potential in Southern Europe is 14170 MW. Currently, in Southern Europe only 5642 MW is created. In Southern Europe, the greatest small hydropower potential is located in Italy (7067 MW).

The total small hydropower potential in Northern Europe is almost 3842 MW. The currently created small hydropower potential in Northern Europe is 3644 MW. The total small hydropower potential in Western Europe is almost 6645 MW. The currently created small hydropower potential in Western Europe is 5810 MW. In Western Europe, the greatest small hydropower potential is found in France (2652 MW). The small hydropower potential of Australia and New Zealand is almost 933 MW (up to 10 MW). The developed small hydropower potential is 309 MW. The Pacific Island Countries and Territories (PICT's) has a hydropower potential of 307 MW. Currently, only 104 MW has been created. In Pacific Island Countries and Territories (PICT's), the greatest small hydropower potential is found in Papua New Guinea country (154 MW).

2.2.8 Small Hydropower in Pakistan

In Pakistan, abundant water assets are present in hilly areas. Due to availability of abundant water resource in Khyber Pakhtunkhwa (KPK) and Azad Kashmir, Pakistan has the broad capability of hydropower generation. Various government and non-governmental association are dealing with the establishment of small hydro power plants in the nation [26]. The major organization working in Pakistan for advancement of small hydro plants are Pakistan Council of Renewable Energy Technologies (PCRET). Some other organization, Sarhad Rural Support Program (SRSP) and Alternative Energy Development Board (AEDB), are also working for the exploration of small hydro plants in Pakistan. PCRET installed 678 small hydro power plants (SHPP's) in a country. These 678 small hydro plants are installed from 1978 to 2016 in a country. The scope of these introduced small hydro plants is 5 to 100kW. These installed small plants add 9.5 MW of electricity [22]. Among non- governmental organizations, Sarhad Rural Support Program (SRSP) has performed a significant job in giving power to remote zones that are not associated with the national network. Table 2.3 provides details of the plants installed by PCRET.

Table 2.3: Different Small Plants Installed by PCRET [22].

Region	No of Plants Installed	Installed Capacity (KW)	Houses Electrified
KPK & FATA	553	8239.5	65337
Gilgit	72	401.5	4010
Baluchistan	3	80	800
AJ&K	50	786	4758
Total	678	9507	74905

As per an overview led in Malakand division Khyber Pukhtunkhwa, 26 percent population still don't have electricity in home. There are 166 small hydro power plants which is introduced and working under the Sarhad Rural Support Program (SRSP). They installed these small hydro plants from 2006 to 2014. They introduced 9.6 MW power by using an amount of Rs 1.25 million. These 9.6 MW generated power is used by more than 0.242 million people. Though the quantity of plants introduced has expanded to 422 of every two continuous years because of the expansion in demand. These 422 SHPPs produce 33MW of power and electrify roughly 0.7 million individuals [22]. These plants are made operational with a use of Rs.3.2 billion. Pakhtunkhwa Energy Development Organization (PEDO) is likewise working on little hydropower plants (SHPPs) that will give 2156 MW of electric power by 2020. As indicated by the report of the International Renewable Energy Agency (IRENA), the all out power delivered from the hydro asset (resource) is 7407MW in 2017. This is only 12.65% increase since 2007, which is not appreciable. The expansion in little, medium and enormous hydro since 2007 is 10.5%, 34.28%, and 10.47%. IRENA partitioned hydro plants into small hydro (¡1MW), medium hydro (1–10MW), and large hydro (>10MW). Table 2.4 shows the power produced since 2000 in MW.

TABLE 2.4: Power Produced Since 2006 in Megawatts [22]

Years	Small Hydro	Medium Hydro	Large Hydro	Total
2007	19	70	6485	6574
2009	19	86	6566	6671
2011	19	88	6638	6745
2013	21	94	6978	7094
2015	21	94	7108	7224
2016	21	94	7164	7255
2017	-	-	-	7407

According to Water and Power Development Authority, the total small hydropower potential in our country is 2265 MW. Unfortunately, little hydropower advancement has no capability in Baluchistan province, Pakistan only because of unavailability of required head to generate electricity. The total small hydropower potential and installed capacity is shown in figure 2.4.

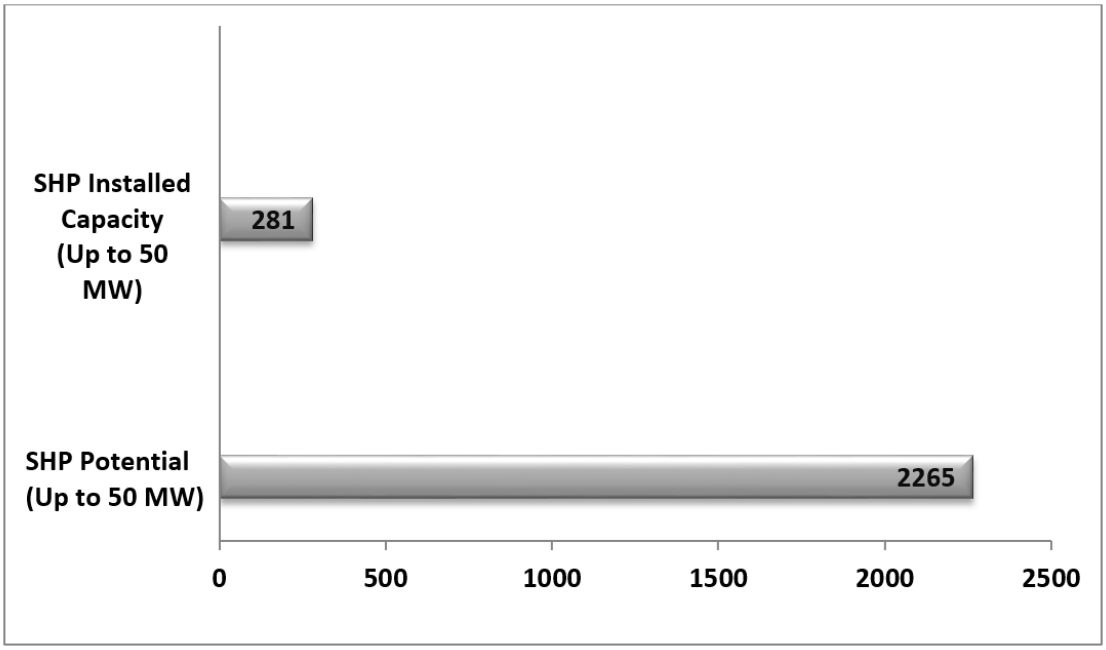

FIGURE 2.4: Small Hydropower Capacities in Pakistan [5]

2.3 Hydraulic Turbine

2.3.1 Introduction

The turbine comprises of a spout or stator, sprinter and shaft. The principle of turbine is to transform energy and pressure of flowing water into rotational mechanical work [28]. The pressure driven turbine is a mechanical gadget that converts the potential energy contained in a raised waterway into rotational mechanical energy. Pressure driven structures (turbine and generator is used to catch the energy (kinetic and Potential) of water. The estimation and computation of the impacts of different pressure driven (hydraulic) structures on volumetric fluid stream (flow) rate are made by hydraulic engineering [29]. Hydraulic turbines can be divided into different types. Choosing the specific type of turbine for generation of electricity depend upon different factors. The most significant factors for determination of turbines in stream are discharge and head. Different type of turbine along with head ranges are listed in Table 2.5.

Table 2.5: Turbine Type and Typical Net Head Range [30].

Turbine Type	Head Ranges (meters)
Kaplan and Propeller	2 to 40
Francis	10 to 350
Archimedes	1 to 10
Pelton	50 to 1300
Cross flow	2 to 200
Turgo	50 to 250

2.3.2 Types of Hydraulic Turbine

There are two different types of turbines: Impulse and Reaction type. Figure 2.5 shows the various types of impulse and reaction types.

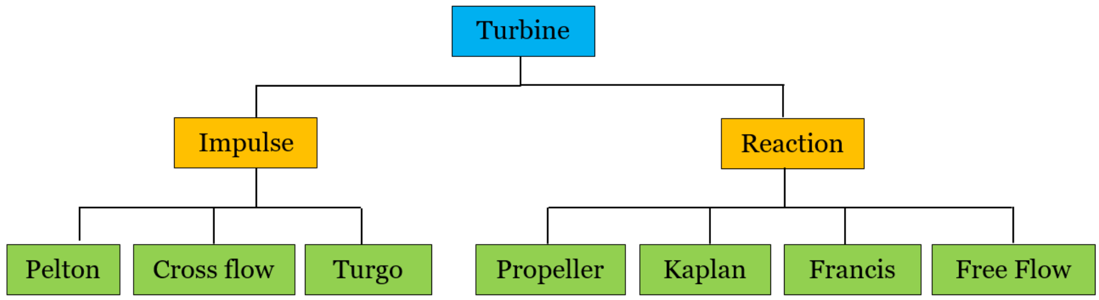

FIGURE 2.5: Types of Turbine [31].

The turbines type shows the way in which the water makes the turbine runner to rotate. Reaction turbine works with their runners completely overflowed and creates force (torque) in light of the response of water pressure against runner blades. Examples of reaction turbines include propeller, Kaplan, and Francis, screw and hydro kinetic turbines (used for low head range less than 5m). For low head, Propeller turbine is very efficient [31]. Kaplan turbine is an evolution of Francis turbine. It is suitable for low head and high flow applications. It is used for head of 6 to 15m and a high rate of flow of water [22]. The Francis turbine is a crude kind of conventional turbine that is utilized generally in SHPPs. The working scope of Francis turbines is somewhere in the range of 1m and 900m for mini, medium or huge hydro plants [22]. Classification of different turbines on the basis of head is shown in Table 2.6.

TABLE 2.6: Turbine Classification [31].

	Low (<10m)	**Medium (10-50m)**	**High (>50m)**
Turbine Type	Cross Flow	Cross Flow	Pelton
	Francis	Francis	Turgo
	Propeller	Turgo	Multi Jet Pelton

Impulse turbines work with their sprinter in air and transform the water's weight energy into kinetic energy of a stream that encroaches onto the sprinter buckets to create torque. Pelton wheel, Turgo wheel and cross-flow (BankiMichell) turbines are three different type of impulse turbines. Pelton turbine is also called free stream turbine. Pelton turbine is utilized for a less volume of water with high heads (100m to 1000m) [32]. A Pelton wheel has one or multi free jets. Recently, Pelton turbines can also be used for small hydropower systems. The efficiency of Pelton turbine is 70 to 90%. Turgo turbine is used for a low volume of water and high heads. Another name of Cross-flow turbine is called as Ossberger turbine. The Ossberger turbine has a littler limit so it is utilized in SHPPs for low head and high stream applications [22]. The various used hydraulic turbines across the world are shown in figure 2.6.

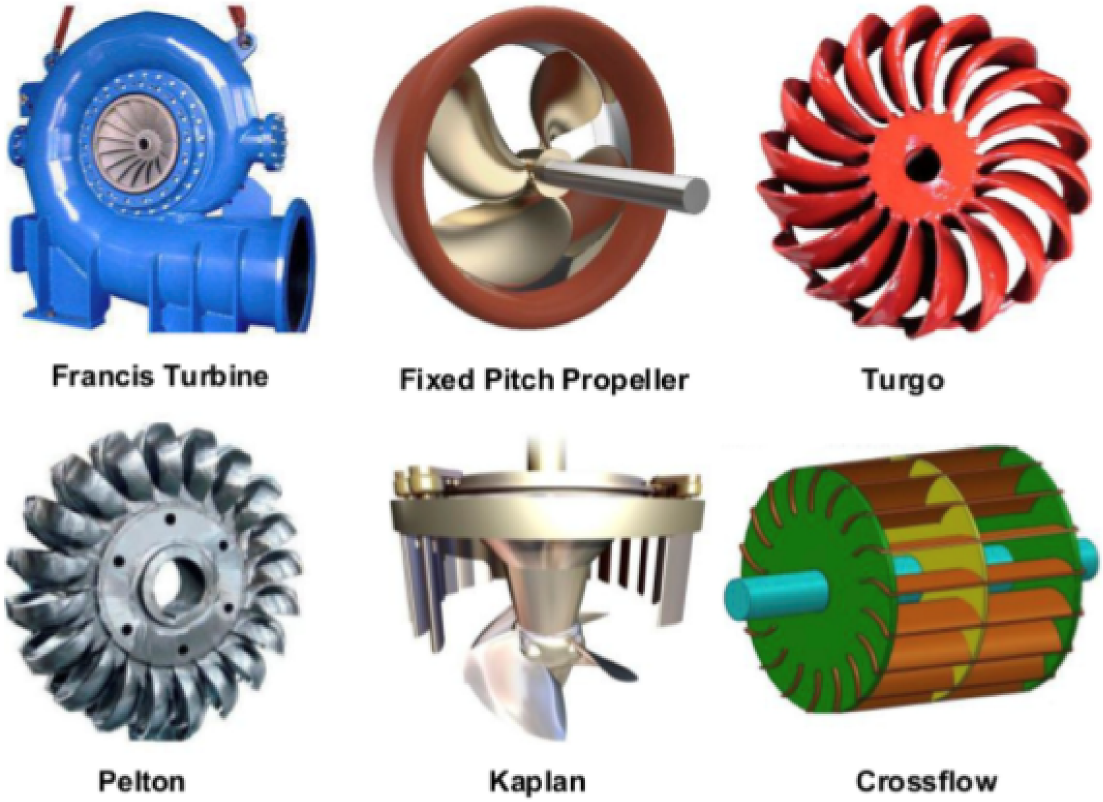

FIGURE 2.6: Commonly Used Hydraulic Turbines [22].

2.3.3 Selection of Turbine

Selection of best turbine for each system depends upon many factors. The important factor for selection of turbine is discharge. The discharge throughout a year helps the designer for better turbine selection. The reaction turbine is optimal option for less to moderate head. For moderate to greater head, Pelton turbine is optimal choice [22]. Pelton or Turgo turbine is the most ideal decision in case of little water flow and greater head (>50m). The appropriate decision for huge water stream and less head (<10m) is Propeller or Kaplan. The two techniques which are used for determination of turbine are as follows:

(a) Thumb Rule (b) Scientific Method

(a) Thumb Rule

By computing given head and stream conditions, various types of turbines can be chosen. Figure 2.7 summarizes the selection of turbines related to the head and power generated.

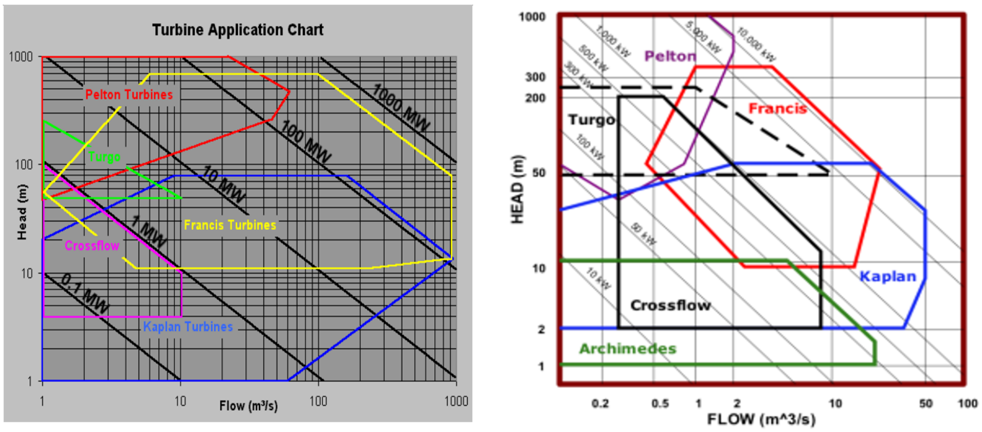

FIGURE 2.7: Turbine Selection Chart Based on Head and Flow [33].

(b) Scientific Method

The most significant factor of turbine is specific speed. The specific speed is denoted by symbol N_s. Previously, different turbines have been chosen by calculating specific speed. The formula for calculating specific speed is given below as equation 2.1:

$$N_s = \frac{n(\sqrt{(p \times 1.358)})}{(H)^{\frac{4}{5}}} \tag{2.1}$$

Where N_s = specific speed of turbine in revolutions per minute,

n = rated speed of turbine in revolution per minutes,

P = turbine output in KW

H = rated head in meters.

The diagram given in literature review (Head versus Specific Speed) can be utilized for selection of various turbines after the computation of specific speed. Figure 2.8 shows the diagram for selection of turbines, if head and specific speed is known.

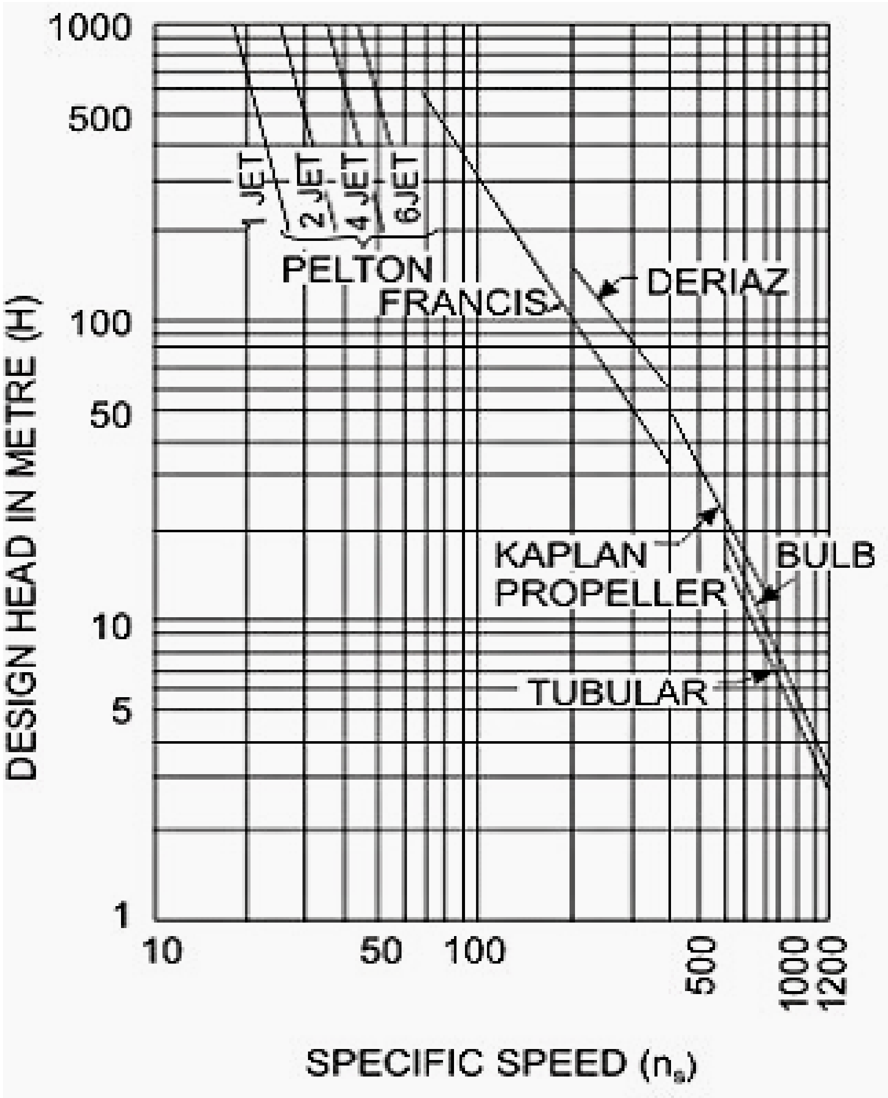

FIGURE 2.8: Chart for Determining the Selection of Turbines [34].)

2.3.4 Turbine Power

Hydro-power generation relies on water fall from height. The fuel of a hydropower plant is river flow. The generation of hydro power stop, when water stop flowing in a river. Despite the water way through an open channel or penstock, the force created in a turbine (lost from water potential energy) is computed by applying equation 2.2 [35]:

$$Pt = \rho \times Q \times g \times H \times \eta t \tag{2.2}$$

Where Pt = power in watt generated in the turbine shaft,

ρ = density of water,

H = head,

Q = water flow rate,

g = acceleration due to gravity, and

ηt = turbine efficiency (normally 80 to 90%)

The proportion of intensity provided by the turbine to the consumed power is called as turbine efficiency. To evaluate the overall efficiency of the small hydropower plant, the turbine efficiency is multiplied by the efficiencies of the speed increaser and the alternator.

2.4 Geographic Information System (GIS)

2.4.1 Introduction

GIS is the abbreviation for Geographic Information System. GIS refers to the integration of technology, software hardware, management and showing different types of the geo referenced data. It is a powerful set of tools for gathering, storing, retrieving, transforming, and then displaying spatial data from around the world [36-38]. It is also used for computerized mapping and spatial analysis. The discipline of GIS is not restricted by one science category; rather, it was established as a beneficial tool for miscellaneous specialties, such as geologists, engineers, environmentalists, photogrammetrists, urban planners, and cartographers. During a last decade, GIS is often used for spatial data manipulation and information management [39].

2.4.2 Arc-GIS

ArcGIS is a geographic data framework for working with geographic data and maps. It is used for; utilizing and making maps; breaking down mapped data; sharing and finding geographic data; compiling geographic data; managing geographic data in a database and utilizing maps and geographic data in a range of applications [40].

2.4.3 Component of Arc-GIS

Four main components contribute to the establishment of geographic information system: hardware, software, GIS specialists and infrastructures. These components ensure that it is not far from other information technologies. The GIS specialists define the purpose and aims, as well as provide the justification and the reason, for using the GIS.

Arc-Map, Arc-Catalog, Arc-Toolbox, Arc-Scene, Arc-Globe, Arc-Hydro and ArcGIS Pro is the integrated application of ArcGIS. Arc-Map is the main mapping application which allows creating map, querying attributes, analyzing spatial relationship, and layout final projects. Spatial information contained on PC is arranged by Arc-Catalog. Arc-Catalog likewise permits looking; reviewing and adding information to Arc-map just as oversees metadata and setup address locator services (geocoding). Arc-Toolbox contains apparatus for geo handling, information change and coordinate system etc. Arc-Toolbox isn't open from start menu. Arc-Toolbox is built within Arc-Map and Arc-Catalog. Arc-Globe is a 3D perception application that permits viewing a lot of GIS information on a globe surface. Arc- Scene permits client to see GIS information in three measurements.

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.

2.4.4 GIS Application in Hydropower Generation

In last couples of years, Geographic Information Systems (GIS) have demonstrated to be an efficient tool in the identification of potential sites for hydropower improvement. Different studies and research have been done in different pieces of the globe on the utilization of GIS for identifying potential sites for conservative hydropower projects. To create area specific energy asset and utilization profile in rural territories of Nepal, Pokharel [41] performed spatial analysis by utilizing GIS in 2000. For distinguishing appropriate area for hydropower in West Bengal, Das and Paul utilized GIS tool in 2006. Ramachandra et al. (2004) [42] created spatial choice supportive network for surveying smaller and little hydro venture in Karnataka (India). The choice supportive network incorporates spatial data created through GIS and water assets appraisal techniques. Cyr et al. (2011) [43] surveyed the little hydroelectric potential for a wide region in Canada by utilizing GIS apparatuses and a provincial regression model to assess flow of river. To create a GIS based algorithm for recognization of potential hydropower destinations in Scotland, Forrest et al. developed a GIS-based algorithm in 2019. Gergel'ova et al. in 2013 [44] utilized GIS apparatuses to examine the hydropower capability of the Horna'd stream basin in Slovakia. To examine the little hydropower potential in a GIS tool, Palla et al. in 2013 [45] proposed an analytical. Larentis et al. [46] in 2010 built up a GIS-based computational program for enormous scope study of hydropower possible sites in Brazil. To distinguish areas for little hydropower plants in the upper part of Geum River Basin in Korea, Yi et al. [47] created and applied a philosophy that depends on a Geo-Spatial Information System in 2010. Guiamel et al. (2020) [48] used GIS tool identify and classify the theoretical hydropower potential sites in Misamis Occidental, Philippines. Buehler (2011) [49] discussed the design of an ArcGIS toolset to assess the flow direction curves (FDCs) at areas where information do not exist, helping in deciding the most suitable site for small hydroelectric power development in the Dominican Republic Jha (2011) [50] used GIS for preprocessing of the SRTM (Shuttle Radar Topographic Mission) to generate the stream network and for catchment delineation. Feizizadeh and Haslauer (2012) [51] 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. Gergeov et al. (2013) [52] 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).

2.5 Hydropower and Weir

The existence or installation of a weir are beneficial to generate a head and, ultimately for electricity generation. The available of a differential head (drop in water level) in a river create a golden opportunity for small scale hydro power generation. The various going small head hydropower frameworks have been created by constructing small weir with aim that a little scope power can be generated [53]. The principle for generation of small scale electricity by installing weir is that water is dammed with the help of weir to make a little reservoir and head of water. The water is then permitted to move through low head turbines housed in the weir to produce power. The outpouring is for all intents and purposes equivalent to inflow, and the water is returned straight forwardly to the river without changing the current stream flow or water levels. Figure 2.9 shows working of small scale hydropower generation by constructing weir without diversion of flow. The other option for power generation is that water is dammed up by constructing small weir and then from upstream water is diverted. The diverted water is then allowed to pass through turbines to generate electricity. After passing through turbines, diverted water again joins the main river.

2.6 Structure for Sides Protection of River

For developing a hydraulic structure over a waterway, a water resource engineer should likewise consider the impact of the structure on the hydraulic of river and the best ways to train the river such an extent that the structure performs

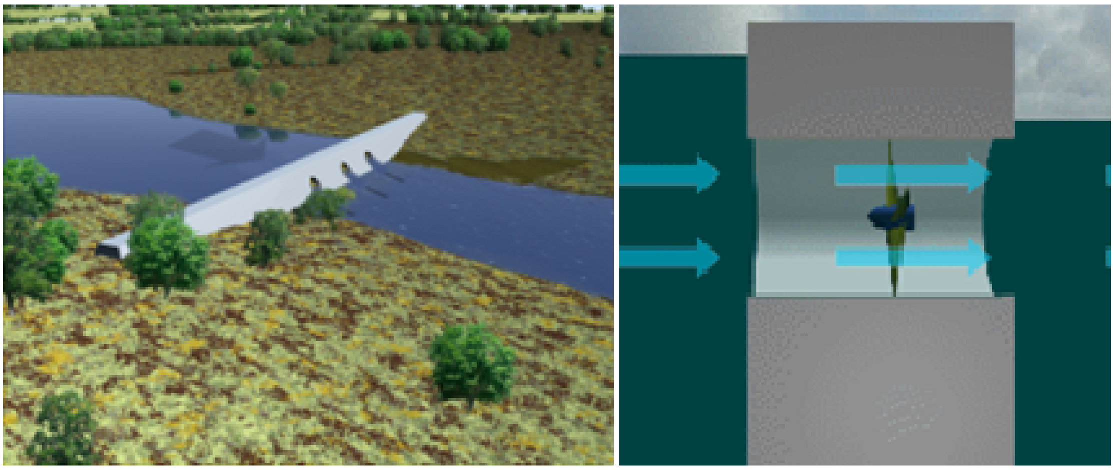

FIGURE 2.9: Small Scale Hydropower Generation by Constructing Weir without diverting Flow

FIGURE 2.10: Small Scale Hydropower Generation by Constructing Weir with Diverting Flow [54].

satisfactory and furthermore there is no noteworthy harm to the riverine condition. With the development of weir, the degree of water in the stream upstream is raised by a couple of feet in all seasons. This is called afflux. The rise of water level is felt up to several miles upstream. This effect of water at upstream is called backwater effect. If this rise is felt unattended, it will threaten the areas of upstream. For protection of back water effect, sides of river can be protected by number of methods. The choice of structure or method depends on multiple factors such as budget available, topography of area and volume of water etc. To protect properties from submergence and destruction, a lot of dikes (embankment) are built on the two sides of the stream upstream sides of weir. These embankments are called marginal bunds. The marginal bunds are permanent structures so they are aligned in such ways that they don't interfere with the river meander. They are tied or joined to the high ground upstream so that the river flows with in the two marginal bunds and is not allowed to outflow the embankments. Height and length of marginal bunds (figure 2.11) vary according to backwater effect caused by weirs.

FIGURE 2.11: Marginal Bund

2.6.1 Previous Studies Conducted on Soan River

Soan River is a significant tributary of Indus River. It is also a primary hydrological unit of Potohar plateau Pakistan. Prior to falling into the Indus River, the Soan River goes through many stations i.e. Chirah, Rawalpindi, Dhoke Pathan and Makhad [55]. Height of Soan river basin lies in between 265 to 2274m. The total area of Soan river catchment is 6480 sq. km. The slope of Soan river basin is steep at upstream i.e. near Murree. The slope changes from steep to gentle at its downstream side. The major flow generated in Soan River is because of monsoon rain [56]. The average annual precipitation of Soan river basin varies from 250mm to 1800mm. The maximum precipitation occurs in north and minimum precipitation occur in the south west [55]. Different studies and research have been done on Soan River in last couples of years. Ashfaq et al. [56] in 2014 led a detail research on groundwater study of Soan catchment of Pakistan. Jawed et al. (2018) [57] deduced in his examination that there is a high spatial and transient variety of precipitation in the Soan catchment. After 1984, the precipitation in Soan basin is reduced bringing less catchment outflow. The dry season was observed from 1997 to 2002 in Soan basin. After 2002, the precipitation in Soan catchment is increased but no huge increment in catchment outflow was watched because of increase in ground water utilization (95% population increase) [56]. Shahid et al [55] in 2017 conducted a research on the effect of environmental change and human exercises on flow of Soan River. They conduct a Mann-Kendal and Pettit test to discover the pattern and change point in hydro climatic factors from 1983 to 2012. The approaches consider measuring the effect of environmental change and land use change on stream flow are hydrological model and budyko framework. The result of these method shows that annual runoff has significantly decreased from 1997 onward. They concluded that main reason for runoff reduction after 1997 is because of agricultural activities growing in Soan catchment. They also concluded that decrease in precipitation and increase in evapotranspiration contributes 68% of the detached change while the rest of the detached change is due to land use change. Yang et al (2019) [58] predicted steam flow of Soan river basin. They proposed two deep learning techniques to predict stream flow and also concluded that stream flow is directly affected by precipitation, land usage and temperature. They also concluded that precipitation, land usage and temperature are critical factor which can be used by hydrologist to identify the potential for stream flow. Jawed et al. (2018) [57] contemplated a hydrological reaction to environmental change on Soan stream catchment. They utilized satellite imaginary for land spread arrangement and to research the land use changes in the Soan catchment, utilizing Earth Recourses Data Analysis System (ERDAS). They inferred environmental change anticipated precipitation information under the moderate and greater emission situations RCP 4.5 and RCP 8.5 respectively. After the investigation, the two situations RCP45 and RCP 85 show the likely increment in stream flow at Dhok Pathan that could impressively prompt raise the water assets of the catchment under the changing environment. In this way, huge and little reservoirs are basically required to oversee the flood conditions in Soan River catchment.

2.7 Summary

Hydropower is one of the most efficient and well established electrical power generations. Small hydropower plants are one of the alternative sources of energy generation [14]. Small hydroelectric plants are low cost; small sized and can be installed to serve a small community (Joshi et al. 1994). To select an appropriate turbine, discharge and head of river or stream is two most important factors. GIS is a computer system for gathering, inquiring, analyzing and displaying geospatial data [24]. In recent years, GIS and remote sensing tools have additionally been utilized for evaluating hydropower potential. Carroll et al. (2004) observed the possibility of utilizing GIS tools to distinguish potential small hydropower (under 1 MW) sites in USA. To create area specific energy asset and utilization profile in rural territories of Nepal, Pokharel performed spatial analysis by utilizing GIS in 2000. Ramachandra et al. (2004) [42] created spatial choice supportive network for surveying smaller and little hydro venture in Karnataka (India). For distinguishing appropriate area for hydropower in West Bengal, Das and Paul utilized GIS tool in 2006. Cyr et al. (2011) [43] surveyed the little hydroelectric potential for a wide region in Canada by utilizing GIS apparatuses and a provincial regression model to assess flow of river. To create a GIS based algorithm for recognization of potential hydropower destinations in Scotland, Forrest et al. developed a GIS-based algorithm in 2019. Different studies and research have been done on Soan River in last couples of years. Ashfaq et al. [56] in 2014 led a detail research on groundwater study of Soan catchment of Pakistan. It can be concluded after studying a variety of researcher that no studies is conducted for evaluating hydropower potential of Soan River till now. It is also concluded that

GIS is broadly used to gauge hydropower potential in numerous nations around the globe. Notwithstanding having extraordinary potential, GIS based innovation has been utilized to lesser degree for the evaluation of the hydro potential in Pakistan in light of the complexities and advancement procedure. To the best of author's knowledge, electrical storage being faced by the country can only be overcome by evaluating hydropower potential of different small rivers using GIS and installing different small scale turbines for generation of electricity.

Chapter 3

Methodology

3.1 Background

In this chapter, the methodology used to accomplish the research objectives is discussed in detail. The software which is used to achieve the research objective is ArcGIS, Google Earth Pro and AutoCAD. ArcGIS is used for terrain pre-processing of study area and to calculate discharge at different point in study area. To calculate slope of river from study area, Google Earth Pro is used. This chapter also explains the detail method for generating head (weir height) at different selected point in study area. The method used for calculating back water length i.e. direct step method and standard step method is also discussed in detail. Furthermore, in this chapter techniques used for evaluating hydropower potential are also discussed in detail.

3.2 Study Area

The study area comprises of Soan River watershed from flow originating point (village Bun of Murree) to Rawalpindi but hydropower potential is only evaluated for the reach starting from Chirah station on Rawalpindi station of Soan River. The study area is located between longitudes 73° 5’ E to 73° 31’ E and latitude

33°29’ N to 33° 53’ N. The study area has been determined to have a size of nearly 1495 Km^2 catchment. The elevation of study area lies from 411m to 2207m. Along the way of study area, two main streams (Ling stream and Korang stream) join the river. Ling stream originate from foothills of the Lhetrar area near Kahuta and joins the study area just before the famous bridge, named Kaak Bridge. Korang stream originates from Murree hills and flows toward Islamabad and joins the study area just before the Soan Bridge. The average annual rainfall in the study area varies from 780 mm to 1307mm (Shahid et al., 2018). At Murree (high rainfall area), the average rainfall from 1985 to 2005 is 1307mm (Ashfaq et al., 2014). The temperature falls below the freezing point from December to February in Murree (Ashfaq et al., 2014), whereas at Rawalpindi the temperature is quite high in summer. However the winter is relatively mild. Tables 3.1 and 3.2 show the coordinates and elevation of study area (Murree to Rawalpindi) and hydro potential evaluated area (i.e. from Chirah to Rawalpindi) respectively. Figure 3.1 shows the location of study area on topographic map.

Table 3.1: Coordinates and Elevation Range of Study Area

Study Area	**River**	**Longitude Range**	**Latitude Range**
Murree to Rawalpindi	Soan	73° 5’ E to 73° 31’ E	33°29’N to 33°53N

Table 3.2: Coordinates and Elevation Range of Hydro Potential Evaluated Area of Soan River

Study Area	**Longitude Range**	**Latitude Range**	**Elevation**	**Length (Along the River)**
Chirah to Rawalpindi	73° 5’ E to 73° 19’ E	33°29’N to 33°38’N	411m to 552m	32km

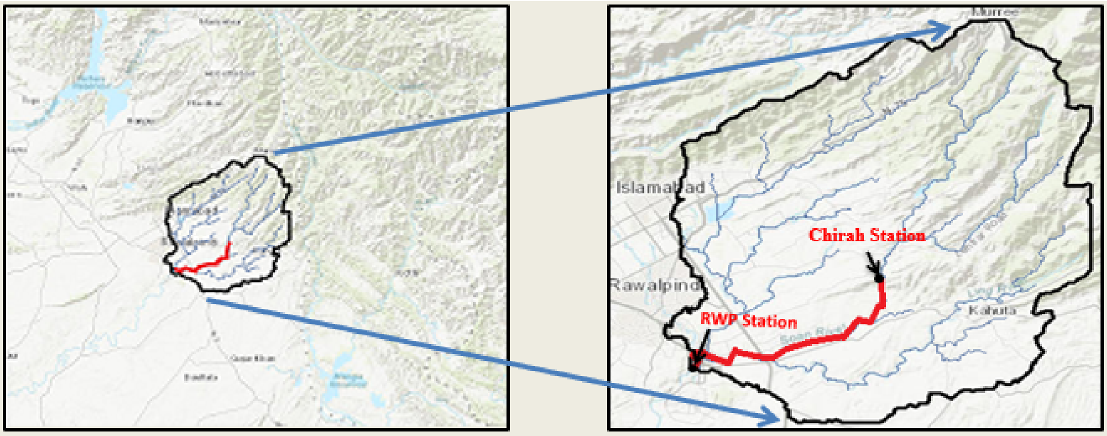

FIGURE 3.1: Location of Study Area on Topographic Map

3.3 Data Acquisition

For evaluation of hydro potential of river, following data was acquired:

- Stream flow data
- Topographic data

3.3.1 Stream Flow Data

The stream flow data of Soan River at different stations is collected or extracted from study of different researchers [55, 56]. The annual stream flow data for the period of 1983 to 2010 is acquired from the study of research conducted by Ashfaq et al. (2014) [56]. They collected this data from Water and Power Development Authority (WAPDA). The data was available at two stations i.e. Chirah and Rawalpindi of Soan River. The flow data of Chirah station is located at Chirah dam and flow data of Rawalpindi station is located at 32km downstream along the length of Soan River. The flow data from 2005 to 2010 is calculated by using precipitation data. The precipitation data is collected from study of research conducted by Shahid in 2019. They collected these precipitation data from Pakistan Meteorological Department (PMO). The average annual flow data from 2005 to 2010 is calculated by applying rational formula on precipitation data. Figure 3.2

shows the yearly variations in stream flows of Chirah and Rawalpindi stations of Soan River from 1983 to 1998 while Figure 3.3 shows the yearly variations in stream flow of Chirah and Rawalpindi station of Soan River from 1999 to 2010.

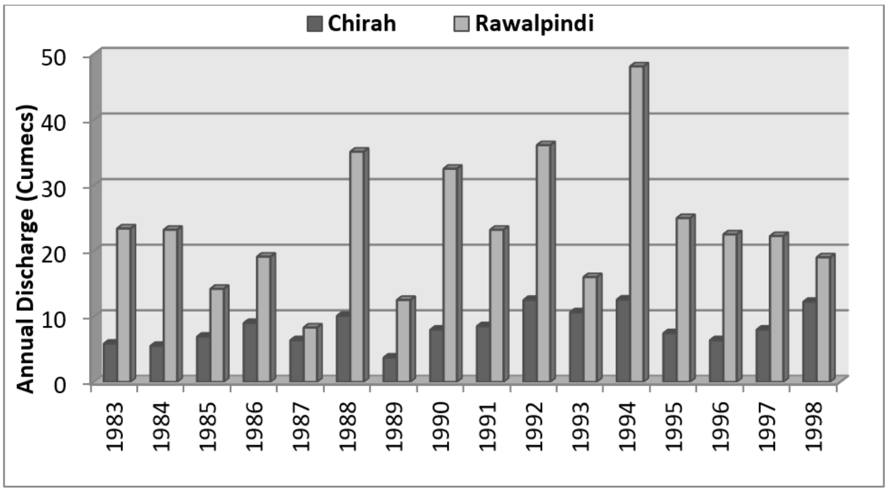

FIGURE 3.2: Average Annual Discharge Variations of Gauging Stations of Soan River from 1983 to 1998

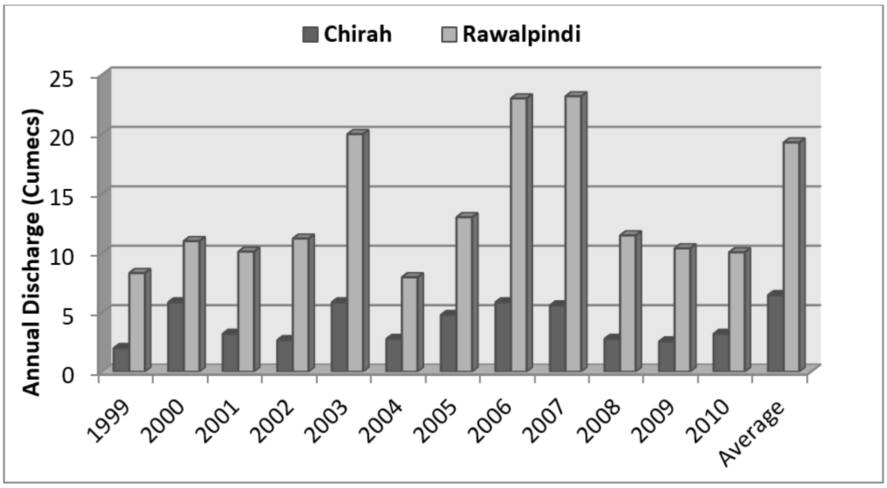

FIGURE 3.3: Average Annual Discharge Variations of Gauging Stations of Soan River from 1999 to 2010

The two streams (Ling and Korang) join the Soan River with in study area (Chirah to Rawalpindi). Ling stream joins the Soan River near Kaak Bridge and Korang stream join the Soan River just before the Soan Bridge. Table 3.3 shows the average annual discharge of streams joins the Soan River within study area.

Table 3.3: Average Annual Discharge of Ling and Korang Stream and Joining Location with Soan River

Stream	Joining Location	Longitude	Latitude	Average Discharge
Ling	Kaak Bridge	73°10'53" E	33°32'44"N	2.66 cumecs
Korang	Soan Bridge	73°06'10" E	33°33'06"N	6.60 cumecs

3.3.2 Topographic Data

Topographic data is obtained in the form of Digital Elevation Model (DEM) from NASA Shuttle Radar Topography Mission (SRTM) 30 m digital elevation data. Shuttle Radar Topography Mission (SRTM) generates one of the most complete high detailed digital topography data-base of world by obtaining elevations on an almost global scale. Shuttle Radar Topography Mission (SRTM) covers the world in 90m x 90m and 30m x 30m grids. It is based on world geodetic system 1984 (WGS84) datum [59]. Digital Elevation Model (DEM) of single grid in which study area (Soan River basin) lie is downloaded from earth explorer website [60] by selecting the file format in Geo Tiff format. The 30m x 30m grid covers wide range of area. To specify only study area in downloaded DEM, first of all terrain pre-processing (fill sinks, flow direction and flow accumulation) of downloaded DEM is done. Coordinates of Rawalpindi station is listed in excel sheet and save in .CSV format. After that, add comma separated value (.CSV) excel file in ArcGIS, Rawalpindi station point is shown on downloaded DEM in ArcGIS. Once Rawalpindi station is shown on flow accumulation, watershed is generated in ArcGIS along Rawalpindi station point. After that polygon shape file is added in Arc Catalog and draw a polygon shape as watershed is generated on DEM. Finally DEM is clipped along the drawn polygon shape i.e. watershed generated. The DEM of generated watershed of study area (Soan river basin from flow originating point i.e. Murree to Rawalpindi station) is shown in separate layer in ArcGIS. The Digital elevation model (DEM) of study area (Soan River basin from flow originating point to Rawalpindi station) is shown in Figure 3.4.

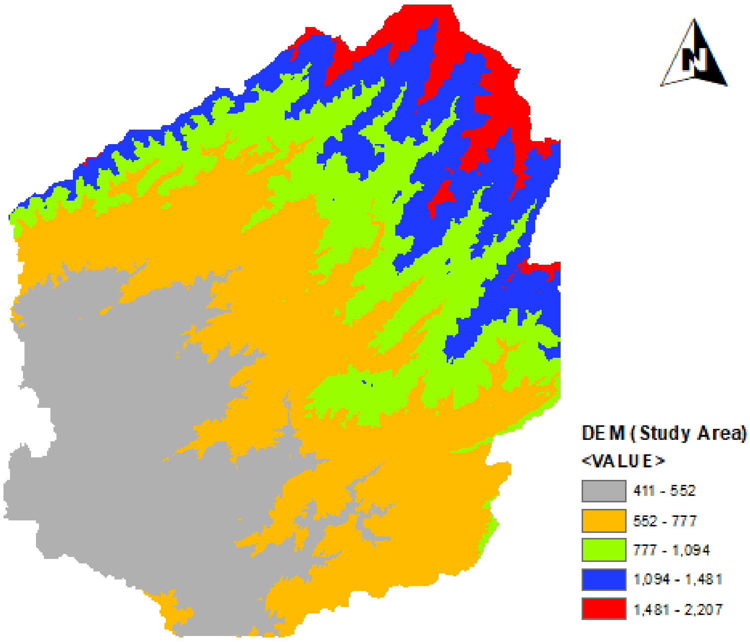

FIGURE 3.4: Digital Elevation Model (DEM) of Soan River Basin from Flow Origin Point (Murree) to Rawalpindi obtained from SRTM 30m

3.4 Methodology

The approach used for evaluation of hydropower potential of study area is discussed in this section. Terrain pre-processing of study area is done by using ArcGIS. Potential of hydropower sites are identified at every 2km from Chirah to Rawalpindi station of Soan River basin. Slope of river in study area is calculated by using Google Earth Pro. Discharges are interpolated at every identified point by using ArcGIS. For generation of head, a control structure (Weir) is proposed at every identified hydropower sites point. Height of control structure as well as backwater protection length is found out by using direct step or standard step method. Hydraulic turbine is selected from standard graph and chart by using head and discharge at each identified point. Theoretical hydropower potential is also evaluated either by using standard graph or by using standard formula. Figure 3.5 shows the step wise procedure for evaluation of theoretical hydropower potential of study area.

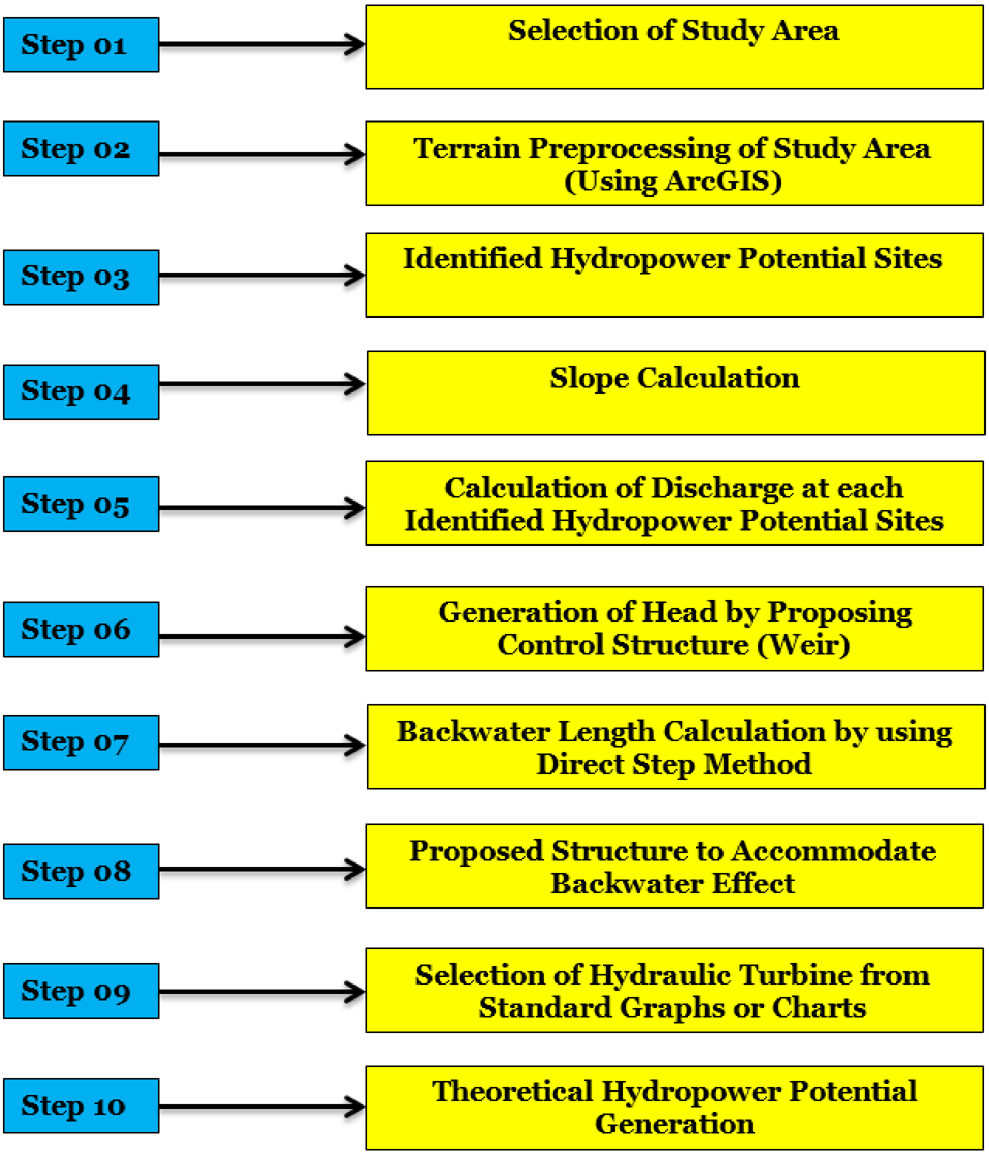

FIGURE 3.5: Step Wise Procedure for Evaluating Hydropower Potential of Study Area

3.5 Terrain Preprocessing

ArcGIS is used for terrain preprocessing of Soan River basin from flow originating point (Murree) to Rawalpindi. Digital Elevation model (DEM) obtained from Shuttle Radar Topography Mission (SRTM) 30m spatial resolution is processed further to obtain the stream network and to delineate the watershed of study area. For this purpose, ArcMap is used along with Arc Hydro tool set. The steps involved to generate the stream network and delineate the watershed for Soan River Basin (Study area) in ArcGIS are shown in figure 3.6.

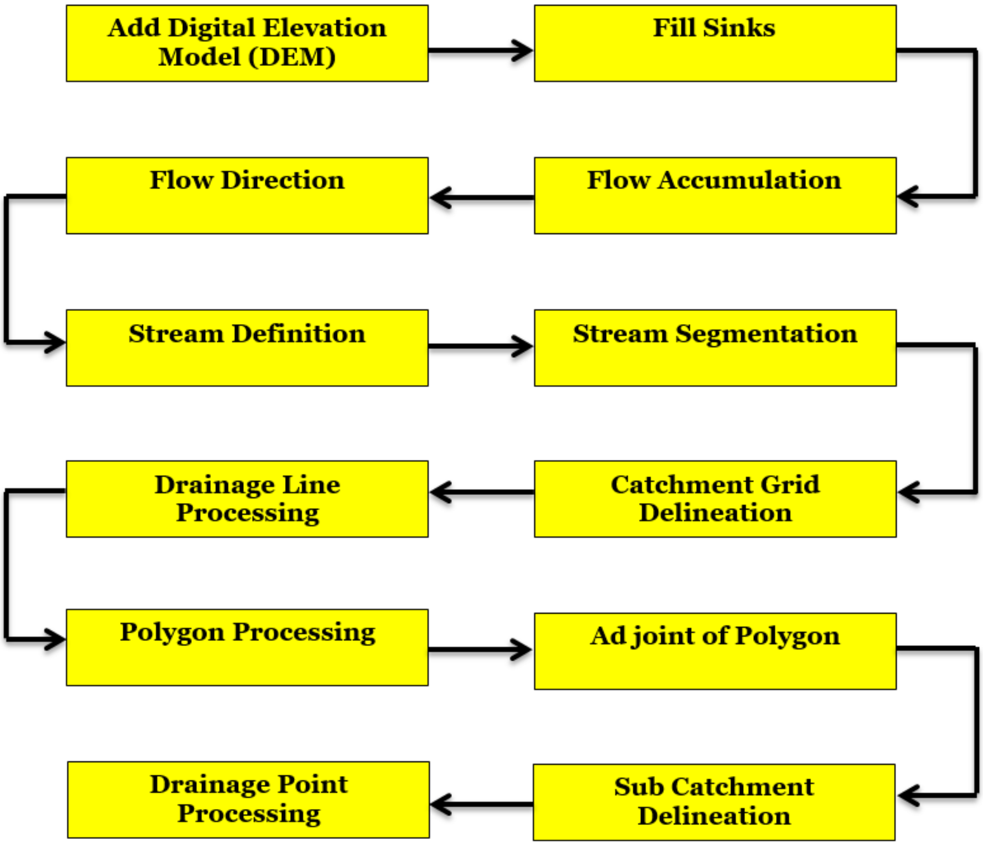

FIGURE 3.6: Step Wise Procedure for Terrain Preprocessing in ArcGIS

3.5.1 Add DEM and Clipped in Arc Map

Digital Elevation Model (DEM) in which study area lies is downloaded by selecting that grid and then selecting the file in Geo tiff format. Once the DEM tiles is downloaded, add the DEM in Arc Map 10.1 by clicking the add data tool. The DEM is then clipped to only study area. The procedure of how to clip a DEM and get a DEM of study area is already explained in section 3.2.2. Digital Elevation Model (DEM) of study area i.e. Soan River Watershed from flow originating point (Murree) to Rawalpindi station is also shown in figure 3.4.

3.5.2 Fill Sinks

Fill Sink tool is used to modify the elevation value, if cell is surrounding by a cell of higher elevation because water cannot flow and trapped in the cell surrounding by higher values. To fill the sinks, click arc hydro tool in ArcGIS and then go to terrain processing. Once terrain processing drop down window open, find fill sink function and click on it. The pictorial representation of fill sink of study area is shown in figure 3.7.

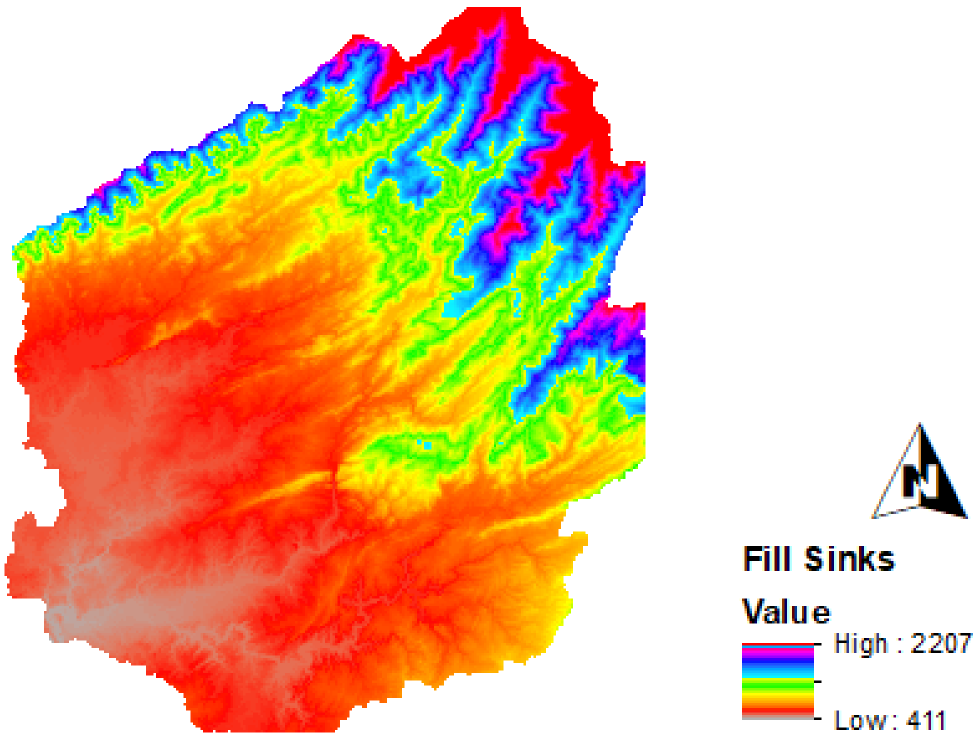

FIGURE 3.7: Fill Sinks

3.5.3 Flow Direction

Flow direction command creates a raster from each cell to develop a flow direction from its downslope. The output of the Flow Direction tool is an integer raster whose values range from 1 to 128. To generate a flow direction from DEM, click spatial analyst tool from arc tool box window, then go to hydrology and finally click flow direction Flow direction of study area is shown in figure 3.8.

3.5.4 Flow Accumulation

Flow accumulation in Arc GIS helps to find the area where the water will be collected. To generate the flow accumulation from DEM, click arc hydro tool in

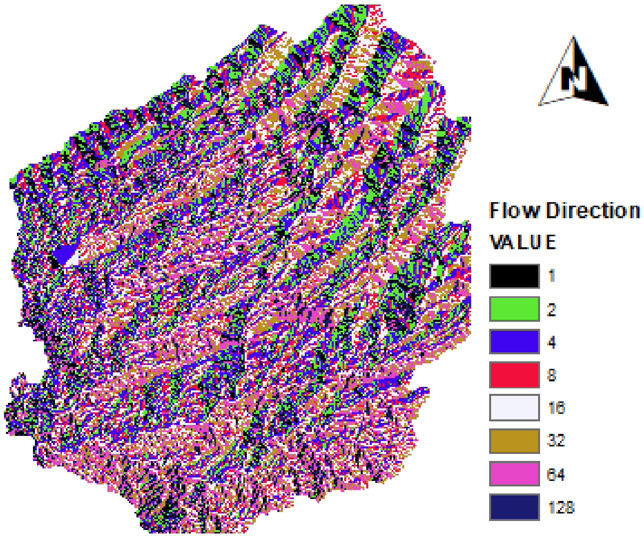

FIGURE 3.8: Flow Direction

ArcGIS and then go to terrain processing. Once terrain processing drop down window open, find flow accumulation function and click on it. Flow direction of study area is shown in figure 3.9.

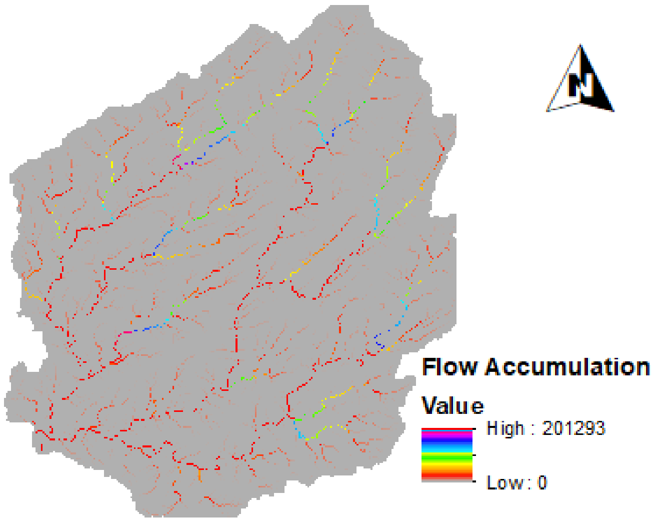

FIGURE 3.9: Flow Accumulation

3.5.5 Stream Definition

The results of flow accumulation can be used to create a stream network by applying a cluster of values to selected cells with greater values of accumulations. The stream definition of study area is shown in figure 3.10.

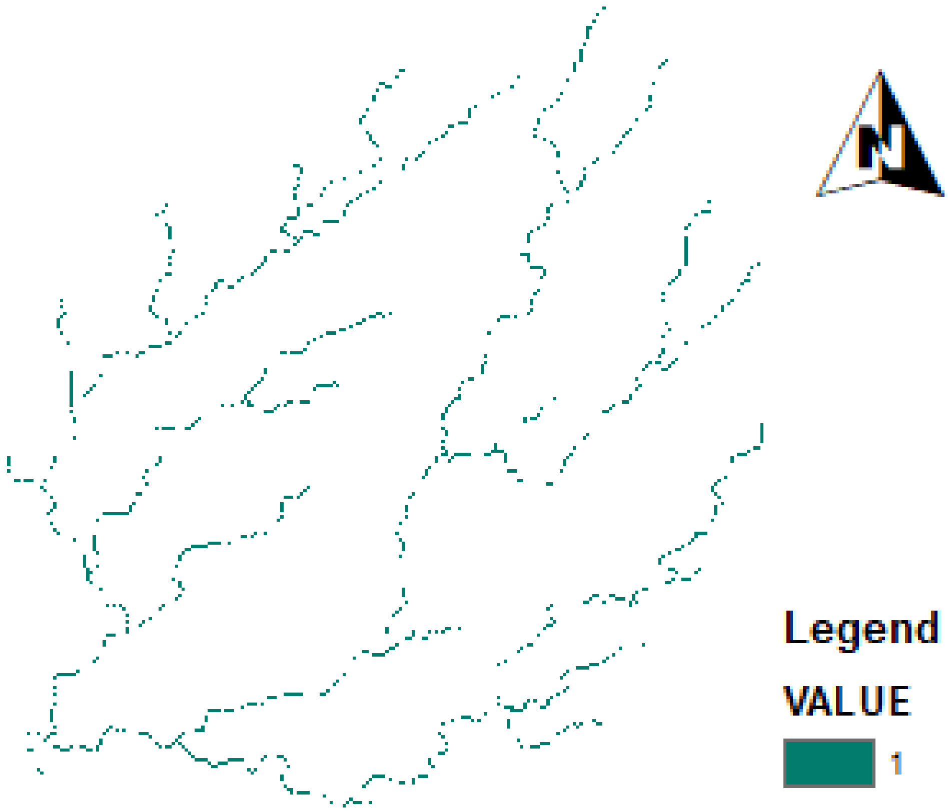

FIGURE 3.10: Stream Definition

3.5.6 Stream Segmentation

The stream segmentation function creates a grid of stream segments that have a unique identification. To use a stream segmentation function in ArcGIS, click spatial analyst tool from arc tool box window, then go to hydrology and finally click stream segmentation function. The pictorial representation of stream segmentation of study area is shown in figure 3.11.

3.5.7 Drainage Line Processing

The drainage line processing command highlights different lines over the polygons created in previous step. These lines are basically the stream line segmentations that were constructed in section 3.5.5. This command only highlights these streams over the polygons for the user ease. This command also helps in determining the

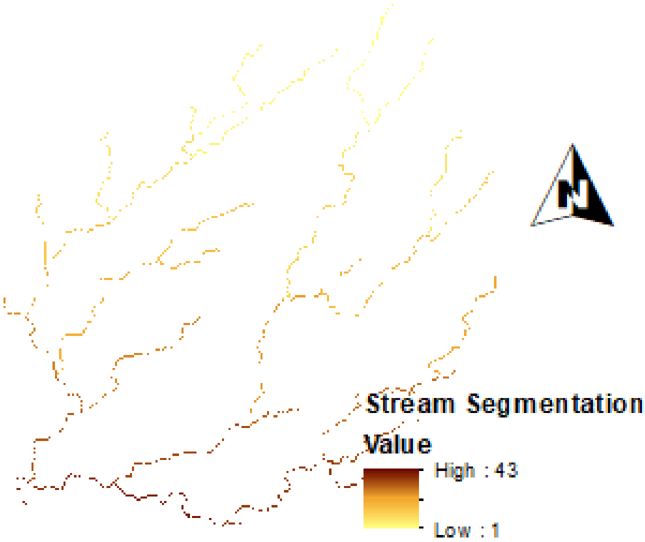

FIGURE 3.11: Stream Segmentation

drainage line of the small areas as well as main drainage lines. The highlighted drainage lines of study area are shown in Figure 3.12.

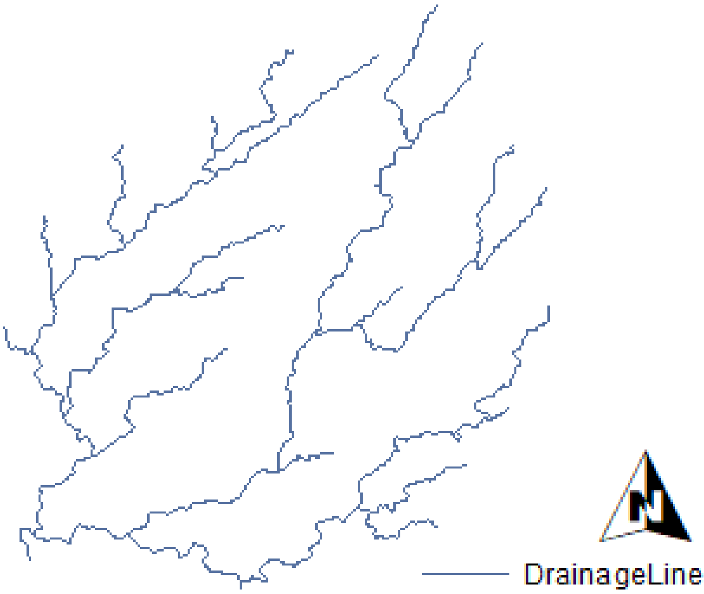

FIGURE 3.12: Drainage Line Processing

3.5.8 Catchment Grid Delineation

Catchment grid delineation used 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. The catchment grid delineation is shown in figure 3.13.

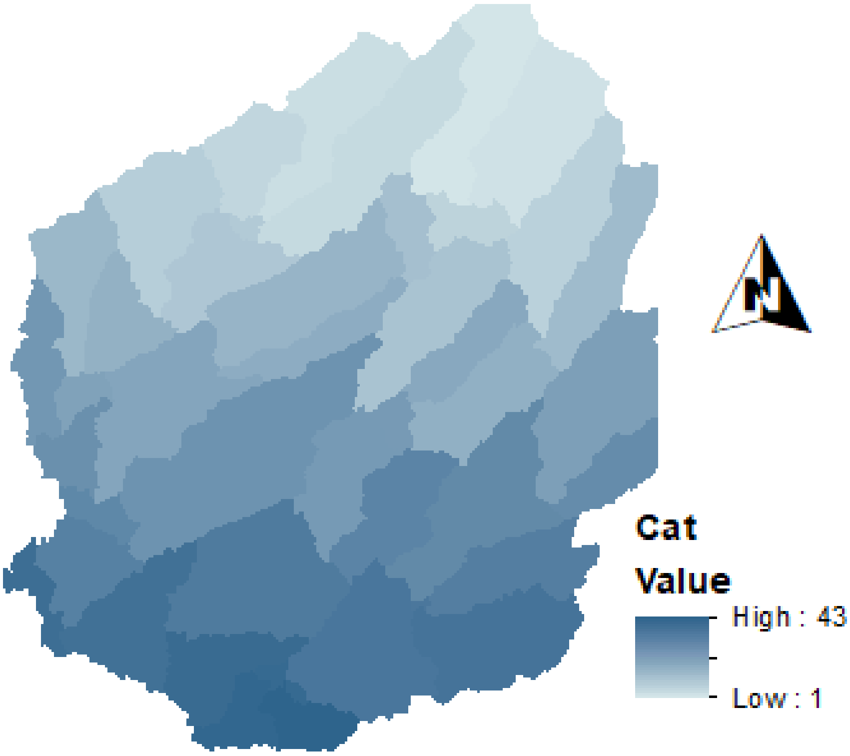

FIGURE 3.13: Catchment Grid Delineation

3.5.9 Catchment Polygon Processing

Polygon Processing command was carried out which distributes the area into different small catchments. To use Catchment polygon function in ArcGIS, click arc hydro tool in ArcGIS and then go to terrain processing. Once terrain processing drop down window open, find catchment polygon processing and click on it. The pictorial representation of catchment polygon processing of study area is shown in figure 3.14.

3.5.10 Ad joint Catchment Processing

Ad joint catchment processing functions generates the aggregated upstream catchments from the "Catchment" feature class. For each catchment that is not a head

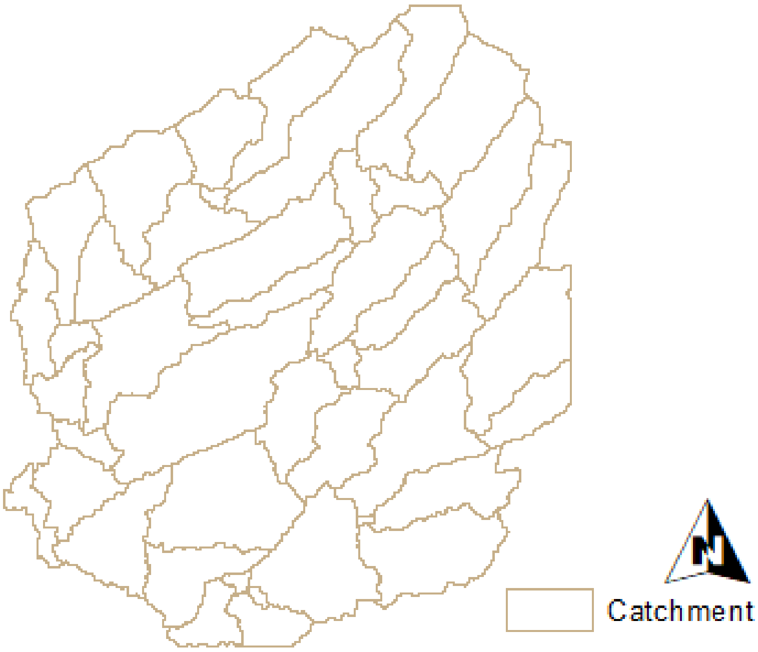

FIGURE 3.14: Catchment Polygon Processing

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. The Ad joint catchment processing is shown in figure 3.15.

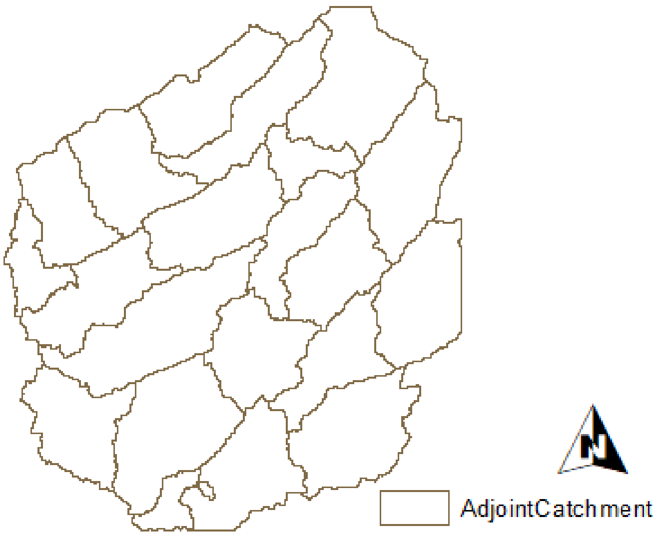

FIGURE 3.15: Ad joint Catchment Processing

3.5.11 Drainage Point Processing

Drainage point processing function is used to generate point of drain from catchment. To generate drainage point in ArcGIS, click arc hydro tool and then go to terrain processing. Once terrain processing drop down window open, find drainage point processing and click on it. The drainage point of study area is shown in figure 3.16.

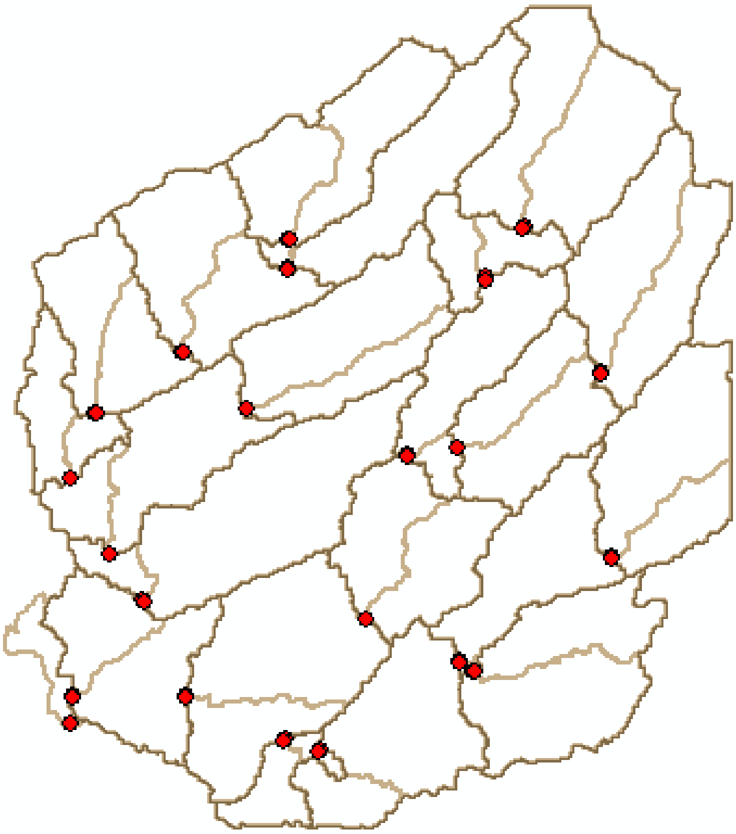

FIGURE 3.16: Drainage Point Processing

3.5.12 Batch Watershed Delineation

This function is also used to locate the outlet of the watershed. To activate "Batch Watershed Delineation", insert the Batch point by clicking the yellow button on the upper right corner from Arc hydro window. The new window will appear. Insert the detail and change Snap on from 1 to 0 and then click watershed processing batch on lower elevation point in study area. The batch watershed delineation point of study area is shown in figure 3.17.

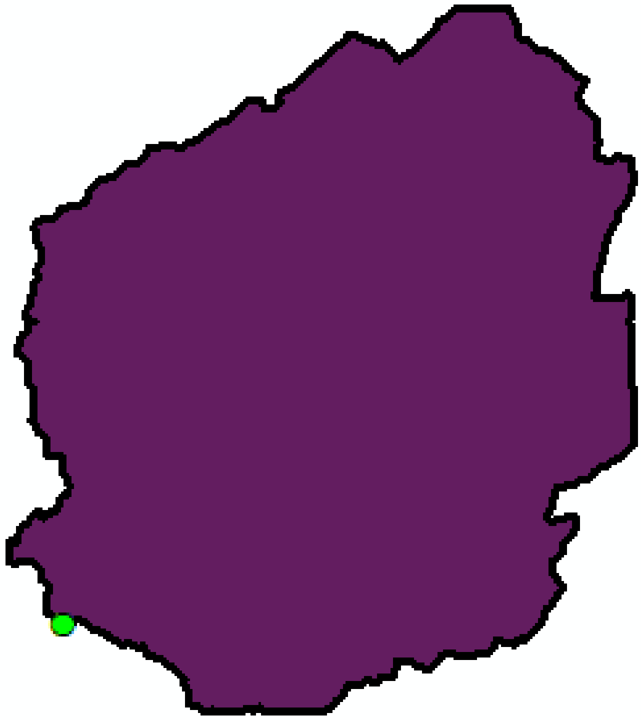

FIGURE 3.17: Batch Water shed Delineation of Study Area

3.6 Slope Calculation

The software used for slope calculation of study area is Google Earth Pro. First of all use a search tool to find the location of Chirah station and Rawalpindi station of Soan River. The coordinates of Chirah and Rawalpindi station of Soan River is already known. The next step to do is use "Add Path" tool in Google Earth Pro and draws a path along a flow of river from Chirah Station to Rawalpindi station of Soan River. After that, points are marked at every 2km interval from Chirah station to Rawalpindi Station of Soan River as shown in Figure 3.18.

Once points are marked at every 2km portion the slopes are calculated either by using generated slope profile in Google Earth pro or by noting the latitude, longitude and elevation of each point (distance between two points is already

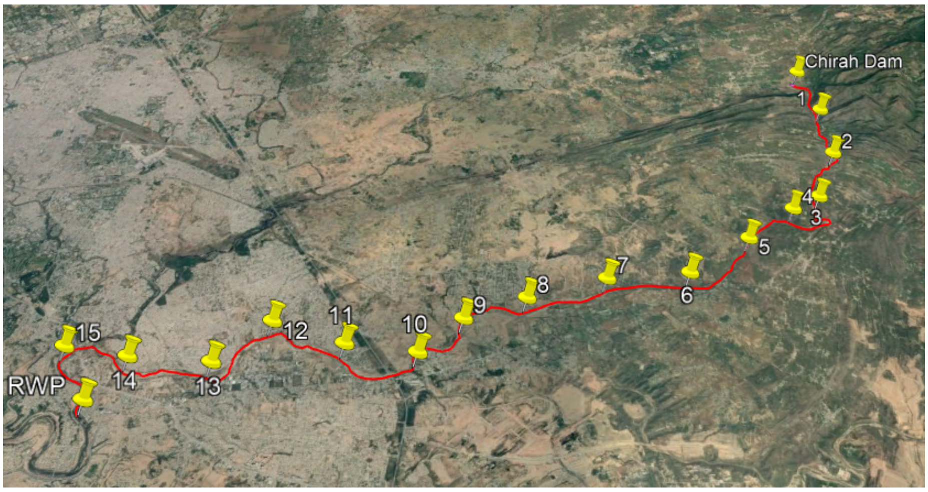

FIGURE 3.18: Marked Point (at every 2km) from Chirah to Rawalpindi station of Soan River

known i.e. 2km). The technique used here for slope calculation between Chirah station and marked point 1 in Figure 3.16 is that elevations is noted at Chirah station in and marked point 1 in Google Earth Pro software. Once the elevation is known at two points, find out the difference between the elevations. The distance between two stations is already known i.e. 2km. Slope is calculated by dividing the difference of elevation between two points and length between two points. Similarly slope is calculated at every 2km distance from Chirah to Rawalpindi station. Figure 3.19 shows the schematic diagram of measuring slope between two points.

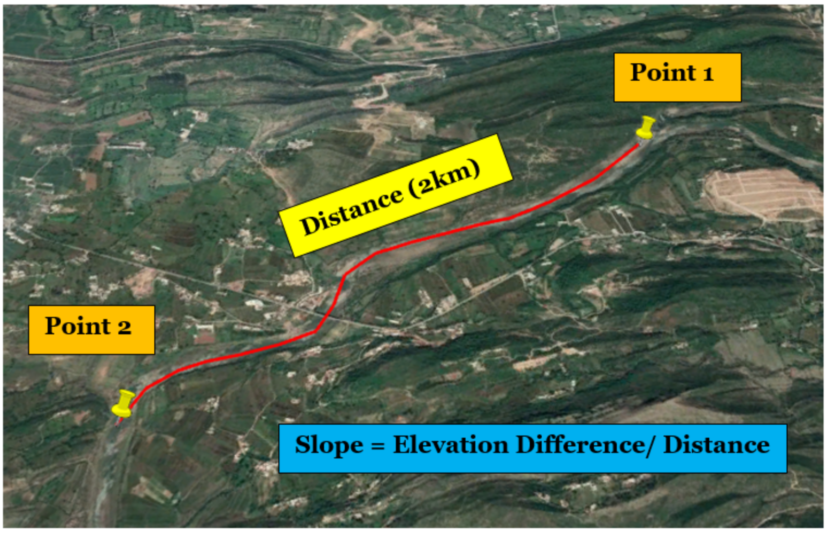

FIGURE 3.19: Schematic Diagram of Measuring Terrain Slope between Two Points

3.7 Criteria for Identification of Hydropower Sites

For assessment of hydropower potential of any river, identification of sites and determination of flows at selected sites is the main and basic requirements. The identification of sites is the first step for assessment of hydropower potential. The identification of sites for hydropower depends upon many factors for example flow, head, slope and minimum hydropower sites interval and site condition etc. The most important factors are flow, bottom slope and distance between two consecutive hydropower sites. The following four main criteria are considered for selection of sites from study area [61].

- Order of stream: To ensure sufficient amount of flow, only higher order streams are considered for selection of sites.
- Bottom slope: Selected sites should be such that average gradient along the bottom slope of the stream or river should be such that if the control structure is constructed, the backwater length doesn't exceed the one fifth of distance between consecutive hydropower sites.
- Minimum hydropower sites interval: Distance between two consecutive hydropower sites should not be less than 500m.
- In order to lower the project cost, the height of weir and length of structure required for back water protection should be justified

Initially, points are marked at every 2 Km from Chirah to Rawalpindi station of Soan River as shown in figure 3.16. The length of Soan River from Chirah to Rawalpindi station is almost 32 km. Hence, total 16 numbers of sites are marked initially from Chirah to Rawalpindi station of Soan River. These 16 selected points are assessed according to criteria listed above. The overall 13 hydropower potential sites are selected for evaluation of hydropower potential upon 16 initially marked points. The three sites out of sixteen were dropped because slope at these points were less. If a weir of 2.5m is proposed at these sites/points, the backwater length exceed too much and the selected sites/points will be uneconomical. The selected sites/points from study area for evaluation of hydropower potential are marked in Google Earth Pro and ArcGIS and shown in figure 3.20 and 3.21 respectively.

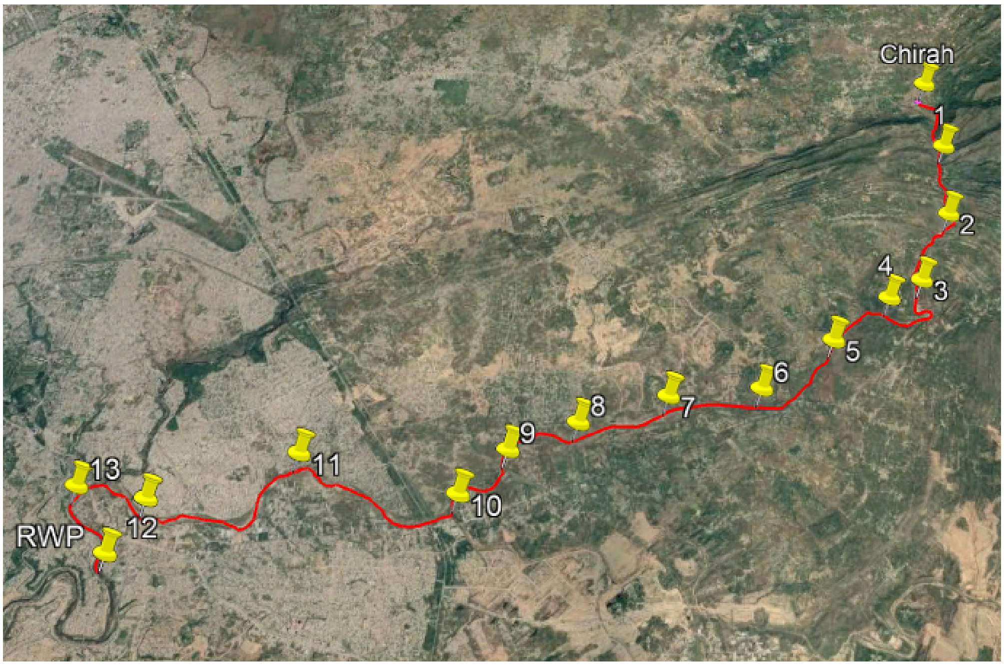

FIGURE 3.20: Selected Sites for Hydropower Potential Evaluation (marked in Google Earth Pro)

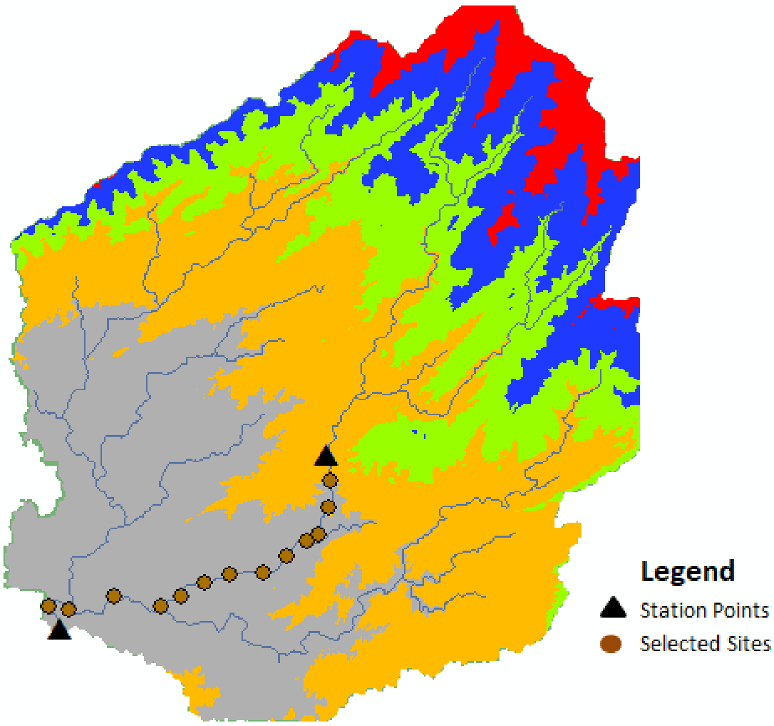

FIGURE 3.21: Selected Sites for Hydropower Potential Evaluation (marked in ArcGIS)

3.8 Calculation of Discharge at Each Identified Hydropower Potential Points of Study Area

The discharge values are required at every proposed location in a river where hydropower potential needs to be evaluated. So for this purpose, ratio proportion techniques in ArcGIS is used for calculating relative discharge at each identified hydropower potential points of study area. The discharge at ungauged points are calculated by interpolating the discharge of various gauging station points [62, 63]). The technique used for calculation of relative discharge at different unknown points between Chirah and Rawalpindi station of Soan River is as follows:

- Assume Point 1 and Point 2 is a station point of Chirah and Rawalpindi of Soan River where flow Q1 and Q2 is known.
- The respective sub drainage area of point1 and point 2 are A1 and A2 respectively.
- Let there are two more points X1 and X2. X1 is located downstream of Chirah station where as X2 is located at upstream of Rawalpindi station where flow is need to be estimated.
- The sub catchment area of X1 and X2 are AX1 and AX2 respectively.
- The flow QX1 at point X1 (ungauged point) located downstream of Chirah station of Soan river is found by using equation 3.1:

$$QX1 = (AX1/A1) \times Q1 + Q1 \tag{3.1}$$

- The flow QX2 at point X2 (ungauged point) located upstream of Rawalpindi station of Soan river is found by using equation 3.2:

$$QX2 = (AX2/A2) \times Q2 – Q2 \tag{3.2}$$

Note: In equation 3.1 Q1 is added for calculating cumulative this is because point X1 is located downstream of point1 whereas in equation 3.2 Q2 is subtracting for calculating cumulative discharge this is because point X2 is located upstream of point 2. Sub catchment area (A1, A2, AX1 and AX2) is calculated by using ArcGIS.

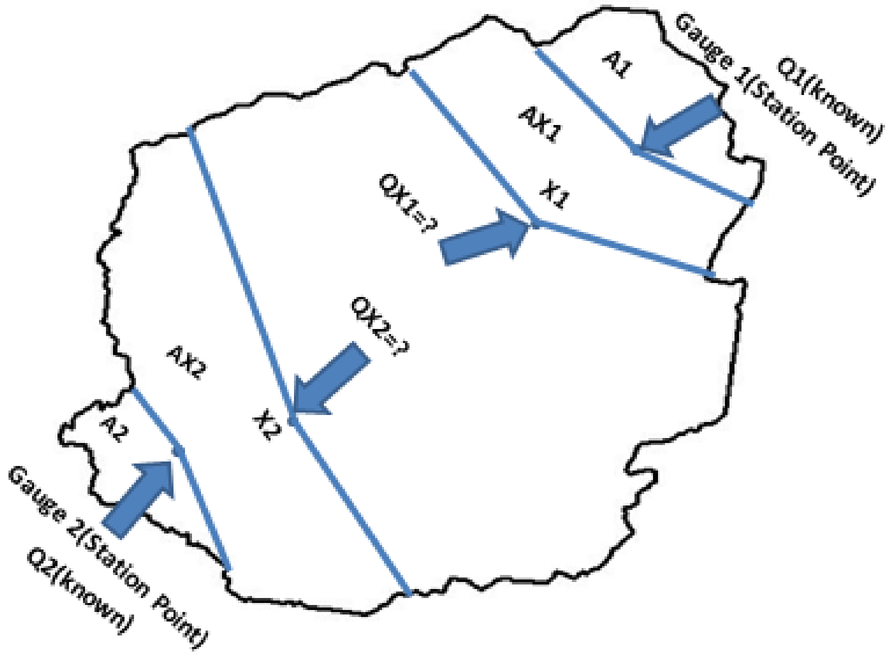

Figure 3.22: Approach used for Calculation of Discharge at unknown points

3.9 Head Generation and Backwater Length Calculations

Head can be calculated by subtracting the elevation of the upstream point from the downstream elevation. For generation of head, a control structure (weir) is proposed at every hydro potential evaluated point. The height of control structure (weir) depends upon slope, velocity of flow, width of river and power generated etc. Head generation at each point is almost equal to height of weir. The optimal height of water and backwater protection length is found out by using Direct Step Method. The effect of backwater is negligible when flow depth is within five percent of normal depth The most critical factors related to hydraulic conditions are slope, head, discharge and cross-sectional shape of river. The hydraulic parameter of rivers for example flow depth, cross sectional area, hydraulic radius, slope and manning constant and height of control structure are required for back water length calculation. The procedural step to find out hydraulic parameters and backwater length by using direct step method is shown below:

3.9.1 Flow Depth (y), Area (A) and Hydraulic Radius (R)

Field study is carried out at different point in a river to find out the cross-sectional shape of Soan River from Chirah to Rawalpindi station. The study is conducted near Chirah, Chakian Bridge, Kaak Bridge and Soan Bridge to find out the cross-sectional shape of Soan River. The cross-sectional shape of Soan river is irregular in nature. While proposing weir at each of 13 selected points and providing guide banks, river cross-section will also need modification and this is proposed to be done through a trapezoidal cross-section. The flow depth at different points in a river where hydropower potential is evaluated is found by using Trial and Error procedure. The trial and error procedure to find out the flow depth of trapezoidal section is shown below:

- First of all $AR_{2/3}$ factor is computed by using equation 3.3:

$$AR_{2/3} = n \times Q/S^{0.5} \tag{3.3}$$

  In equation 3.3 above, n is taken from literature review, Q and S_0 is already found in section 3.7 and 3.6 respectively.

- The cross sectional Area (A) of trapezoidal section is calculated by using equation 3.4:

$$A = (B_o + s \times y) \times y \tag{3.4}$$

  Here Bo is bottom width of river and s is the side slope of river which is 0.5

- The top of width (Tw) is found out at each point by using Google Earth Pro. So the bottom width (B_0) in trapezoidal section is calculated by using equation 3.5:

$$B_o = (A/y) - s \times y \tag{3.5}$$

- Putting the value of Bo in cross-sectional area equation and Simplify, we get the cross-sectional area of trapezoidal section (A) as given in equation 3.6:

$$A = T_w \times y – s \times y^2 \tag{3.6}$$

- The perimeter (P) of trapezoidal section is calculated by using equation 3.7:

$$P = B_o + 2y\sqrt{(1 + s^2)} \tag{3.7}$$

- Put the value of $B_o = T_W - 2sy$ and $s = 0.5$ in perimeter equation and simplify, we get perimeter of trapezoidal (P) as shown in equation 3.8:

$$P = T_w + 1.24y \tag{3.8}$$

- As, we know that hydraulic radius R = A/P. Put the value of A and P computed in equation 3.6 and 3.7. We get the equation 3.9:

$$AR^{2/3} = \frac{(T_w \times y – 0.5 \times y^2) \times (T_w \times y – 0.5 \times y^2)^{2/3}}{(T_w + 1.24y)^{2/3}} \tag{3.9}$$

  Note: In equation 3.9, only Flow depth (y) is unknown.

- The Value of AR2/3 is also computed by using equation 3.3.
- Compare the equation 3.3 and 3.9 equations and find the value of flow depth (y) as shown in equation 3.10:

$$\frac{(T_w \times y – 0.5 \times y^2) \times (T_w \times y – 0.5 \times y^2)^{2/3}}{(T_w + 1.24y)^{2/3}} = \frac{n \times Q}{S^{00.5}} \tag{3.10}$$

- Once value of flow depth (y) is known, the bottom width can be find by using equation 3.11:

$$Bo = Tw – 2sy \tag{3.11}$$

3.9.2 Flow Velocity (V) and Friction Slope (S f)

The flow velocity at identified hydropower potential points from study area is computed by dividing the specified rate of discharge (Q) by the flow area (A). The rate of discharge (Q) at each identified hydropower potential point is calculated in section 3.7. The cross-sectional area (A) is calculated at each identified hydropower potential point by using equation 3.2. The friction slope (S f) at each identified hydropower potential point is computed by using equation 3.12.

$$Sf = n^2 \times V^2/R^{1.33} \tag{3.12}$$

Manning constant (n) is calculated by comparing the photographs of natural stream of study area with photographs published by United States Geological Survey [65] and the Department of Agriculture [64, 66]. The comparison of study area imaginary with different natural stream for extraction of manning constant (n) are shown in Annexure A. Hydraulic Radius (R) at each identified hydropower potential point is calculated by dividing the cross-sectional area at that point with wetted perimeter of river. The formula for calculation of wetted perimeter is shown in equation 3.7 above.

3.9.3 Average Friction Slope (Avg. S_f) and Bottom Slope (So)

Average friction slope is the average of fraction slope (S_f) for the current depth and for the previous depth. The average of friction slope can be calculated by using three methods.

$$Average\ Friction\ Slope = (Avg.S_f) = (\frac{1}{2}) \times (S_f1 + S_f2) \quad (3.13)$$

$$Geometric\ Mean\ Friction\ Slope = (Avg.S_f) = \sqrt{(S_f1 + S_f2)} \quad (3.14)$$

$$Harmonic\ Mean\ Friction\ Slope = (Avg.S_f) = \frac{2S_f1Sf2}{(S_f1 + S_f2)} \quad (3.15)$$

The average friction slope is calculated using equation 3.13 for calculation of backwater length. The bottom slope at each identified hydropower potential is calculated in section 3.6 by using Google Earth Pro. The difference of bottom slope and average friction slope is also calculated and shown in separate column.

3.9.4 Specific Energy (E) and Difference of Energy (ΔE)

Specific Energy (E) is the energy length, or head, relative to channel bottom. It is expressed in terms of kinetic energy (K.E), potential energy (P.E) and internal energy (E). In open channel flow, the water surface is open to atmosphere; the pressure between two points has the same value and therefore is ignored. Hence, if the specific energy (E) and the velocity of flow (V) of channel are known, the depth of flow (y) can be determined. The specific energy (E) is computed by using equation 3.16.

$$E = \frac{y + \alpha V^2}{(2g)} \quad (3.16)$$

This relationship is used to calculate changes in depth upstream or downstream of changes in the channel such as steps, constrictions or control structures. The relationship E = y + α V^2 / (2g) is used in direct step method to calculate how depth of flow changes over a reach from the energy gained or lost due to slope of channel. The difference of specific energy (ΔE) is obtained by subtracting specific energy (E) for the current depth from specific energy (E) for the previous depth.

3.9.5 Distance Increment (Δx) and Backwater Length (x2)

The distance increment (Δx) is computed by using equation 3.17 [64]:

$$Distance\ increment\ (\Delta x) = \frac{(E2 - E1)}{(So - Avg.S_f)} \tag{3.17}$$

In this relation E2 – E1 is a difference of specific energy. S_0 is a bottom slope of channel and Avg. S_f is the average fraction slope. The method of average friction slope calculation is shown in section 3.9.3. The length (x2) is the distance where effect of backwater is almost negligible, if control structure is constructed in the way of flow in a river or stream. It is obtained by adding distance increment Δx to the backwater length (x2) value for the previous depth. The definition sketch of backwater curve is shown in figure 3.23.

Note: The detailed backwater calculation at each identified hydropower potential point is shown in Annexure D.

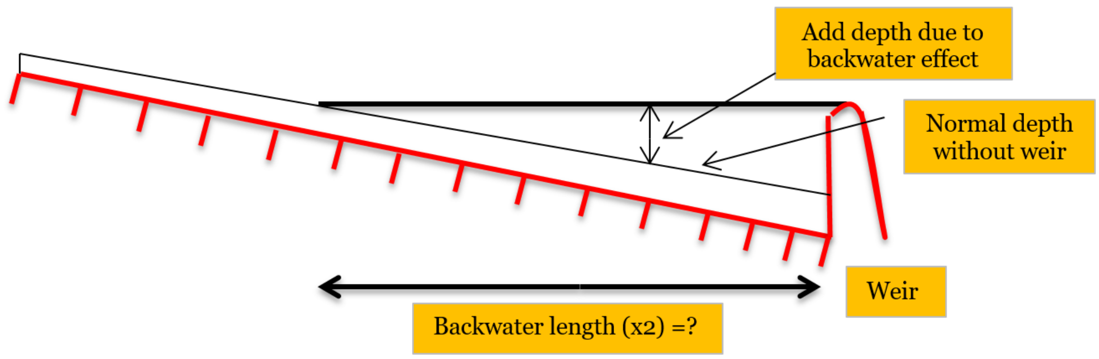

FIGURE 3.23: Definition Sketch of Back Water Curve

3.10 Selection of Hydraulic Turbine

Hydraulic turbine can be selected at each identified hydropower potential sites by calculating head (h) and discharge (Q). The head is calculated by using the methodology explained in section 3.8 and discharge is calculated by using the methodology explained in section 3.9. Once head and discharge is calculated at each identified hydropower potential point, a hydraulic turbine is selected from standard graph or chart as shown in figure 2.7.

3.11 Evaluation of Hydropower Potential

For evaluation of hydropower potential, initially points are marked at every 2km interval from Chirah to Rawalpindi station of Soan River. Once points are marked, slope is calculated at each point by using Google Earth Pro. Discharge is calculated at each marked point by using ratio proportion technique in ArcGIS. Head is generated by proposing weir at each marked point by using direct step method. Head at each point is calculated by subtracting the elevation of water above the crest of weir from downstream sides of weir water elevation. The theoretical hydropower is either calculated directly by using standard graph or chart as shown in Figure 2.7 above or by using the equation 3.18: The distance increment (Δx) is computed by using equation 3.17:

$$Pt = \rho \times Q \times g \times H \tag{3.18}$$

Where Pt = power output in watt ρ = density of water = 1000kg/m^3. H = head, (y) Q = water flow rate in m^3/s, g = acceleration due to gravity = 9.81 m^3/s.

In above equation, the density of water and acceleration due to gravity is constant. The density of water is 1000kg/m^3. The value of acceleration due to gravity or gravitational constant is 9.81m^3/sec. The efficiency of different hydraulic turbines ranges 0.80 to 0.90. The only variable in equation is Head (H) and Discharge (Q). The head (H) and discharge (Q) is varying along the length of river. The head generated depend upon height of weir and calculated in section 3.8. The discharge (Q) is also calculated already in section 3.7 by using ratio proportion techniques in ArcGIS. So the power output (Pt) can be easily evaluated. The diagrammatic approach used for evaluating hydropower potential is shown in figure 3.24.

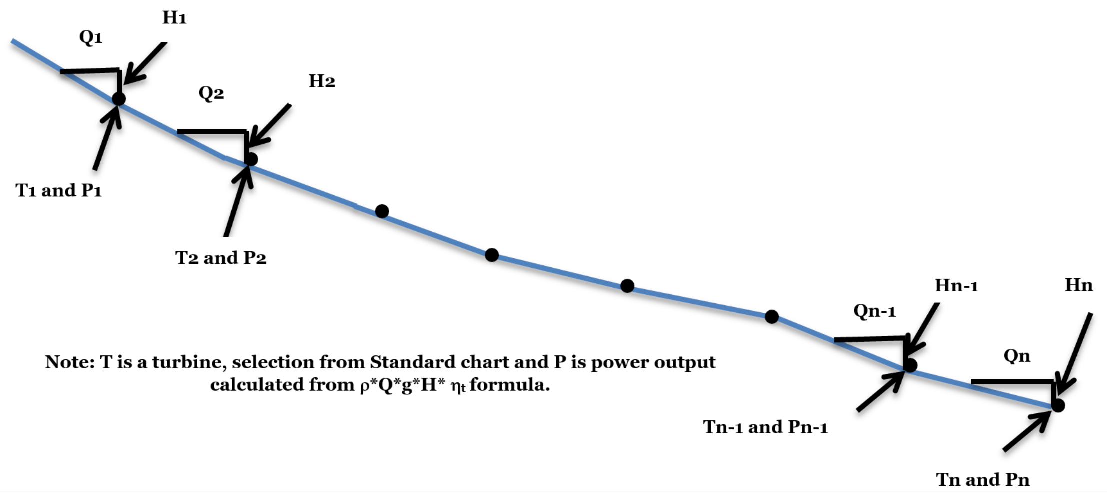

Figure 3.24: Diagrammatic Approach used for Evaluating Hydropower Potential

3.12 Summary

The methodology adapted for research is summarized as first of all terrain preprocessing of study area is done in ArcGIS by downloading digital elevation model (DEM). After that, points are marked at every 2km from Chirah to Rawalpindi station of Soan River. Once points are marked, slope is calculated at every marked point using Google Earth Pro. Discharge at each marked point is calculated by using ratio proportion technique in ArcGIS. Head is generated by proposing weir with the help of detail analysis using direct step method. Once weir is proposed, Back water effect length is calculated at each marked point using direct step method. For evaluation of hydropower potential, two main factors discharge (Q) and head (h) is required. Once discharge (Q) and head (H) is find out, hydraulic turbine is easily selected from standard graph and hydropower potential is also evaluated from either by using standard graph or by using equation explained in section 3.10.

Chapter 4

Result and Analysis

4.1 Background

The study area selected for research and methodology used to accomplish the research objectives is discussed in previous chapter. This chapter explains the result of calculated slope at selected hydropower potential sites/points by using the methodology adopted in previous chapter. The result of calculated discharge at un-gauged point i.e. selected hydropower potential points is also shown in this chapter. The height of weir (head) required or proposed at each point is also shown in this chapter. This chapter also explains that how much length of backwater protection is required at each point. Furthermore, in this chapter overall hydropower obtained and hydropower obtained at each selected hydropower sites/points from study area by selecting hydraulic turbines are shown separately.

4.2 River Gradient

The river gradient is a grade measured in by the ratio of drop of elevation in stream per unit of horizontal distance (steepness of river). The river gradient of study area is calculated by using Google Earth Pro software. The longitudinal profile of Soan River from Chirah station to Rawalpindi station and calculated slope are shown in figures 4.1 and 4.2 respectively. This longitudinal profile (figure 4.1) shows that how gradient of Soan River is changed as water is flowing from upstream to downstream i.e. from Chirah station to Rawalpindi station.

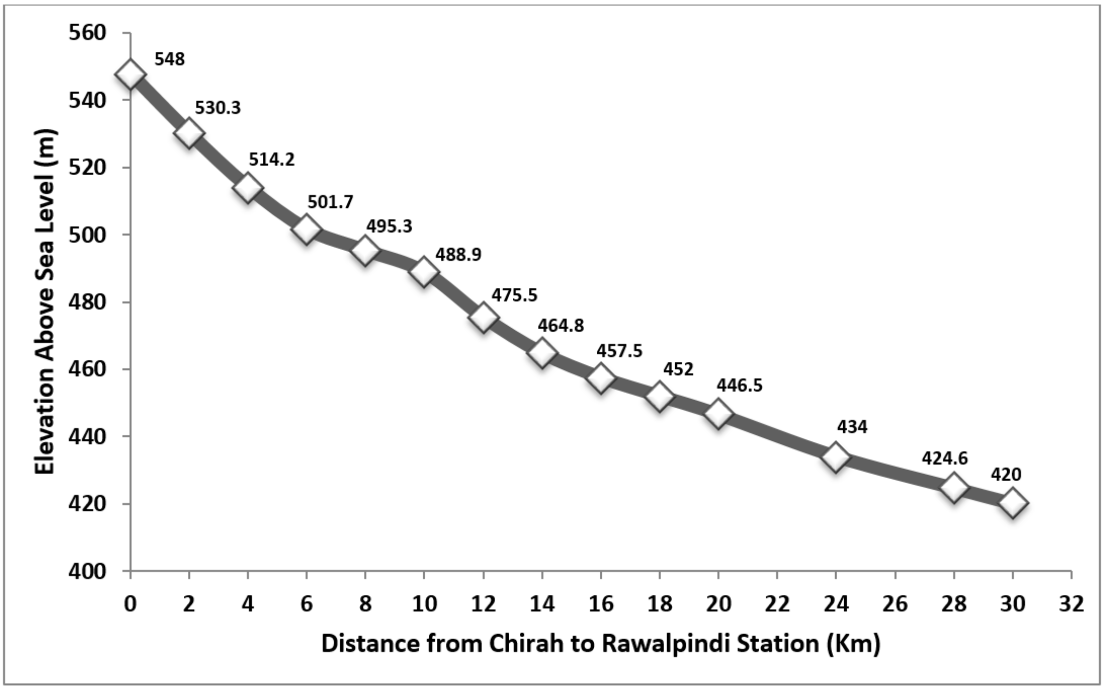

FIGURE 4.1: Longitudinal Profile of Soan River from Chirah to Rawalpindi Station

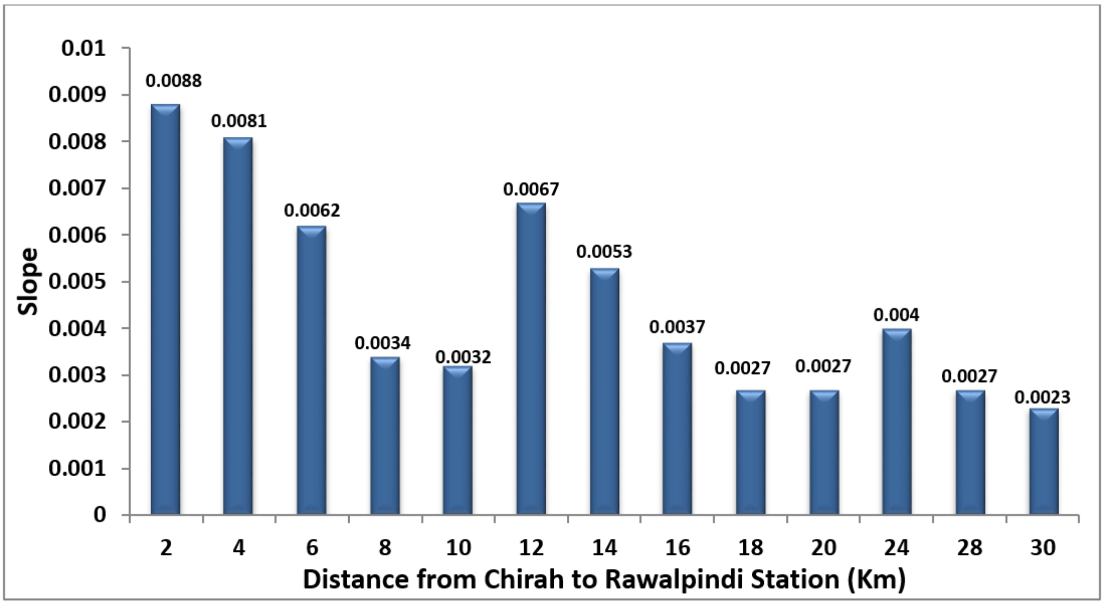

FIGURE 4.2: Calculated Slope of Soan River from Chirah to Rawalpindi Station

The discharge value is required at each location in a river where hydropower potential needs to be evaluated. To calculate a discharge at un-gauged point, discharge are interpolated between two gauging station i.e. Chirah station and Rawalpindi station. The discharge is calculated at each identified hydropower potential sites/-points by using ratio proportion techniques in ArcGIS. The detail procedure of calculation of discharge at un-gauged point is explained in section 3.8. The calculated discharge value between Chirah and Rawalpindi station of Soan River in ArcGIS is shown in Figure 4.3.

The verification of calculated flow data is done at Rawalpindi station. To verify a flow, the data from Chirah station and all tributaries flow added between Chirah and Rawalpindi station must be equal to data available at Rawalpindi station. The calculation of verification of flow data is shown in Annexure F. The value of average annual discharge at Chirah station and Rawalpindi station of Soan River is 6.45 cumecs and 19.40 cumecs respectively.

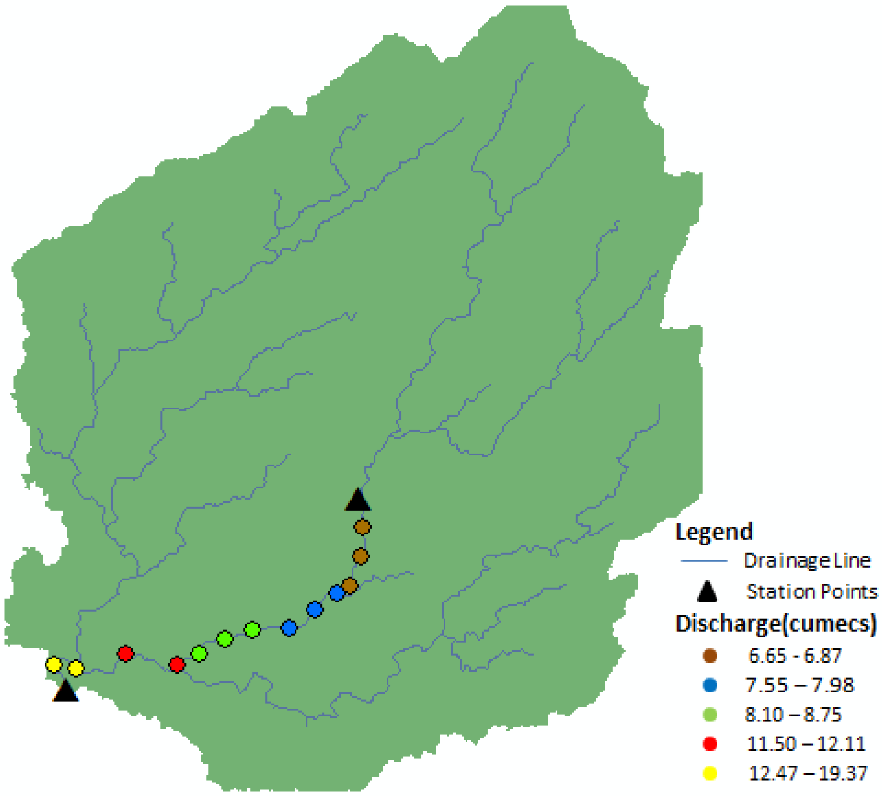

FIGURE 4.3: Discharge Interpolated at each Identified Hydropower Potential Point

The two major increments occur in discharge values. The major increment in discharge value occurs just before the Rawalpindi station (at Soan Bridge) in which korang stream joins the river. The second major increment in discharge value occurs just before the Kaak Bridge in which ling stream join the Soan River. The discharge calculated at each identified hydropower potential point and the major increment occur because of ling stream and korang stream are shown in figure 4.4.

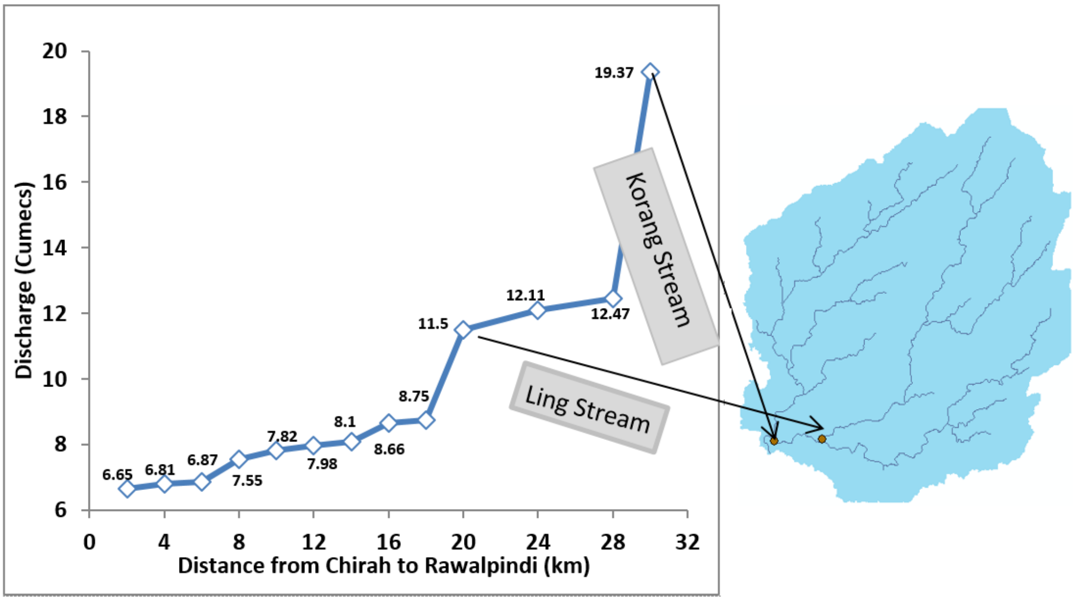

FIGURE 4.4: Discharge at each Identified Hydropower Point (Steps represent increase in discharge and arrows highlight the correspondence between the steps and the location in the map

4.3 Head Generated at each Selected Hydropower Sites/Points

The detail analysis step for proposed height of weir at each identified hydropower points is shown in Annexure D. The detail procedure for head generation and selection of height of control structure (weir) is explained in section 3.9. The graphical representation of head value at each selected hydropower potential sites/points is shown in figure 4.5. The selected height of weir (head generated) and calculated discharge and slope at each identified hydropower potential point are shown in table 4.1.

Table 4.1: Values of Slope, Discharge and Head at Selected Sites from Chirah to Rawalpindi Station of Soan River

Point No	Distance from source i.e. from Chirah station (Km)	Slope	Discharge (Q)(cumecs)	Head (m)
01	02	0.0088	6.65	2.50
02	04	0.0081	6.81	2.50
03	06	0.0062	6.87	2.00
04	08	0.0034	7.55	1.25
05	10	0.0032	7.82	1.00
06	12	0.0067	7.98	2.00
07	14	0.0053	8.10	1.75
08	16	0.0037	8.66	1.25
09	18	0.0027	8.75	1.00
10	20	0.0027	11.50	1.00
11	24	0.0040	12.11	1.25
12	28	0.0027	12.47	1.00
13	30	0.0023	19.37	1.00

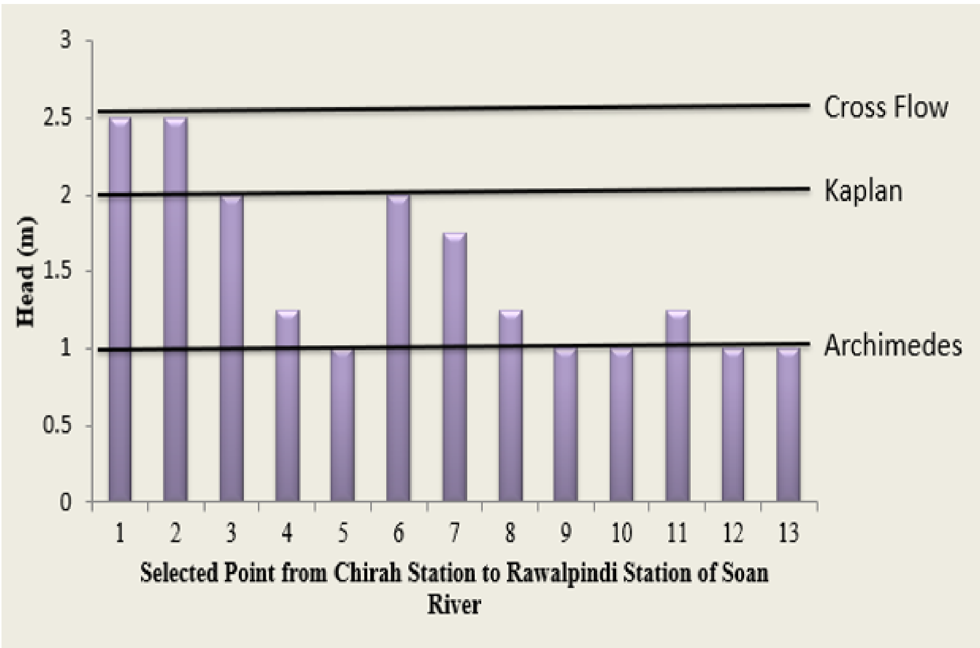

Figure 4.5: Head at each Selected Hydropower Sites/Points

4.4 Hydraulic Parameter and Backwater Length

The length at which water level disturb at upstream because of hydraulic structure (weir) construction is called backwater length. The sides of river or channel can be protected by providing marginal bunds on both sides of river. The calculation of hydraulic parameters and backwater length at each selected hydropower sites/-points from Chirah to Rawalpindi station of Soan River is shown in Annexure D. The backwater length is calculated by proposing a weir of height 1 to 3m ranges. The backwater length is such selected that height of weir and length of structure required for backwater protection is justified (i.e. neither too much height of weir not too much backwater length). The backwater length is fixed 300m because there is no significant impact on power generation if backwater length goes beyond 300m.

Table 4.2: Values of Hydraulic Parameters and Backwater length at Selected Sites from Chirah to Rawalpindi Station of Soan River

Point No	Flow Depth (y)M	Width (b)(m)	Area (A)m^2	Velocity (v) m/s	Slope (s) m/m	Head (H) m	Backwater Length (x)m
01	0.35	13.65	4.85	0.18	0.0088	2.50	258.3
02	0.37	13.43	5.02	0.19	0.0081	2.50	280.6
03	0.36	16.44	5.90	0.20	0.0062	2.00	295.3
04	0.48	14.72	7.21	0.39	0.0034	1.25	289.7
05	0.41	20.19	8.42	0.38	0.0032	1.00	253.7
06	0.34	19.26	6.57	0.20	0.0067	2.00	269.6
07	0.39	17.61	6.89	0.25	0.0053	2.00	298.6
08	0.49	15.11	7.59	0.44	0.0037	1.25	262.7
09	0.37	21.43	8.00	0.40	0.0027	1.00	288.2
10	0.40	24.8	9.97	0.45	0.0027	1.00	280.5
11	0.34	28.16	9.60	0.34	0.0040	1.25	251.5
12	0.45	24.75	11.26	0.49	0.0027	1.00	282.2
13	0.57	33.23	19.14	0.57	0.0023	1.00	298.8

Hydraulic parameters and backwater length at each hydropower sites is shown in table 4.2.

4.5 Hydraulic Turbines Selection

Hydraulic turbine is selected at each identified hydropower potential sites by noting head (h) and discharge (Q). Once head and discharge is calculated at each identified hydropower potential point, a hydraulic turbine is selected from standard graph (Figure 2.7). The speed of turbine is calculated by using Eq 4.1:

$$Ns = \frac{n\sqrt{P}}{(H)^{5/4}} \tag{4.1}$$

The methodology or procedure for selection of hydraulic turbines at each selected hydropower sites/points are discussed in section 3.10.

TABLE 4.3: Hydraulic Turbine Selection based on Discharge (Q) and Head (H)

Point No	**Discharge Q (m3/sec)**	**Head H (m)**	**Specific Speed ns (m/sec)**	**Hydraulic Turbine (Selected type)**
01	6.65	2.50	406.1	Cross flow
02	6.81	2.50	411.1	Cross flow
03	6.87	2.00	488.2	Kaplan
04	7.55	1.25	728.1	Archimedes
05	7.82	1.00	864.3	Archimedes
06	7.98	2.00	526.1	Cross flow
07	8.10	2.00	585.9	Kaplan
08	8.66	1.25	779.7	Archimedes
09	8.75	1.00	926.5	Archimedes
10	11.50	1.00	1062.1	Archimedes
11	12.11	1.25	922	Kaplan
12	12.47	1.00	1105.9	Archimedes
13	19.37	1.00	1378.4	Archimedes

4.6 Hydropower Potential from Chirah to Rawalpindi Station of Soan River

The total potential for hydropower generation from Chirah to Rawalpindi station of Soan River is 1913.24KW with 13 points of interest. The total 16 sites are evaluated out of which 13 sites is selected. The three sites out of sixteen were dropped because slope at these points were less. If a weir of 2.5m is proposed at these sites, the backwater length exceed too much and the selected sites will be uneconomical. The backwater length is calculating by proposing a weir of 1 to 3m.

The backwater length is fixed 300m because there is no significant impact on power generation if backwater length goes beyond 300m The maximum and minimum hydropower potential is 190.01KW and 74.70KW respectively with an average hydropower potential of 130.27KW at each point of interest. The detail result for hydropower potential of Soan river basin from Chirah to Rawalpindi station is shown in table 4.4.

The green highlighted points are representing the sites/points that have hydropower potential less than 100KW. The potential for hydropower generation from Chirah to Rawalpindi station of Soan River at each selected point in ArcGIS is shown in figure 4.6. The brown point shows the site of hydropower potential range from 70 to 100KW.

The yellow points represent the hydropower potential of ranges in between 101KW to 130KW. The red point shows the hydropower potential of ranges in between 131KW to 160KW and the green points shows the sites of hydropower potential ranges in between 161KW to 190KW.

The maximum and minimum hydropower potential is 190.01KW and 74.70KW respectively with an average hydropower potential of 130.27KW at each point of interest. Archimedes, Kaplan and Cross flow hydraulic turbine is selected based on head and discharge for hydropower potential sites.

TABLE 4.4: Evaluation of Hydropower Potential by Selecting Hydraulic Turbines from Chirah to Rawalpindi Station of Soan River

Sr. No	**Longitude (Decimal)**	**Latitude (Decimal)**	**Elevation Above Mean Sea Level (m)**	**Slope (s)**	**Discharge (Q) (m^3/sec)**	**Head (H) (m)**	**Backwater Length (x)(m)**	**Hydraulic Turbine**	**Hydropower Potential (KW)**
01	73.299E	33.622N	530.3	0.0088	6.65	2.50	258.3	Cross flow	163.0
02	73.298E	33.606N	514.2	0.0081	6.81	2.50	280.6	Cross flow	167.0
03	73.290E	33.590N	501.7	0.0062	6.87	2.00	295.3	Kaplan	134.80
04	73.282E	33.587N	495.3	0.0034	7.55	1.25	289.7	Archimedes	92.60
05	73.268E	33.578N	488.9	0.0032	7.82	1.00	253.7	Archimedes	74.70
06	73.251E	33.568N	475.5	0.0067	7.98	2.00	269.6	Cross flow	156.60
07	73.228E	33.567N	464.8	0.0053	8.10	2.00	296.8	Kaplan	158.9
08	73.210E	33.562N	457.5	0.0037	8.66	1.25	262.7	Kaplan	106.2
09	73.193E	33.554N	452	0.0027	8.75	1.00	288.2	Archimedes	85.84
10	73.179E	33.548N	446.5	0.0027	11.50	1.00	280.5	Archimedes	112.80
11	73.145E	33.554N	434	0.0040	12.11	1.25	251.5	Kaplan	148.50
12	73.113E	33.546N	424.6	0.0027	12.47	1.00	282.2	Archimedes	122.33
13	73.100E	33.548N	420	0.0023	19.37	1.00	298.8	Archimedes	190.00
								Total	1713.24

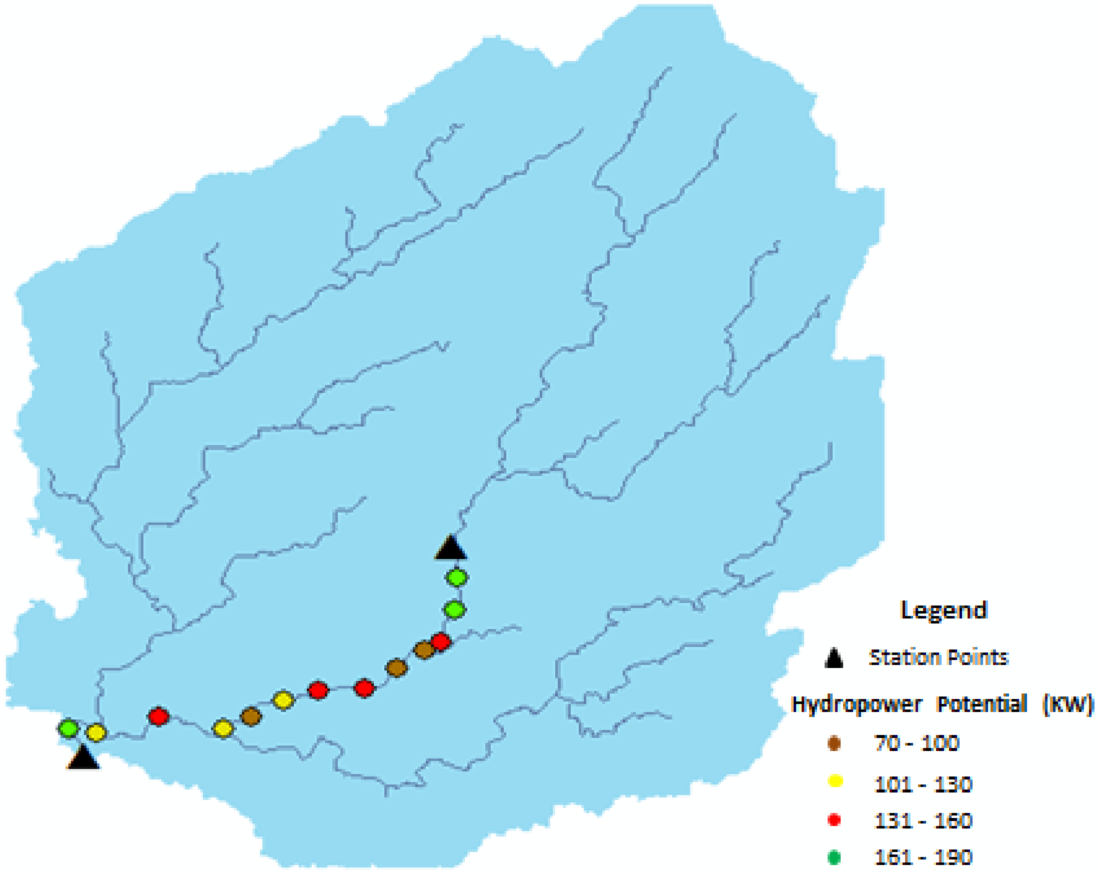

FIGURE 4.6: ArcGIS Evaluated Sites/Points for the Generation of Hydropower from Chirah to Rawalpindi station of Soan River.

4.7 Overall Analysis of Results

The first site (site 1) selected for hydropower generation is located at 2km downstream from Chirah station. The first selected site (site 1) has coordinates of longitude 73.299E and latitude 33.622N. The average annual discharge at site 1 is 6.65m3/sec. The slope at selected site 1 is 0.0088. The weir of height 2.5m (8.2ft) is proposed at selected site 1 that will have 258.3m backwater curve i.e. 258.3m (847.5ft) protection of side bunds are required. The potential for hydropower generation at site 1 is found to be 163KW by selecting cross flow hydraulic turbine. The average power requirement of average house is almost 5KW (Official of WAPDA). So, with an average power requirement of 5Kw per house, site 1 will serve almost 32 houses. The second site (site 2) selected for hydropower generation is located at almost 4km downstream from Chirah station. The second selected site (site 2) has coordinates of longitude 73.298E and latitude 33.606N. The average annual discharge at site 1 is 6.81m3/sec. The slope at selected site 2 is 0.0081. The weir of height 2.5m (8.2ft) is proposed at selected site 2 that will have 280.6m backwater curve i.e. 280.6m (920.6ft) protection of side bunds are required. The potential for hydropower generation at selected site 2 is found to be 167KW by selecting cross flow hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, site 2 will serve almost 33 houses. The third selected site (site 3) for hydropower generation is located at almost 6km downstream from Chirah station. The third selected site (site 3) has coordinates of longitude 73.290E and latitude 33.590N. The average annual discharge at selected site 3 is 6.87m3/sec. The slope at site 3 is 0.0062. The weir of height 2m (6.5ft) is proposed at selected site 3 that will have 295.3m backwater curve i.e. 295.3m (968.9ft) protection of side bunds are required. The potential for hydropower generation at selected site 3 is found to be 134.8KW by selecting Kaplan hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, site 3 will serve almost 27 houses.

The fourth selected site (site 4) for hydropower generation is located at almost 8km downstream from Chirah station. The fourth selected site (site 4) has coordinates of longitude 73.282E and latitude 33.587N. The average annual discharge at selected site 4 is 7.55m3/sec. The slope at site 5 is 0.0034. The weir of height 1.25m (4ft) is proposed at selected site 4 that will have 289.7m backwater curve i.e. 289.7m (950.5ft) protection of side bunds are required. The potential for hydropower generation at selected site 4 is found to be 92.60KW by selecting Archimedes hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, site 4 will serve almost 18 houses.

The fifth selected site (site 5) for hydropower generation is located at almost 10km downstream from Chirah station. The fifth selected site (site 5) has coordinates of longitude 73.268E and latitude 33.578N. The average annual discharge at selected site 5 is 7.82m3/sec. The slope at site 5 is 0.0032. The weir of height 1.0m (3.5ft) is proposed at selected site 5 that will have 253.7m backwater curve i.e. 253.7m (832.4ft) protection of side bunds are required. The potential for hydropower generation at selected site 5 is found to be 74.70KW by selecting Archimedes hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, selected site 5 will serve almost 15 houses.

The sixth selected site (site 6) for hydropower generation is located at almost 12km downstream from Chirah station. The sixth selected site (site 6) has coordinates of longitude 73.251E and latitude 33.568N. The average annual discharge at selected site 6 is 7.98m3/sec. The slope at site 6 is 0.0067. The weir of height 2m (6.5ft) is proposed at selected site 6 that will have 269.6m backwater curve i.e. 269.6m (884.6ft) protection of side bunds are required. The potential for hydropower generation at selected site 6 is found to be 156.6KW by selecting cross flow hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, selected site 6 will serve almost 31 houses.

The seventh selected site (site 7) for hydropower generation is located at almost 14km downstream from Chirah station. The seventh selected site (site 7) has coordinates of longitude 73.228E and latitude 33.567N. The average annual discharge at selected site 7 is 8.10m3/sec. The slope at site 7 is 0.0053. The weir of height 2.00m (6.5ft) is proposed at selected site 7 that will have 296.8m backwater curve i.e. 296.8m (938.7ft) protection of side bunds are required. The potential for hydropower generation at selected site 7 is found to be 158.90KW by selecting Kaplan hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, selected site 7 will serve almost 32 houses.

The eighth selected site (site 8) for hydropower generation is located at almost 16km downstream from Chirah station. The eighth selected site (site 8) has coordinates of longitude 73.210E and latitude 33.562N. The average annual discharge at selected site 8 is 8.66m3/sec. The slope at site 8 is 0.0037. The weir of height 1.25m (4.25ft) is proposed at selected site 8 that will have 262.7m backwater curve i.e. 262.7m (862ft) protection of side bunds are required. The potential for hydropower generation at selected site 8 is found to be 106.2KW by selecting Kaplan hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, selected site 8 will serve almost 21 houses.

The ninth selected site (site 9) for hydropower generation is located at almost 18km downstream from Chirah station. The ninth selected site (site 9) has coordinates of longitude 73.193E and latitude 33.554N. The average annual discharge at selected site 10 is 8.75m3/sec. The slope at site 9 is 0.0027. The weir of height 1.m (3.5ft) is proposed at selected site 9 that will have 288.2m backwater curve i.e. 288.2m (946ft) protection of side bunds are required. The potential for hydropower generation at selected site 9 is found to be 85.84KW by selecting Archimedes hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, selected site 9 will serve almost 17 houses.

The tenth selected site (site 10) for hydropower generation is located at almost 20km downstream from Chirah station. The tenth selected site (site 10) has coordinates of longitude 73.179E and latitude 33.548N. The average annual discharge at selected site 10 is 11.50m3/sec. The slope at site 10 is 0.0027. The weir of height 1.0m (3.5ft) is proposed at selected site 10 that will have 280.5m backwater curve i.e. 280.5m (921ft) protection of side bunds are required. The potential for hydropower generation at selected site 10 is found to be 112.80KW by selecting Archimedes hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, selected site 10 will serve almost 22 houses.

The eleventh selected site (site 11) for hydropower generation is located at almost 24km downstream from Chirah station and almost 8km upstream from Rawalpindi station of Soan River. The eleventh selected site (site 11) has coordinates of longitude 73.145E and latitude 33.554N. The average annual discharge at selected site 11 is 12.11m3/sec. The slope at site 11 is 0.0040. The weir of height 1.25m (4ft) is proposed at selected site 11 that will have 251.5m backwater curve i.e. 251.5m (826ft) protection of side bunds are required. The potential for hydropower generation at selected site 11 is found to be 148.5KW by selecting Kaplan hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, selected site 11 will serve almost 30 houses. The selected site (site 12) for hydropower generation is located at almost 28km downstream from Chirah station and almost 4km upstream from Rawalpindi station of Soan River. The selected site (site 12) has coordinates of longitude 73.113E and latitude 33.546N. The average annual discharge at selected site 12 is 12.47m3/sec. The slope at site 12 is 0.0027. The weir of height 1.0m (3.5ft) is proposed at selected site 12 that will have 282.2m backwater curve i.e. 282.2m (926ft) protection of side bunds are required. The potential for hydropower generation at selected site 12 is found to be 122.3KW by selecting Archimedes hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5Kw per house, selected site 11 will serve almost 24 houses. The selected site (site 13) for hydropower generation is located at almost 30km downstream from Chirah station and almost 2km upstream from Rawalpindi station of Soan River. The selected site (site 13) has coordinates of longitude 73.100E and latitude 33.548N. The average annual discharge at selected site 13 is 19.37m3/sec. The slope at site 12 is 0.0023. The weir of height 1.0m (3.5ft) is proposed at selected site 13 that will have 298.8m backwater curve i.e. 298.8m (981ft) protection of side bunds are required. The potential for hydropower generation at selected site 13 is found to be 190.05KW by selecting Archimedes hydraulic turbine. The average power requirement of average house is almost 5KW. So, with an average power requirement of 5KW per house, selected site 11 will serve almost 38 houses. The overall total potential for hydropower generation from Chirah to Rawalpindi station of Soan River is 1713.24KW with 13 points of interest. The total 16 sites are evaluated out of which 13 sites is selected. The maximum and minimum hydropower potential is 190.01KW and 74.70KW respectively with an average hydropower potential of 130.27KW at each point of interest. The average power requirement of average house is 5KW. So, with an average power requirement of 5KW per house, almost 342 houses will be served from Chirah to Rawalpindi station of Soan River.

4.8 Summary

The result shows that discharge (flow rate) is increasing as water is flowing from Chirah to Rawalpindi because two main tributaries (ling stream and Korang stream) join the Soan River. The maximum discharge is 19.40cumecs which is at Rawalpindi station and minimum discharge is 6.45cumecs which is at Chirah station of Soan River. The gradient (slope) of Soan River is decreasing as water is flowing from upstream (Chirah) to downstream (Rawalpindi). The value of slope of Soan River near Chirah station is 0.0088 but the value of slope near Rawalpindi is 0.0023 which is very less. The maximum elevation value is at 548m which is at Chirah station and minimum elevation value is 419m which is at Rawalpindi station. The height of weir (head generated) is proposed after detail analysis two parameter i.e. slope and backwater curve by using direst step method (DSM). The maximum head (height of weir) proposed at hydropower evaluating sites/points is 2.5m and minimum height of weir (head) proposed is 1m. The point/site which has slope less than 0.0023 is not selected for hydropower potential sites because backwater length exceeds the 300m even if the height of weir is proposed by 1m only. The total hydropower potential from Chirah to Rawalpindi station of Soan River is 1713.24KW with 13 point of interest. The selected hydropower potential sites (13 point of interest) are located 02, 04, 06, 08, 10, 12, 14, 16, 18, 20, 24, 28 and 30 km downstream from Chirah station. Archimedes, Cross flow and Kaplan turbine is selected at sites from standard graph/charts based on discharge (Q) and head (H) generated The average power requirement of average house is 5KW. So, with an average power requirement of 5KW per house, almost 342 houses will be served from Chirah to Rawalpindi station of Soan River. This shows that

Soan River has hydropower potential. The graphical representation of hydropower potential at each selected hydropower potential sites is shown in figure 4.7.

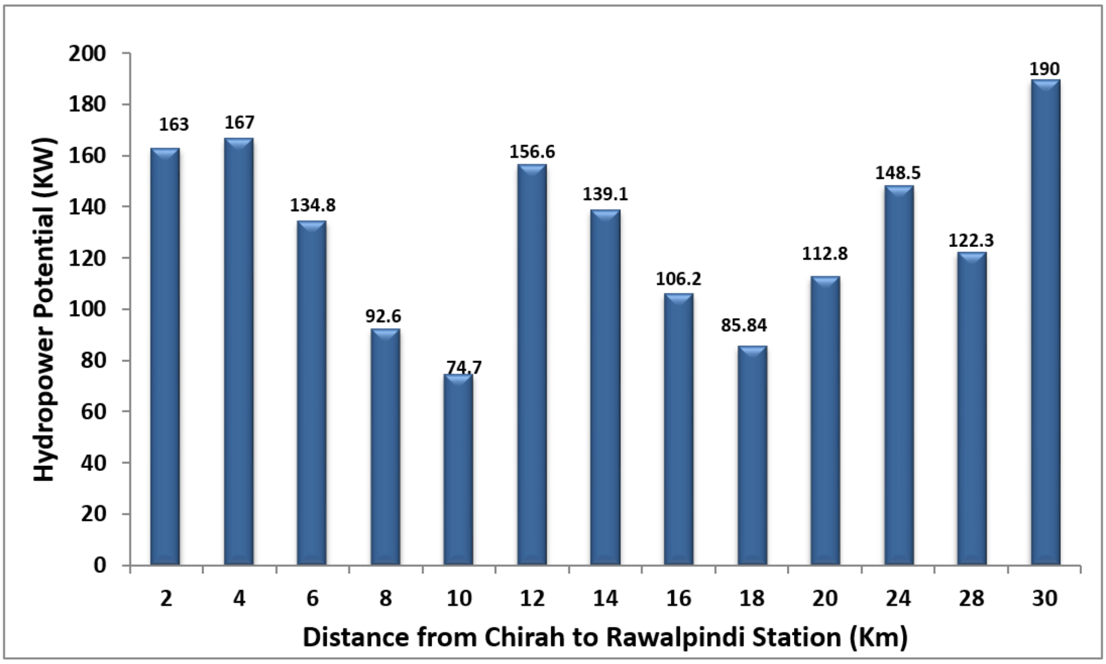

Figure 4.7: Hydropower Potential at each Selected Hydropower Sites from Chirah to Rawalpindi Station of Soan River.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

Energy crisis is one of major issues in developing countries. Pakistan has been suffering from energy crisis since last few decades due to increasing population and industrial development. According to International Energy Agency (IEA), the energy demand in Pakistan is expected three times higher by 2050. By keeping this point in mind, hydropower generation is one of the cost effective solution. Unfortunately, economic condition in Pakistan is a favorable for starting large hydropower projects. In Pakistan, thousands of small rivers or streams are flowing. Hence, Small hydro is one of the most cost effective and alternative solutions for Pakistan energy crisis situation. In this research, major tributary of Indus River i.e. Soan River is selected and hydropower potential is evaluated from Chirah to Rawapindi station by managing water. For evaluation of hydropower potential of study area terrain pre-processing of study area is done in ArcGIS by downloading digital elevation model (DEM). The hydropower potential sites/ points are selected based on analysis of digital elevation model (DEM) of study area and also with the help of literature review. Slope is calculated at every selected hydropower potential sites/points using Google Earth Pro and cross verify it in ArcGIS. Discharge at each marked point is calculated by using ratio proportion technique in ArcGIS. Head is generated by proposing weir with the help of detail analysis and site survey. Back water effect length is calculated at each marked point using direct step method. The theoretical power is evaluated by using the standard formula and hydraulic turbine is selected at each hydropower sites using standard graphs. The structure for protection of sides of backwater effect is also proposed to accommodate backwater effect. In this research, hydraulic condition of Soan River from Chirah to Rawalpindi is only evaluated and also proposes hydraulic turbines at each selected hydropower sites/points. Structural design and design of hydraulic turbine is not included in this research. Financial aspect of this study is also not a part of this research.

After detail analysis of result the following conclusion are drawn:

- The total hydropower potential of Soan River basin from Chirah to Rawalpindi station is 1713 KW with 13 point of interests.
- The hydraulic turbine proposed at each selected site/points based on head and discharge is Archimedes, Kaplan or Cross flow.
- For protection of sides of river, sides bunds are proposed to accommodate back water curve.

The detail analysis of result is carried out for all selected hydropower potential sites in result and analysis section. The maximum hydropower potential site in study area is located 2 Km upstream from Rawalpindi station and 30Km downstream of Chirah station of Soan River with hydropower potential of 192KW. The minimum hydropower potential site in study area is located at 10Km downstream from Chirah station and 20Km upstream from Chirah station with hydropower potential of 74.7MW. The average hydropower potential at each site in study area is 130.27KW. This study is not only beneficial for small scale hydropower generation. By adapting this technique i.e. developing weir and managing flow, aesthetic view of river can also be improved and flood can also be controlled at some extant.

This study is concluded by the statement that small scale hydropower is not only generated by ROR scheme but also generated by pounding water by proposing small weirs which is not only beneficial for small scale hydropower generation but also helpful for flood prevention at some extant.

5.2 Recommendation

Following are the recommendations for the future:

- The study area in this research is only limited to Chirah station to Rawalpindi station of Soan River which is less than one-fourth of total Soan River basin. So, it is recommended to apply this approach to whole length of Soan river and to evaluate hydropower potential.
- It is also recommended that distance between two consecutive intervals of hydropower sites should be varied and evaluates the hydropower potential.
- Power loss study at each selected hydropower sites and economic feasibility assessment of this research is also recommended.
- Policies are required to be developed for hydraulic structure (weirs) in mild slope small rivers which is not only helpful for small scale hydropower generation but also beneficial for flood control at some extant in monsoon season.

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Annexure A

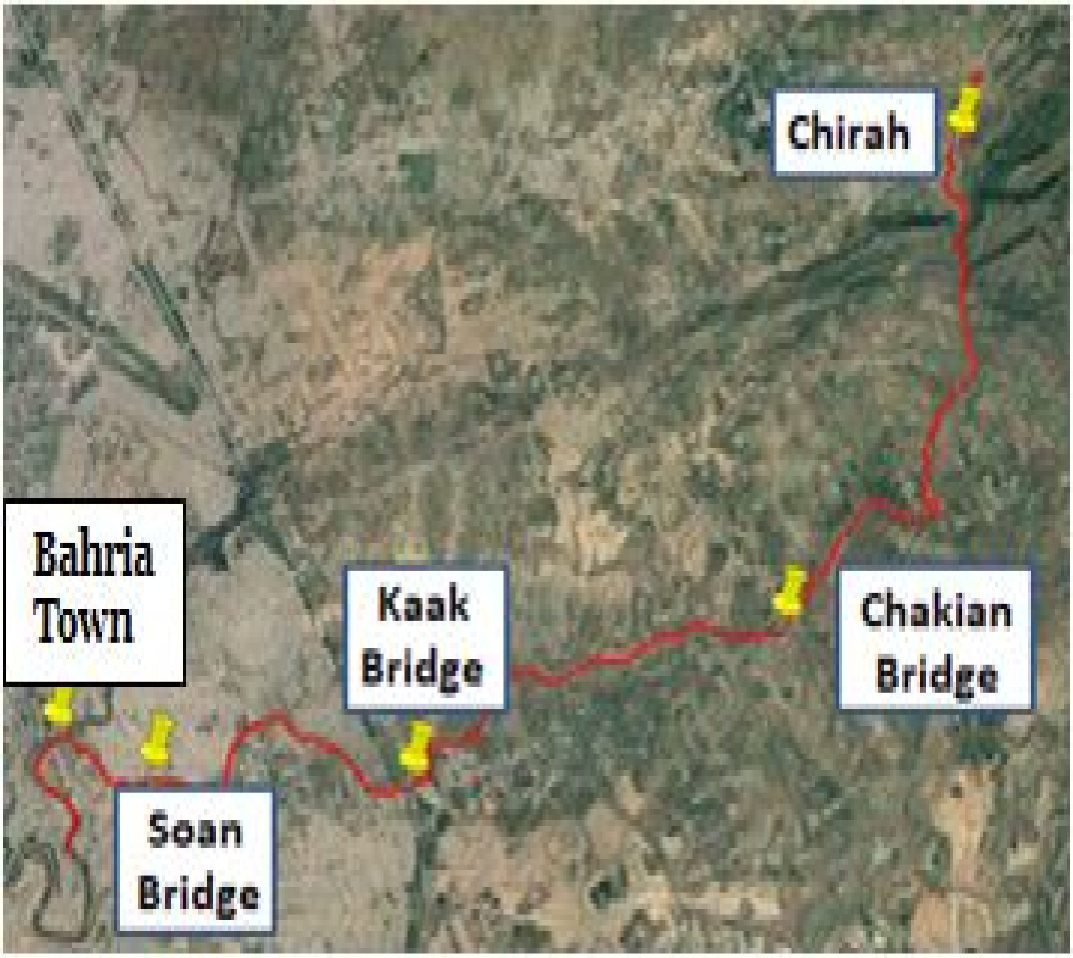


Figure A1: Imaginary Taken Points for Value of Manning Constant "n"

Chirah (n=0.033)

Chakian Bridge (n=0.032)

Kaak Bridge (n=0.024)

Soan Bridge (n=0.032)

Bahria Town (n=0.027)

FIGURE A2: Extracted Value of Manning Constant "n" after Comparison the Imaginary Available in Literature Review

Annexure B

Point 1 (Longitude 73.299E and Latitude 33.622N)

A*R^2/3 = n*Q/(So)$^{0.5}$ = 2.3393

Top Width (T) = 14m — From Google Earth Pro

Bottom width(Bo) = T-2sy = 14-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 14-2sy in Area equation

Area(A) = (14-2(0.5)y+0.5y)y

Area(A) = $14y-0.5y^2$

Perimeter(P) = $Bo+2y\sqrt{(1 + s^2)}$

s=0.5 and Bo= 14-2(0.5)y

Perimeter(P) = 14+1.24y

$A*R^{2/3} = (14*y - 0.5*y^2) * (14*y - 0.5* y^2)^{2/3} / (14+1.24y)^{2/3}$ — R=A/P

$0 = (14*y - 0.5*y^2)^{5/3} - 2.3393\,(14 + 1.24*y)^{2/3}$

At y = 0.351m both sides of above equation is equal

Hence y_n = 0.351m

B = 13.6488m — B= 14-2sy

Point 2 (Longitude 73.298E and Latitude 33.606N)

A*R^2/3 = n*Q/(So)$^{0.5}$ = 2.4970

Top Width (T) = 13.8m From Google Earth Pro

Bottom width(Bo) = T-2sy = 13.8-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 13.8-2sy in Area equation

Area(A) = (13.8-2(0.5)y+0.5y)y

Area(A) = 13.8y-0.5y^2

Perimeter(P) = Bo+2y√(1 + s^2)

s=0.5 and Bo= 14-2(0.5)y

Perimeter(P) = 13.8+1.24y

A*R$^{2/3}$ = (13.8*y - 0.5*y^2) * (13.8*y - 0.5* y^2)$^{2/3}$ / (13.8+1.24y)$^{2/3}$ R=A/P

0 = (13.8*y - 0.5*y^2)$^{5/3}$ - 2.4970 (13.8 + 1.24*y)$^{2/3}$

At y = 0.369m both sides of above equation is equal

Hence y $_n$ = 0.369m

As we know B= 13.8-2sy

Hence B = 13.4311m

Point 3 (Longitude 73.290E and Latitude 33.590N)

A*R^2/3 = n*Q/(So)$^{0.5}$ = 2.8792

Top Width (T) = 16.8m From Google Earth Pro

Bottom width(Bo) = T-2sy = 16.8-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 16.8-2sy in Area equation

Area(A) = (16.8-2(0.5)y+0.5y)y

Area(A) = 16.8y-0.5y^2

Perimeter(P) = Bo+2y√(1 + s^2)

s=0.5 and Bo= 16.8-2(0.5)y

Perimeter(P) = 16.8+1.24y

A*R$^{2/3}$ = (16.8*y - 0.5*y^2) * (16.8*y - 0.5* y^2)$^{2/3}$ / (16.8+1.24y)$^{2/3}$ R=A/P

0 = (16.8*y - 0.5*y^2) $^{5/3}$ - 2.8792 (16.8 + 1.24*y)$^{2/3}$

At y = 0.355m both sides of above equation is equal

Hence y $_n$ = 0.355m

As we know B= 16.8-2sy

B = 16.4448m

Point 4 (Longitude 73.282E and Latitude 33.587N)

$A*R^{2/3}$ = $n*Q/(So)^{0.5}$ = 4.2729
Top Width (T) = 15.2m From Google Earth Pro
Bottom width(Bo) = T-2sy = 15.2-2sy
Geometry of Soan River is almost Trapezoidal with 1V:2H
So, Area(A) = (Bo + s*y)*y
Put the value of Bo= 15.2-2sy in Area equation
Area(A) = (15.2-2(0.5)y+0.5y)y
Area(A) = $15.2y-0.5y^2$
Perimeter(P) = $Bo+2y\sqrt{(1 + s^2)}$
s=0.5 and Bo= 15.2-2(0.5)y
Perimeter(P) = 15.2+1.24y
$A*R^{2/3}$ = $(15.2*y - 0.5*y^2) * (15.2*y - 0.5*y^2)^{2/3} / (15.2+1.24y)^{2/3}$ R=A/P
0 = $(15.2*y - 0.5*y^2)^{5/3} - 4.2729\,(13.8 + 1.24*y)^{2/3}$
At y = 0.483m both sides of above equation is equal
Hence y_n = 0.483m
As we know B= 15.2-2sy
Hence B = 14.7173m

Point 5 (Longitude 73.268E and Latitude 33.578N)

$A*R^{2/3}$ = $n*Q/(So)^{0.5}$ = 4.5619
Top Width (T) = 20.6m From Google Earth Pro
Bottom width(Bo) = T-2sy = 20.6-2sy
Geometry of Soan River is almost Trapezoidal with 1V:2H
So, Area(A) = (Bo + s*y)*y
Put the value of Bo= 20.6-2sy in Area equation
Area(A) = (20.6-2(0.5)y+0.5y)y
Area(A) = $20.6y-0.5y^2$
Perimeter(P) = $Bo+2y\sqrt{(1 + s^2)}$
s=0.5 and Bo= 20.6-2(0.5)y
Perimeter(P) = 20.6+1.24y
$A*R^{2/3}$ = $(20.6*y - 0.5*y^2) * (20.6*y - 0.5*y^2)^{2/3} / (20.6+1.24y)^{2/3}$ R=A/P
0 = $(20.6*y - 0.5*y^2)^{5/3} - 4.5619\,(20.6 + 1.24*y)^{2/3}$
At y = 0.414m both sides of above equation is equal
Hence y_n = 0.411m
As we know B= 20.6-2sy
B = 20.1864m

Point 6 (Longitude 73.251E and Latitude 33.568N)

$A*R^{2/3}$ = $n*Q/(So)^{0.5}$ = 3.1197
Top Width (T) = 19.6m From Google Earth Pro
Bottom width(Bo) = T-2sy = 19.6-2sy
Geometry of Soan River is almost Trapezoidal with 1V:2H
So, Area(A) = (Bo + s*y)*y
Put the value of Bo= 19.6-2sy in Area equation
Area(A) = (19.6-2(0.5)y+0.5y)y
Area(A) = $19.6y-0.5y^2$
Perimeter(P) = $Bo+2y\sqrt{(1 + s^2)}$
s=0.5 and Bo= 19.6-2(0.5)y
Perimeter(P) = 19.6+1.24y
$A*R^{2/3}$ = $(19.6*y - 0.5*y^2) * (19.6*y - 0.5*y^2)^{2/3} / (19.6+1.24y)^{2/3}$ R=A/P
0 = $(19.6*y - 0.5*y^2)^{5/3} - 3.1197 (19.6 + 1.24*y)^{2/3}$
At y = 0.339m both sides of above equation is equal
Hence y_n = 0.339m
As we know B= 19.6-2sy
Hence B = 19.2615m

Point 7 (Longitude 73.228E and Latitude 33.567N)

$A*R^{2/3}$ = $n*Q/(So)^{0.5}$ = 3.5604
Top Width (T) = 18m From Google Earth Pro
Bottom width(Bo) = T-2sy = 18-2sy
Geometry of Soan River is almost Trapezoidal with 1V:2H
So, Area(A) = (Bo + s*y)*y
Put the value of Bo= 18-2sy in Area equation
Area(A) = (18-2(0.5)y+0.5y)y
Area(A) = $18y-0.5y^2$
Perimeter(P) = $Bo+2y\sqrt{(1 + s^2)}$
s=0.5 and Bo= 18-2(0.5)y
Perimeter(P) = 18+1.24y
$A*R^{2/3}$ = $(18*y - 0.5*y^2) * (18*y - 0.5*y^2)^{2/3} / (18+1.24y)^{2/3}$ R=A/P
0 = $(18*y - 0.5*y^2)^{5/3} - 3.5604 (18 + 1.24*y)^{2/3}$
At y = 0.387m both sides of above equation is equal
Hence y_n = 0.387m
As we know B= 18-2sy
B = 17.6129m

Point 8 (Longitude 73.210E and Latitude 33.562N)

$A*R^{2/3} = n*Q/(So)^{0.5} = 4.5558$

Top Width (T) = 15.6m From Google Earth Pro

Bottom width(Bo) = T-2sy = 15.6-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 15.6-2sy in Area equation

Area(A) = (15.6-2(0.5)y+0.5y)y

Area(A) = $15.6y-0.5y^2$

Perimeter(P) = $Bo+2y\sqrt{(1+s^2)}$

s=0.5 and Bo= 15.6-2(0.5)y

Perimeter(P) = 15.6+1.24y

$A*R^{2/3} = (15.6*y - 0.5*y^2) * (15.6*y - 0.5*y^2)^{2/3} / (15.6+1.24y)^{2/3}$ R=A/P

$0 = (15.6*y - 0.5*y^2)^{5/3} - 4.5558 (15.6 + 1.24*y)^{2/3}$

At y = 0.494m both sides of above equation is equal

Hence y_n = 0.494m

As we know B= 15.6-2sy

Hence B = 15.1062m

Point 9 (Longitude 73.193E and Latitude 33.554N)

$A*R^{2/3} = n*Q/(So)^{0.5} = 4.0415$

Top Width (T) = 21.8m From Google Earth Pro

Bottom width(Bo) = T-2sy = 21.8-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 21.8-2sy in Area equation

Area(A) = (21.8-2(0.5)y+0.5y)y

Area(A) = $21.8y-0.5y^2$

Perimeter(P) = $Bo+2y\sqrt{(1+s^2)}$

s=0.5 and Bo= 21.8-2(0.5)y

Perimeter(P) = 21.8+1.24y

$A*R^{2/3} = (21.8*y - 0.5*y^2) * (21.8*y - 0.5*y^2)^{2/3} / (21.8+1.24y)^{2/3}$ R=A/P

$0 = (21.8*y - 0.5*y^2)^{5/3} - 4.0415 (21.8 + 1.24*y)^{2/3}$

At y = 0.371m both sides of above equation is equal

Hence y_n = 0.371m

As we know B= 21.8-2sy

B = 21.4293m

Point 10 (Longitude 73.179E and Latitude 33.548N)

A*R^2/3 = n*Q/(So)$^{0.5}$ = 5.3116

Top Width (T) = 25.2m From Google Earth Pro

Bottom width(Bo) = T-2sy = 25.2-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 25.2-2sy in Area equation

Area(A) = (25.2-2(0.5)y+0.5y)y

Area(A) = 25.2y-0.5y^2

Perimeter(P) = Bo+2y√(1 + s^2)

s=0.5 and Bo= 25.2-2(0.5)y

Perimeter(P) = 25.2+1.24y

A*R$^{2/3}$ = (25.2*y - 0.5*y^2) * (25.2*y - 0.5* y^2)$^{2/3}$ / (25.2+1.24y)$^{2/3}$ R=A/P

0 = (25.2*y - 0.5*y^2)$^{5/3}$ - 5.3116 (25.2 + 1.24*y)$^{2/3}$

At y = 0.494m both sides of above equation is equal

Hence y_n = 0.400m

As we know B= 25.2-2sy

Hence B = 24.8001m

Point 11 (Longitude 73.145E and Latitude 33.554N)

A*R^2/3 = n*Q/(So)$^{0.5}$ = 4.5954

Top Width (T) = 28.5m From Google Earth Pro

Bottom width(Bo) = T-2sy = 28.5-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 28.5-2sy in Area equation

Area(A) = (28.5-2(0.5)y+0.5y)y

Area(A) = 28.5y-0.5y^2

Perimeter(P) = Bo+2y√(1 + s^2)

s=0.5 and Bo= 28.5-2(0.5)y

Perimeter(P) = 28.5+1.24y

A*R$^{2/3}$ = (28.5*y - 0.5*y^2) * (28.5*y - 0.5* y^2)$^{2/3}$ / (28.5+1.24y)$^{2/3}$ R=A/P

0 = (28.5*y - 0.5*y^2) $^{5/3}$ - 4.5954 (28.5 + 1.24*y)$^{2/3}$

At y = 0.339m both sides of above equation is equal

Hence y_n = 0.339m

As we know B= 28.5-2sy

B = 28.1607m

Point 12 (Longitude 73.113E and Latitude 33.546N)

$A*R^2/3 = n*Q/(So)^{0.5} = 6.4796$

Top Width (T) = 25.2m From Google Earth Pro

Bottom width(Bo) = T-2sy = 25.2-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 25.2-2sy in Area equation

Area(A) = (25.2-2(0.5)y+0.5y)y

Area(A) = $25.2y-0.5y^2$

Perimeter(P) = $Bo+2y\sqrt{(1 + s^2)}$

s=0.5 and Bo= 25.2-2(0.5)y

Perimeter(P) = 25.2+1.24y

$A*R^{2/3} = (25.2*y - 0.5*y^2) * (25.2*y - 0.5* y^2)^{2/3} / (25.2+1.24y)^{2/3}$ R=A/P

$0 = (25.2*y - 0.5*y^2)^{5/3} - 6.4796 (25.2 + 1.24*y)^{2/3}$

At y = 0.494m both sides of above equation is equal

Hence y_n = 0.451m

As we know B= 25.2-2sy

Hence B = 24.7487m

Point 13 (Longitude 73.100E and Latitude 33.548N)

$A*R^2/3 = n*Q/(So)^{0.5} = 12.9246$

Top Width (T) = 33.8m From Google Earth Pro

Bottom width(Bo) = T-2sy = 33.8-2sy

Geometry of Soan River is almost Trapezoidal with 1V:2H

So, Area(A) = (Bo + s*y)*y

Put the value of Bo= 33.8-2sy in Area equation

Area(A) = (33.8-2(0.5)y+0.5y)y

Area(A) = $33.8y-0.5y^2$

Perimeter(P) = $Bo+2y\sqrt{(1 + s^2)}$

s=0.5 and Bo= 33.8-2(0.5)y

Perimeter(P) = 33.8+1.24y

$A*R^{2/3} = (33.8*y - 0.5*y^2) * (33.8*y - 0.5* y^2)^{2/3} / (33.8+1.24y)^{2/3}$ R=A/P

$0 = (33.8*y - 0.5*y^2)^{5/3} - 12.9246 (33.8 + 1.24*y)^{2/3}$

At y = 0.572m both sides of above equation is equal

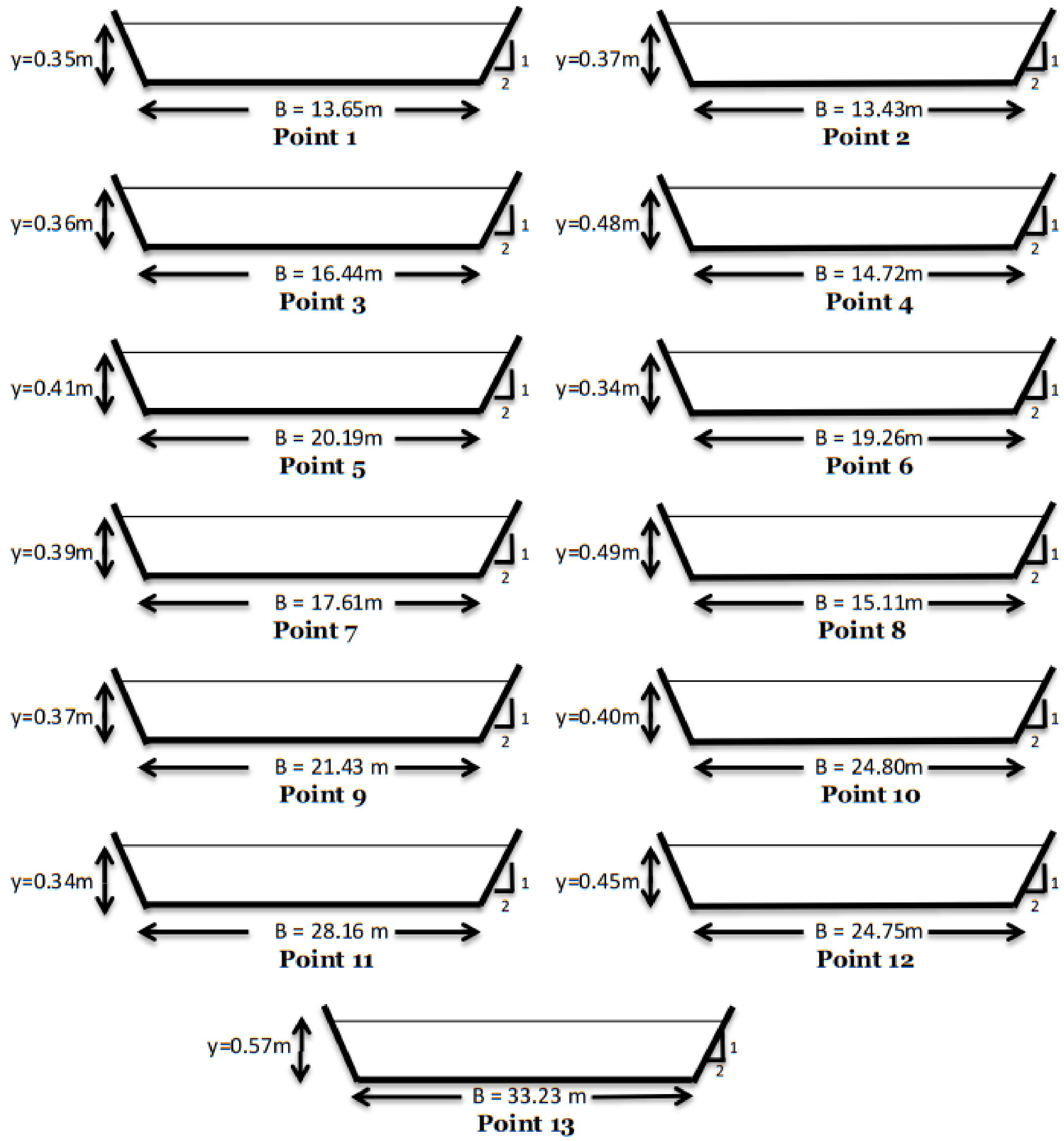
Hence y_n = 0.572m

As we know B= 33.8-2sy

B = 33.2281m

Annexure C

Cross-section at each Selected Hydropower Potential Sites



Annexure D

Height of Weirs Proposed and Backwater Length Calculations at each Hydropower Potential Sites

Calculation at Selected Point 1 (Longitude 73.299E and Latitude 33.622N)

Bottom Slope (So) = 0.0088
Discharge (Q) = 6.65m³/sec
Bottom Width (Bo) = 13.65m
Manning Constant (n) = 0.033
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n*Q / Co* S^{1/2}$
$n*Q / Co*S^{1/2}$ = 2.34
Hence, $AR^{2/3}$ = 2.34 .... (1)
Assume y_n = 0.351m
Area (A) = $(Bo + s*y_n) * y_n$ = 4.85m²
Perimeter (P) = $Bo + 2(1+s2)^{1/2} * y_n$ = 14.43m
Hydraulic Radius (R) = Area/Perimeter = 0.336
$AR^{2/3}$ = 2.35 check if it is closer to (1) above

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.37m

Step 3: Calculation Table

Propose Weir of H = 2.5m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m²)	(m)	(m)	(m/s)				(m)			(m)
2.5	37.25	19.24	1.94	0.18	0.000014			2.50			0
						0.00002	0.00877		-0.499	-56.8	
2.0	29.3	18.12	1.62	0.23	0.000029			2.00			-56.8
						0.00005	0.00874		-0.498	-56.9	
1.5	21.6	17.00	1.27	0.31	0.000075			1.50			-113.8
						0.00017	0.00862		-0.494	-57.2	
1	14.15	15.89	0.89	0.47	0.000280			1.01			-171.0
						0.00150	0.00729		-0.465	-63.7	
0.5	6.95	14.77	0.47	0.96	0.002722			0.55			-234.7
						0.00420	0.00459		-0.073	-15.9	
0.4	5.54	14.54	0.38	1.20	0.005681			0.47			-250.6
						0.00606	0.00273		-0.009	-3.32	
0.38	5.33	14.51	0.37	1.25	0.006444			0.46			-253.9
						0.00689	0.00190		-0.008	-4.38	
0.37	5.12	14.48	0.35	1.30	0.007348			0.45			-258.3

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 2 (Longitude 73.298E and Latitude 33.606N)

Bottom Slope (So) = 0.0081
Discharge (Q) = 6.81m³/sec
Bottom Width (Bo) = 13.43m
Manning Constant (n) = 0.033
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n*Q / Co*S^{1/2}$
$n*Q / Co*S^{1/2}$ = 2.50
Hence, $AR^{2/3}$ = 2.50 .... (1)
Assume y_n = 0.369m
Area (A) = $(Bo + s*y_n) * y_n$ = 5.02m²
Perimeter (P) = $Bo + 2(1+s2)^{1/2} * y_n$ = 14.26m
Hydraulic Radius (R) = Area/Perimeter = 0.352
$AR^{2/3}$ = 2.51 check if it is closer to (1) above

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.39m

Step 3: Calculation Table

Propose Weir of H = 2.5m

Y (m)	A (m²)	P (m)	R (m)	V (m/s)	S_f	Avg. S_f	So-Avg. S_f	E (m)	ΔE	Δx	X2 (m)
2.5	36.7	19.02	1.93	0.19	0.000016			2.50			0
						0.00005	0.00805		-0.99	-123.8	
1.5	21.3	16.78	1.27	0.32	0.000081			1.51			-123.8
						0.00019	0.00791		-0.49	-62.4	
1	13.9	15.67	0.89	0.49	0.000304			1.01			-186.1
						0.00162	0.00647		-0.46	-71.3	
0.5	6.8	14.55	0.47	1.00	0.002952			0.55			-257.5
						0.00356	0.00454		-0.04	-8.36	
0.45	6.14	14.44	0.43	1.11	0.004176			0.51			-265.8
						0.00461	0.00349		-0.02	-4.95	
0.43	5.80	14.38	0.40	1.17	0.005042			0.50			-270.8
						0.00560	0.00250		-0.02	-6.32	
0.40	5.45	14.32	0.38	1.25	0.006158			0.48			-277.1
						0.00642	0.00167		-0.01	-3.47	
0.39	5.31	14.30	0.37	1.28	0.006694			0.47			-280.6

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 3 (Longitude 73.290E and Latitude 33.590N)

Bottom Slope (So) = 0.0062
Discharge (Q) = 6.87m³/sec
Bottom Width (Bo) = 16.44m
Manning Constant (n) = 0.033
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n^*Q / Co^* S^{1/2}$
$n^*Q / Co^*S^{1/2}$ = 2.88
Hence, $AR^{2/3}$ = 2.88 .... (1)
Assume y_n = 0.355m
Area (A) = $(Bo + s^*y_n) * y_n$ = 5.90m²
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} * y_n$ = 17.23m
Hydraulic Radius (R) = Area/Perimeter = 0.342
$AR^{2/3}$ = 2.89 check if it is closer to (1) above

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.37m

Step 3: Calculation Table

Propose Weir of H = 2.0m

Y (m)	A (m²)	P (m)	R (m)	V (m/s)	S_f	Avg. S_f	So-Avg. S_f	E (m)	ΔE	Δx	X2 (m)
2.0	34.9	20.91	1.67	0.20	0.000021			2.00			0
						0.00004	0.00616		-0.49	-80.9	
1.5	25.8	19.79	1.30	0.27	0.000054			1.50			-80.9
						0.00013	0.00607		-0.49	-81.6	
1.0	16.9	18.68	0.91	0.41	0.000204			1.01			-162.5
						0.00109	0.00510		-0.47	-92.9	
0.5	8.35	17.56	0.48	0.82	0.001989			0.53			-255.3
						0.00240	0.00380		-0.04	-11.0	
0.45	7.50	17.45	0.43	0.92	0.002816			0.49			-266.3
						0.00349	0.00271		-0.03	-14.2	
0.40	6.66	17.33	0.38	1.03	0.004156			0.45			-280.5
						0.00454	0.00166		-0.01	-8.47	
0.38	6.32	17.29	0.37	1.09	0.004923			0.44			-288.9
						0.00515	0.00105		-0.01	-6.35	
0.37	6.15	17.27	0.36	1.12	0.005377			0.43			-295.3

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 4 (Longitude 73.282E and Latitude 33.587N)

Bottom Slope (So) = 0.0034
Discharge (Q) = 7.55m³/sec
Bottom Width (Bo) = 14.72m
Manning Constant (n) = 0.033
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n*Q / Co* S^{1/2}$
$n*Q / Co*S^{1/2}$ = 4.27
Hence, $AR^{2/3}$ = 4.27 .... (1)
Assume y_n = 0.482m
Area (A) = $(Bo + s*y_n) * y_n$ = 7.21m²
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} * y_n$ = 15.80m
Hydraulic Radius (R) = Area/Perimeter = 0.456
$AR^{2/3}$ = 4.28 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.51m

Step 3: Calculation Table

Propose Weir of H = 1.25m

Y (m)	A (m²)	P (m)	R (m)	V (m/s)	S_f	Avg. S_f	So-Avg. S_f	E (m)	ΔE	Δx	X2 (m)
1.25	19.2	17.52	1.10	0.39	0.000149			1.26			0
						0.00023	0.00317		-0.25	-77.4	
1.0	15.2	19.96	0.90	0.50	0.000309			1.01			-77.4
						0.00048	0.00292		-0.19	-65.9	
0.80	12.1	16.51	0.73	0.62	0.000642			0.82			-143.3
						0.00082	0.00258		-0.09	-36.3	
0.70	10.5	16.29	0.65	0.72	0.000995			0.73			-179.6
						0.00132	0.00207		-0.09	-43.5	
0.60	9.01	16.06	0.56	0.84	0.001651			0.64			-223.1
						0.00192	0.00148		-0.04	-29.2	
0.55	8.25	15.95	0.52	0.92	0.002199			0.59			-252.3
						0.00234	0.00106		-0.02	-15.7	
0.53	7.94	15.91	0.50	0.95	0.002483			0.58			-268.0
						0.00265	0.00075		-0.02	-21.7	
0.51	7.64	15.86	0.48	0.99	0.002819			0.56			-289.7

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 5 (Longitude 73.268E and Latitude 33.578N)

Bottom Slope (So) = 0.0032
Discharge (Q) = 7.82m^3/sec
Bottom Width (Bo) = 20.19m
Manning Constant (n) = 0.033
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n^*Q / Co^* S^{1/2}$
$n^*Q / Co^*S^{1/2}$ = 4.56
Hence, $AR^{2/3}$ = 4.56 .... (1)
Assume y_n = 0.413m
Area (A) = $(Bo + s^*y_n)^* y_n$ = 8.42m^2
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} {}^* y_n$ = 21.11m
Hydraulic Radius (R) = Area/Perimeter = 0.399
$AR^{2/3}$ = 4.57 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.43m

Step 3: Calculation Table

Propose Weir of H = 1.00m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m^2)	(m)	(m)	(m/s)				(m)			(m)
1.00	20.7	22.43	0.92	0.38	0.000173			1.01			0
						0.00027	0.00293		-0.20	-66.8	
0.80	16.5	21.98	0.75	0.47	0.000361			0.81			-66.8
						0.00065	0.00255		-0.19	-74.7	
0.60	12.3	21.53	0.57	0.64	0.000930			0.62			-141.5
						0.001314	0.00189		-0.09	-48.1	
0.50	10.2	21.31	0.58	0.77	0.001698			0.53			-189.6
						0.001890	0.00131		-0.03	-19.9	
0.47	9.60	21.24	0.45	0.81	0.002083			0.50			-209.5
						0.002244	0.00096		-0.02	-17.7	
0.45	9.19	21.20	0.43	0.85	0.002405			0.49			-227.1
						0.002498	0.00070		-0.01	-11.8	
0.44	8.98	21.17	0.42	0.87	0.002591			0.48			-238.9
						0.002693	0.00051		-0.01	-16.1	
0.43	8.77	21.15	0.41	0.89	0.002795			0.47			-255.0

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 6 (Longitude 73.251E and Latitude 33.568N)

Bottom Slope (So) = 0.0067
Discharge (Q) = 7.98m³/sec
Bottom Width (Bo) = 19.26m
Manning Constant (n) = 0.033
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n*Q / Co* S^{1/2}$
$n*Q / Co*S^{1/2}$ = 3.12
Hence, $AR^{2/3}$ = 3.12 .... (1)
Assume y_n = 0.338m
Area (A) = $(Bo + s*y_n) * y_n$ = 6.57m²
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} * y_n$ = 20.02m
Hydraulic Radius (R) = Area/Perimeter = 0.328
$AR^{2/3}$ = 3.12 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.35m

Step 3: Calculation Table

Propose Weir of H = 2.00m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m²)	(m)	(m)	(m/s)				(m)			(m)
2.00	40.5	23.73	1.71	0.20	0.000019			2.00			0
						0.00003	0.00667		-0.50	-74.8	
1.50	30.0	22.61	1.33	0.27	0.000050			1.50			-74.8
						0.00012	0.00658		-0.50	-75.3	
1.00	19.8	21.50	0.92	0.40	0.000187			1.01			-150.0
						0.00033	0.00637		-0.24	-38.2	
0.75	14.7	20.94	0.70	0.54	0.000481			0.76			-188.2
						0.00116	0.00554		-0.23	-41.6	
0.5	9.76	20.38	0.48	0.82	0.001829			0.53			-229.9
						0.00283	0.00387		-0.08	-20.8	
0.4	7.78	20.15	0.39	1.03	0.003825			0.45			-250.7
						0.00428	0.00242		-0.02	-7.2	
0.38	7.29	20.10	0.36	1.09	0.004736			0.44			-257.9
						0.00534	0.00136		-0.02	-11.7	
0.35	6.80	20.04	0.34	1.17	0.005951			0.42			-269.6

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 7 (Longitude 73.228E and Latitude 33.567N)

Bottom Slope (So) = 0.0053
Discharge (Q) = 8.1m³/sec
Bottom Width (Bo) = 17.61m
Manning Constant (n) = 0.032
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n^*Q / Co^* S^{1/2}$
$n^*Q / Co^*S^{1/2}$ = 3.56
Hence, $AR^{2/3}$ = 3.56 .... (1)
Assume y_n = 0.387m
Area (A) = $(Bo + s^*y_n) * y_n$ = 6.89m²
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} * y_n$ = 18.48m
Hydraulic Radius (R) = Area/Perimeter = 0.373
$AR^{2/3}$ = 3.57 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.41m

Step 3: Calculation Table

Propose Weir of H = 2.00m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m²)	(m)	(m)	(m/s)				(m)			(m)
2	37.2	22.08	1.69	0.22	0.000024			2.00			0
						0.00004	0.00526		-0.50	-80.8	
1.5	27.5	20.96	1.31	0.29	0.000062			1.50			-80.8
						0.00015	0.00515		-0.49	-79.6	
1	18.1	19.85	0.91	0.45	0.000231			1.01			-160.4
						0.00041	0.00489		-0.24	-52.5	
0.75	13.5	19.29	0.70	0.60	0.000595			0.77			-212.9
						0.00143	0.00387		-0.23	-48.3	
0.5	8.9	18.73	0.48	0.91	0.002261			0.54			-261.2
						0.00273	0.00257		-0.04	-22.6	
0.45	8.0	18.62	0.43	1.01	0.003202			0.50			-283.8
						0.00346	0.00184		-0.01	-6.7	
0.43	7.7	18.57	0.41	1.06	0.003721			0.49			-290.5
						0.00404	0.00126		-0.01	-6.3	
0.41	7.3	18.53	0.39	1.11	0.004355			0.47			-296.8

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 8 (Longitude 73.210E and Latitude 33.562N)

Bottom Slope (So) = 0.0037
Discharge (Q) = 8.66m³/sec
Bottom Width (Bo) = 15.11m
Manning Constant (n) = 0.032
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n{*}Q / Co{*} S^{1/2}$
$n{*}Q / Co{*}S^{1/2}$ = 4.56
Hence, $AR^{2/3}$ = 4.56 .... (1)
Assume y_n = 0.494m
Area (A) = $(Bo + s{*}y_n) * y_n$ = 7.59m²
Perimeter (P) = $Bo + 2\,(1+s2)^{1/2} * y_n$ = 16.21m
Hydraulic Radius (R) = Area/Perimeter = 0.468
$AR^{2/3}$ = 4.57 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.52m

Step 3: Calculation Table

Propose Weir of H = 1.25m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m²)	(m)	(m)	(m/s)				(m)			(m)
1.25	19.7	17.91	1.10	0.44	0.000175			1.26			0
						0.00027	0.00343		-0.24	-71.2	
1.00	15.6	17.35	0.90	0.55	0.000363			1.02			-71.2
						0.00046	0.00324		-0.12	-37.1	
0.88	13.6	17.07	0.80	0.64	0.000561			0.90			-108.2
						0.00075	0.00295		-0.12	-39.7	
0.75	11.6	16.79	0.69	0.75	0.000930			0.78			-148.0
						0.00121	0.00249		-0.09	-36.3	
0.65	10.0	16.56	0.61	0.86	0.001488			0.69			-184.2
						0.00203	0.00167		-0.08	-50.8	
0.55	8.5	16.34	0.52	1.02	0.002579			0.60			-235.0
						0.00270	0.00100		-0.01	-11.9	
0.54	8.2	16.31	0.50	1.05	0.002824			0.59			-246.9
						0.00296	0.00074		-0.01	-15.8	
0.52	8.0	16.27	0.49	1.08	0.003102			0.58			-262.7

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 9 (Longitude 73.193E and Latitude 33.554N)

Bottom Slope (So) = 0.0027
Discharge (Q) = 8.75m³/sec
Bottom Width (Bo) = 21.43m
Manning Constant (n) = 0.024
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n^*Q / Co^* S^{1/2}$
$n^*Q / Co^*S^{1/2}$ = 4.04
Hence, $AR^{2/3}$ = 4.04 .... (1)
Assume y_n = 0.37m
Area (A) = $(Bo + s^*y_n) * y_n$ = 8.00m²
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} * y_n$ = 22.26m
Hydraulic Radius (R) = Area/Perimeter = 0.359
$AR^{2/3}$ = 4.04 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.39m

Step 3: Calculation Table

Propose Weir of H = 1.00m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m²)	(m)	(m)	(m/s)				(m)			(m)
1	21.9	23.67	0.93	0.40	0.000102			1.01			0
						0.00016	0.00254		-0.20	-76.8	
0.8	17.5	23.22	0.75	0.50	0.000211			0.81			-76.8
						0.00038	0.00232		-0.19	-81.8	
0.6	13.0	22.77	0.57	0.67	0.000546			0.62			-158.6
						0.00077	0.00193		-0.09	-46.5	
0.5	10.8	22.55	0.48	0.81	0.000996			0.53			-205.1
						0.00120	0.00150		-0.04	-28.1	
0.45	9.7	22.44	0.43	0.90	0.001412			0.49			-233.2
						0.00156	0.00114		-0.02	-17.5	
0.43	9.2	22.38	0.41	0.95	0.001705			0.47			-250.7
						0.00189	0.00081		-0.02	-23.6	
0.4	8.7	22.32	0.39	1.01	0.002084			0.45			-274.3
						0.00218	0.00052		-0.01	-13.9	
0.39	8.4	22.30	0.38	1.04	0.002266			0.44			-288.2

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 10 (Longitude 73.179E and Latitude 33.548N)

Bottom Slope (So) = 0.0027
Discharge (Q) = 11.5m³/sec
Bottom Width (Bo) = 24.8m
Manning Constant (n) = 0.024
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n*Q / Co* S^{1/2}$
$n*Q / Co*S^{1/2}$ = 5.31
Hence, $AR^{2/3}$ = 5.31 .... (1)
Assume y_n = 0.399m
Area (A) = $(Bo + s*y_n) * y_n$ = 9.97m²
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} * y_n$ = 25.69m
Hydraulic Radius (R) = Area/Perimeter = 0.338
$AR^{2/3}$ = 5.31 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.42m

Step 3: Calculation Table

Propose Weir of H = 1.00m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m²)	(m)	(m)	(m/s)				(m)			(m)
1	25.3	27.04	0.94	0.45	0.000130			1.01			0
						0.00018	0.00252		-0.15	-57.8	
0.85	21.4	26.70	0.80	0.54	0.000222			0.86			-57.8
						0.00032	0.00238		-0.14	-60.1	
0.7	17.6	26.37	0.67	0.65	0.000421			0.72			-117.9
						0.00056	0.00214		-0.09	-43.0	
0.6	15.1	26.14	0.58	0.76	0.000701			0.63			-160.9
						0.00099	0.00171		-0.09	-50.7	
0.5	12.5	25.92	0.48	0.92	0.001280			0.54			-211.6
						0.00155	0.00115		-0.04	-34.5	
0.45	11.3	25.81	0.44	1.02	0.001814			0.50			-246.2
						0.00192	0.00078		-0.01	-14.4	
0.44	10.9	25.77	0.42	1.06	0.002030			0.49			-260.6
						0.00215	0.00055		-0.01	-19.9	
0.42	10.5	25.74	0.41	1.09	0.002280			0.48			-280.5

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 11 (Longitude 73.145E and Latitude 33.554N)

Bottom Slope (So) = 0.0040
Discharge (Q) = $12.11 m^3/sec$
Bottom Width (Bo) = 28.16m
Manning Constant (n) = 0.024
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n*Q / Co* S^{1/2}$
$n*Q / Co*S^{1/2}$ = 4.60
Hence, $AR^{2/3}$ = 4.60 .... (1)
Assume y_n = 0.339m
Area (A) = $(Bo + s*y_n) * y_n$ = $9.60 m^2$
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} * y_n$ = 28.92m
Hydraulic Radius (R) = Area/Perimeter = 0.332
$AR^{2/3}$ = 4.61 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.36m

Step 3: Calculation Table

Propose Weir of H = 1.25m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m^2)	(m)	(m)	(m/s)				(m)			(m)
1.25	36.0	30.96	1.16	0.34	0.000053			1.26			0
						0.00008	0.00392		-0.25	-63.0	
1	28.7	30.40	0.94	0.42	0.000111			1.01			-63.0
						0.00020	0.00380		-0.24	-63.9	
0.75	21.4	29.84	0.72	0.57	0.000287			0.77			-126.8
						0.00069	0.00331		-0.23	-69.3	
0.5	14.2	29.28	0.49	0.85	0.001098			0.54			-196.2
						0.00133	0.00267		-0.04	-15.4	
0.45	12.8	29.17	0.44	0.95	0.001556			0.50			-211.6
						0.00193	0.00207		-0.04	-18.2	
0.4	11.3	29.05	0.39	1.07	0.002300			0.46			-229.8
						0.00251	0.00149		-0.01	-9.2	
0.38	10.8	29.01	0.37	1.12	0.002726			0.44			-239.0
						0.00299	0.00101		-0.01	-12.5	
0.36	10.2	28.96	0.35	1.19	0.003261			0.43			-251.5

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 12 (Longitude 73.113E and Latitude 33.546N)

Bottom Slope (So) = 0.0027
Discharge (Q) = 12.47m3/sec
Bottom Width (Bo) = 24.75m
Manning Constant (n) = 0.027
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = n*Q / Co* $S^{1/2}$
n*Q / Co*$S^{1/2}$ = 6.48
Hence, $AR^{2/3}$ = 6.48 .... (1)
Assume y_n = 0.451m
Area (A) = (Bo + s*y_n) * y_n = 11.26m²
Perimeter (P) = Bo + 2 (1+s2)$^{1/2}$ * y_n = 25.76m
Hydraulic Radius (R) = Area/Perimeter = 0.437m
$AR^{2/3}$ = 6.49 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.47m

Step 3: Calculation Table

Propose Weir of H = 1.00m

Y	A	P	R	V	S_f	Avg. S_f	So-Avg. S_f	E	ΔE	Δx	X2
(m)	(m²)	(m)	(m)	(m/s)				(m)			(m)
1	25.3	26.99	0.94	0.49	0.000194			1.01			0
						0.00030	0.00240		-0.19	-80.3	
0.8	20.1	26.54	0.76	0.62	0.000405			0.82			-80.3
						0.00052	0.00218		-0.09	-43.0	
0.7	17.6	26.32	0.67	0.71	0.000629			0.73			-123.4
						0.00084	0.00186		-0.09	-48.7	
0.6	15.0	26.09	0.58	0.83	0.001047			0.64			-172.0
						0.00122	0.00148		-0.04	-29.2	
0.55	13.8	25.98	0.53	0.91	0.001396			0.59			-201.3
						0.00165	0.00105		-0.04	-39.3	
0.5	12.5	25.87	0.48	1.00	0.001913			0.55			-240.6
						0.00201	0.00069		-0.01	-17.2	
0.49	12.1	25.83	0.47	1.03	0.002116			0.54			-257.8
						0.00223	0.00047		-0.01	-24.5	
0.47	11.7	25.80	0.46	1.06	0.002347			0.53			-282.2

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Calculation at Selected Point 13 (Longitude 73.100E and Latitude 33.548N)

Bottom Slope (So) = 0.0023
Discharge (Q) = 19.37m³/sec
Bottom Width (Bo) = 33.23m
Manning Constant (n) = 0.032
Side Slopes (s) = 2H:1V

Step 1: Determination of Normal Depth, y_n

$AR^{2/3}$ = $n*Q / Co* S^{1/2}$
$n*Q / Co*S^{1/2}$ = 12.92
Hence, $AR^{2/3}$ = 12.92 .... (1)
Assume y_n = 0.571m
Area (A) = $(Bo + s*y_n) * y_n$ = 19.14m²
Perimeter (P) = $Bo + 2 (1+s2)^{1/2} * y_n$ = 34.51m
Hydraulic Radius (R) = Area/Perimeter = 0.555m
$AR^{2/3}$ = 12.92 closer to (1) above (ok)

Step 2: To determine the limit of depth (y) up to which water surface profiling is to be done:

The limiting value is 5% above y_n i.e. up to y = 0.60m

Step 3: Calculation Table

Propose Weir of H = 1.00m

Y (m)	A (m²)	P (m)	R (m)	V (m/s)	S_f	Avg. S_f	So-Avg. S_f	E (m)	ΔE	Δx	X2 (m)
1	33.7	35.47	0.95	0.57	0.000361			1.02			0
						0.00044	0.00186		-0.10	-51.5	
0.9	30.3	35.24	0.86	0.64	0.000511			0.92			-51.5
						0.00063	0.00167		-0.09	-56.6	
0.8	26.9	35.02	0.77	0.72	0.000754			0.83			-108.1
						0.00084	0.00146		-0.05	-31.8	
0.75	25.2	34.91	0.72	0.77	0.000934			0.78			-139.9
						0.00105	0.00125		-0.05	-36.5	
0.7	23.5	34.80	0.68	0.82	0.001173			0.73			-176.4
						0.00134	0.00096		-0.04	-46.1	
0.65	21.8	34.68	0.63	0.89	0.001499			0.69			-222.5
						0.00160	0.00070		-0.02	-31.1	
0.63	21.0	34.63	0.61	0.92	0.001707			0.67			-253.6
						0.00183	0.00047		-0.02	-45.2	
0.6	20.1	34.57	0.58	0.96	0.001954			0.65			-298.8

Note: The formula of All above calculated perimeter is shown in section 3.9. Here x2 is the backwater length

Annexure E

Imaginary of Site Survey Conducted for Research

Annexure F

Verification of Discharge Value

Station/ Sites	Area (sq. km)	Calculation	Q (cumecs)
Chirah	352.58		6.45
1.	10.93	Q1 = {(10.93/352.58) x 6.45} + 6.45	6.65
2.	8.68	Q2 = {(8.68/363.52) x 6.65} + 6.65	6.81
3.	3.13	Q3 = {(3.13/375.33) x 6.81} + 6.81	6.87
4.	37.29	Q4 = {(37.29/412.62) x 6.87} + 6.87	7.54
5.	14.67	Q5 = {(14.67/427.29) x 7.54} + 7.54	7.80
6.	8.80	Q6 = {(8.80/436.09) x 7.80} + 7.80	7.96
7.	6.68	Q7 = {(6.68/442.78) x 7.96} + 7.96	8.08
8.	30.56	Q8 = {(30.56/473.32) x 8.08} + 8.08	8.63
9.	4.71	Q9 = {(4.71/478.02) x 8.63} + 8.63	8.72
10.	4.80	Q10 = ({(4.80/482.84) x 8.72} + 8.72) + 2.66	11.47
11.	25.65	Q11 = {(27.20/517.40) x 11.47} + 11.47	12.08
12.	15.06	Q12 = {(15.06/532.4) x 12.08} + 12.08	12.43
13.	10.02	Q13 = ({(10.02/542.4) x 12.43 + 12.43) + 6.6	19.32
Rawalpindi	2.073	Q = {(2.073/546.47) x 19.34} + 19.34	19.39

Note: Catchment area between two points is calculated in ArcGIS.

The calculated value of discharge at Rawalpindi station is 19.39cumecs which is almost equal to value of discharge known (19.40 cumecs) at Rawalpindi station which shows that calculated value of discharge is accurate.