ASSESSMENT OF HYDRO POWER POTENTIAL IN AFGHANISTAN, USING ARCGIS AND REMOTE SENSING TOOLS

A DISSERTATION

Submitted In partial fulfilment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

ALTERNATE HYDRO ENERGY SYSTEMS

by

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JUNE, 2019

CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation report entitled, "**Assessment of Hydropower Potential in Afghanistan, Using ArcGIS and Remote Sensing Tools**", being submitted in partial fulfilment of the requirements for the award of degree of **Master of Technology** in **"Alternate Hydro Energy Systems"** submitted to the **Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee**, is an authentic record of my own work carried out during a period from May 2018 to June 2019 under the supervision of **Dr. M. K. SINGHAL**, Associate Professor, **Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, (India).**

The matter presented in this dissertation has not been submitted by me for the award of any other degree of this or any other institution.

(AHMAD ZUBAIR AHMADI)

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Discharge and head are the fundamental parameters for hydropower potential assessment. The potential site should have good combination of these two parameters. In Afghanistan there are many sites which have best combination of these two parameters but still not explored for hydro projects. These sites are mostly located in hilly and mountainous regions. About 2/3rd of total area of Afghanistan is covered by high mountains with sharp slope and forest.

In this study, the assessment of hydropower potential on Farah River Basin (FRB) of Afghanistan has been carried out by using ArcGIS and SWAT model. The hydropower potential is derived by two main parameters: head and discharge. Head is calculated for the river by using Digital Elevation Model (DEM), slope map and contour map. Thirty nine sites for hydro potential were identified within 22000 km^2 watershed area of the river. The discharge of river is calculated by Soil and Water Assessment Tool (SWAT). The watershed area is divided into 3 sub basins and discharges are calculated in each subbasin outlet. The 75% design discharge calculated from flow duration curve organized by the average discharges computed through model and including 10% deduction of flow for environmental perspective are 14.3 cumecs, 3.97 cumecs and 6.11 cumecs for subbasin 1, 2 and 3 respectively. The total hydropower potential calculated is approx 66.036 MW for the Farah River Basin (FRB).

The hydropower assessment by using ArcGIS, Hydrological model and remote sensing tools in integration is not only cost effective but also less time-consuming. It shows the way to possibly shown the catchment characteristics, watersheds and provisional location for hydropower plants. Moreover, the overall hydropower potential of Afghanistan are assessed, including the installed hydel projects, under construction hydel project and planed hydel projects in next five years. In the meantime the assessment water resources in different river regions of Afghanistan studies are carried out.

ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude and indebtedness to my elite supervisor, **Dr. M. K. Singhal,** Associate Professor, **Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee** for being helpful and a great source of inspiration. I am thankful to them for their persistent interest, constant encouragement, vigilant supervision and critical evaluation. There encouraging attitude have always been a source of inspiration for me. There helping nature, invaluable suggestions and scholastic guidance are culminated in the form of present work.

I express my deep and sincere gratitude to **Dr. S. K. Singal,** Head, **Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee** for the motivation and facilities during the work of my dissertation. Similarly, I thank **Dr. M. P. Sharma,** former Head, **Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee** for inspiration and facilitating the supportive environment during his tenure.

I am also thankful to my seniors and my friends for their help, support and constant discussion throughout the report.

Date: /Jun/2019 (**AHMAD ZUBAIR AHMADI**)

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ABBREVIATIONS

SHP	Small Hydro Power
HRB	Helmand River Basin
FRB	Farah River Basin
RS	Remote Sensing
GIS	Geographical Information System
DABS	Da Afghanistan Breshna Sherkat
NEPS	North East Power System
SEPS	South East Power System
SWAT	Soil and Water Assessment Tool
DEM	Digital Elevation Model
DTM	Digital Terrain Model
SRTM	Shuttle Radar Topographic Mission
USGS	United States Geological Survey
ESRI	Environmental System Research Institute
LULC	Land Use Land Cover
TIN	Triangulated Irregular Network
Cumec	Cubic meter per second
m	Meters
m^2	Square Meter
km^2	Kilometer Square
ϱ	Density
MW	MegaWatt
GW	GigaWatt
KW	KiloWatt

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Afghanistan is dry, mountainous and landlocked country located which share the border with Pakistan in the southeast, Iran in the west, Turkmenistan Tajikistan and Uzbekistan in the north and China in the far northeast. The total area of the country is 650000 square kilometers and most of it covered by the high mountain range of Hindu Kush, which experience very cold weather with snow in the winters. The north part of the country consists of fertile plains which is very cold in the winter, whilst the south-west part is consisting of deserts, which is very hot in the summers.

According to the identified energy potential, Afghanistan currently has around 80 million barrels of proven oil located in the Amu Darya Basin. In addition to this, the total discovered natural gas is 75 billion cubic meters, with undiscovered estimated potential of more than 440 billion cubic meters m^3. Coal reserves are mainly located in the northwest of Bamyan province of Afghanistan with 73 million tons amount. The coal is nominated as the major sources of energy for domestic thermal power generation, like Hajigak and Aynak thermal power plants. The renewable energy sources (RES) are expected to be the largest involvement in the Afghanistan’s energy potential. The Solar system potential has the largest contribution in Afghanistan’s energy generation followed by wind and hydro. The energy generated by Solar, Wind and Hydro are 220 MW, 67 MW and 23 MW respectively.[9]

Kabul as one of largest city with around 70 percent of the population in benefiting from nearly uninterrupted supply of electricity, while around three quarters (67-75) of the country population are still cut off from the power grids[1].

Afghanistan is struggling with an extremely low amount of rural electrification. While 75 percent of the Afghan population live in the rural areas and have involvement of 67 percent to the gross domestic product, these rural areas are enjoying only the 10 percent of the distributed electricity within the country[1].

Afghanistan is still suffering low level of power transmission network in remote areas, which needs to be covered in the rural area in order for the country to enjoy the better energy. As per the report of Ministry of Energy and Water of Afghanistan published on March 2015, the number of afghan's customer connected to the power transmission network was 1,176,030. In recently years, there has been increase approximately an 11 percent per year in electricity grid connections[9]. The Afghan government's power extension policy require a huge increase in the length of the grid network lines inside the country from 2261 km to 6907 km to significantly increase the number of connection in the grid[1].

As per the report published by Ministry of Water and Energy of Afghanistan in 2016, about 78 % of total consumed electricity power in Afghanistan was imported from neighboring countries like: Tajikistan, Turkmenistan, Uzbekistan and Iran as shown in Fig. 1.1[1].

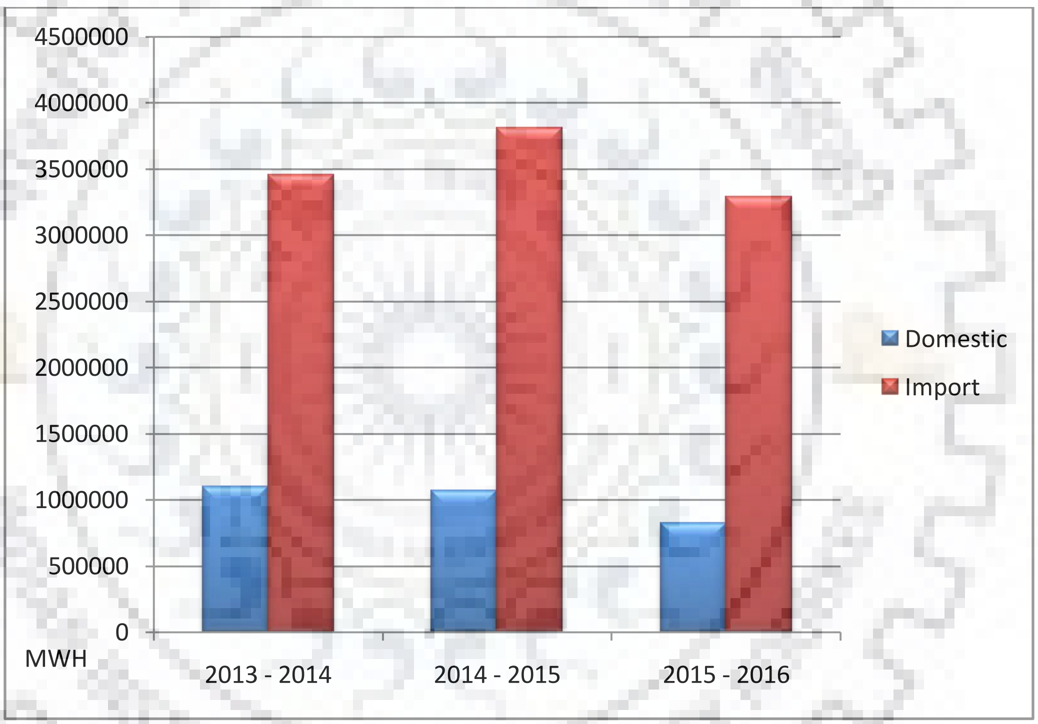


Fig. 1.1: Internal generation and Import power[1]

In the recent decade, serious transformation in Afghanistan's power sector has occurred.

Afghanistan government attempt to solve the problem of the power grid distribution and supply within the country, and the government is also working and prioritized to establishing countrywide electricity transmission lines by connecting isolated grids within a single combined power network. Nine isolated electric grids were reported in 2006, while now only three isolated gird are remain:[1]

- North East Power System(NEPS), which is (with Kabul as the major load Centre) consisting of a grid connecting 17 load centers including (Kabul, Mazar-i-Sharif, Jalalabad, etc.) with Uzbekistan and Tajikistan importing power lines (220 kV, 110 kV, 35 kV);
- South East Power System(SEPS) is consisting of Kandahar and Helmand power system, which are linked to Kajaki hydropower plant (HPP) (110 kV);
- West Power System (with Herat as the major load Centre), which is divide into:
    - Herat Power System, connecting the Herat zone with Iran and Turkmenistan importing power lines (132 kV, 110 kV);
    - Turkmenistan Power System, connecting Herat, Faryab, Jawozjan, Sar-e-Pul and Andkhoy power network system (110 kV).

The next step is connecting the three major systems to establish a centralized national power grid (an electricity ring) via the following transmission lines:[1]

- 500 kV line from Turkmenistan to West Kabul;
- 500 kV line from West Kabul to Kandahar (NEPS-SEPS interconnector);
- 500 kV line from Andkhoy to Heart;
- 220 kV line from Herat to Kandahar.

The ongoing and upcoming decades (2015-2025), are named as Afghanistan's 'Transformation Decade' which will directly affect the economic development According to Afghanistan's power sector Master Plan (from year 2012 to 2032), it is expected that the amount of power consumption will increase to 3500 MW by 2032. The peak power demand is predicting to be 4300 MW by year 2032[1]. As per the draft of Afghanistan's National Renewable Energy Policy pointed that the aim of Ministry of Water and Energy would like to push the target level to 5000-6000 MW by 2032[1]. Meanwhile Afghanistan currently generate around 300 MW of the total electricity from its own hydropower plants. The generation amount will need to be increased 10 times by year 2020 and 20 times by year 2032 to achieve the proposed target[4].

Afghanistan's different power sectors have been developing over 5000 Renewable Energy System (RES) projects, which either of them have been completed or are ongoing. These 5000 projects mostly involves of Micro Hydro Power Plants HPPs and solar system panels projects, with the total amount of only 50 MW energy capacities. Thus, many energy expert and government officials have doubt on the ability of energy sector development agencies to achieve the targeted energy capacities.

1.2 HYDROPOWER IN AFGHANISTAN

Hydropower is named as a clean, green, renewable and reliable energy source that could save the environment from dangerous co_2 gas. It is one of the most important renewable sources for generation of electricity. It is found as renewable in nature, unlike wind, supply variability within shorter time period is less and most importantly with hydro is that the greenhouse gas (GHG) emission is very low. Hydro power is derived from the falling of water, either from rivers or streams flowing downward along the river path due to force of gravity. The energy associated with this flowing water is known as kinetic energy that is achieved through the friction of flown water among the rocks and the sediment in the river beds. Releasing the kinetic energy from the flowing water is using for driving turbine to generates hydropower [20].

The hydropower has been practiced in small scale since pre historic times. With the technological development in enhance with the conversion efficiency, the large scale use of hydropower has been increased due to it is economic feasibility. However, the growth of hydropower has not been proportional to its potentiality. Although huge potential of harnessing energy are achieving from water resources, while its contribution to overall energy mix is still low. This is obvious from some of the recent statistics. The combined contribution of hydropower has been estimated as 6.15% of the total world energy mix. The overall electricity used from hydro so far is only 25% of the economically practicable potential with its application mostly in developed country. Meanwhile Afghanistan has the capacity of generation 23,000 MW electricity through hydropower plants in the country as shown in Fig. 1.2 [9].

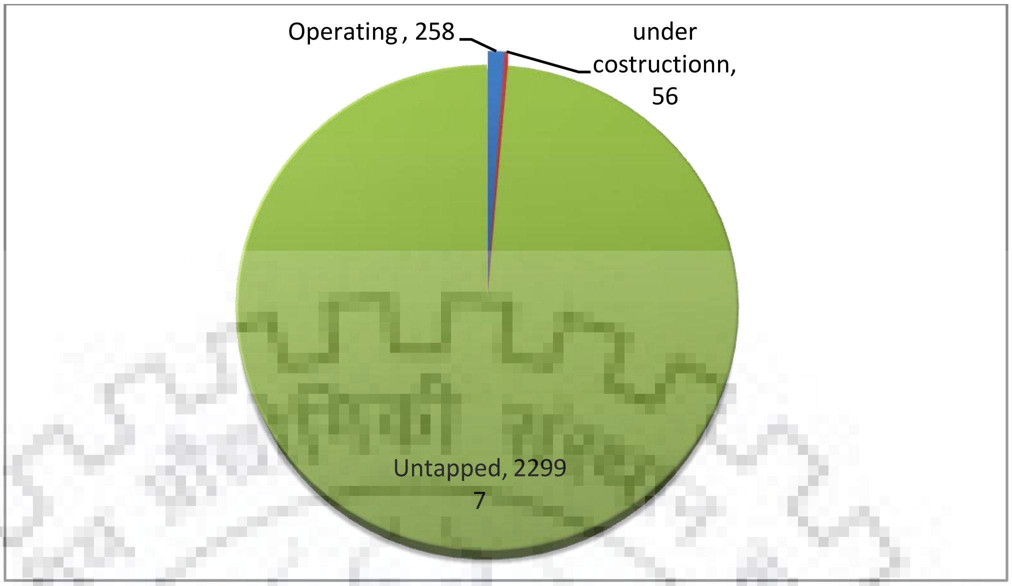


Fig. 1.2: Total capacity of Afghanistan in hydro [9]

Afghan government has set a tremendous goal to achieve 95 percent energy out of the total consumption from renewable energy system according to its new energy policy. To achieve this target the government is planning to utilize this amount of energy from 70 different location and energy source in the country like RES potential. The theoretical estimated potential energy from Solar, Wind, Hydro, Biomass and Geothermal are 222,000 MW, 67,000 MW, 23000 MW (600 MW from small hydro mainly from micro and mini hydropower), 4000 MW, and 4100 MW respectively.

Hydropower project are generally categorized in two segments i.e. small and large hydro projects.

1.2.1 Small Hydropower

There is a general tendency all over the world to define small hydropower by the power output. Different countries have different norms for categorizing hydropower station, the limit ranges are between 3 to 50 MW, as given in Table 1.1.

Table 1.1: World Definition of SHP [9]

Country	Capacity (MW)
Afghanistan	**≤3**
UK	≤5
Sweden	≤15
Australia	≤20
India	≤25
China	≤25
New Zealand	≤50

In Afghanistan hydro project station up to 3 MW capacities have been categorized as small hydro power project.

1.2.2 Hydropower Project Classification in Afghanistan

Hydropower projects are generally categorized in two segments i.e. small and large hydro projects. In Afghanistan hydro project station up to 3 MW capacities have been categorized as small hydro power project. While Ministry of Water and Energy of Afghanistan is responsible for large hydro project as well as the small hydro projects [9]

Further classification of hydropower project in Afghanistan is on the basis of capacity as shown in Table 1.2.

Table1.2: Hydropower Classification on the Basis of Capacity [9]

Type	Unit rating
Pico hydro	Up to 1 KW
Micro hydro	2 KW to 100 KW
Mini hydro	101 KW to 1000 KW
Small hydro	1 MW to 3 MW
Medium & Large hydro	More than 3 MW

1.2.3 Existing Hydropower Plants

Currently Afghanistan has about 304 MW installed capacity; while about 258 MW are operating and out of total installed capacity small hydro power share is about 45 MW from operating capacity. The Theoretical hydropower potential is estimated as about 23 MW capacities (large and small hydro power). The hydro power projects are mostly located in the mountainous regions of North and South-east of Afghanistan like Badakshan, Takhar, Kunar, Paktia, etc provinces [9].

Table 1.3: All Installed Small and Large Hydro Plant [9]

S/N	Name of	Province	Units	Capacity(MW)	Total Power
1	Naghlu PP	Kabul	4	25	100MW
2	Mahipar	Kabul	3	22	66MW
3	Salma	Herat	3	14	42 MW
4	Kajaki	Helmand	3	2x16.5 &1x18.5	51.5MW
5	Sarobi PP	Nangarhar	2	11.5	23 MW
6	Dronta PP	Nangarhar	3	3	9 MW
7	Asad Abad	Kunar	2	0.35	0.7MW
8	Chack PP	Wardak	3	1.1	3.3MW
9	Gershk PP	Helmand	2	1.5	3MW
10	Pulkhumri	Baghlan	3	3	9MW
11	Estalif PP	Kabul	2	0.114	0.288MW
12	Parwan pp	Parwan	3	0.8	2.4MW
13	JabalSarag	Parwan	4	2x0.5 & 2x0.75	2.5MW
14	Baharak	Panjsher	2	0.125	0.25MW
15	Ghor Band	Parwan	3	0.125	0.375MW
16	Faizabad	Badkhshan	2	0.125	0.25MW
17	BabaiWali	Kandahar	1	0.25	0.25MW
18	Chaloarcha	Kunduz	1	0.08	0.08MW
19	Geram	Badkhashn	1	0.145	0.145MW
20	Cheta	Paktika	1	0.125	0.125MW
21	Naland	Daikundi	1	0.135	0.135MW
22	Farghambol	Paktia	2	1x0.18 & 1x0.1	0.19MW
23	Sangab	Bamyan	1	0.135	0.135MW
24	Wersag	Bamyan	1	0.25	0.25MW
Total installed capacities of plants					**295.248 MW**

1.2.4 Planned and Under Construction Projects

Currently most of the power generation capabilities in the country are reservoir or dam storage type HPPs. However, low river flows in the winter and fall seasons time affect the level of electricity production. Thus, only medium and large HPPs could have enough of an impact to lead country to self-sufficient energy. In addition to the obvious advantages of having significant hydropower generation capacity, large HPPs are also have the abilities of accumulating and storing enough water in summer to produce electricity during winter. Unfortunately, four out of five rivers in Afghanistan are trans-boundary, which are located with the borders of neighbors' country. Usually upstream countries accumulating water without any coordination regulation which may impact the availability of water for downstream countries' agricultural and electricity needs.

Table 1.4 : Planed and Under Construction Hydro Projects for Next 4 Years[9]

S.No	Project Name	River	Province	Capacity (MW)	Commencement date	Annual energy (GWh)	Estimated cost (m US$)
1	Baghdara	Panshir	Kapisa/Parwan	210	2021	968	600
2	Surobi 2	Kabul	Laghman	180	2021	891	700
3	Kunar A	Kunar	Kunar	789	2022	4772	2000
4	Kakaji 2	Helmand	Helmand	100	2021	493	300
5	Kukcha	Kukcha	Badakhshan	445	2022	2238	1400
6	Gulbahar	Panshir	Panshir/Baghlan	120	2021	594	500
7	Capar	Panshir	Panshir	116	2021	574	450
8	Kama	Kunar	Nangarhar	45	2021	223	180
9	Kunar B	Kunar	Kunar	300	2021	1485	600
10	Olam bagh	Helmand	Uruzgan	90	2021	444	400
11	Kilagal		Baghlan	60	2021	297	250
12	Upper Amu	Amu Daria	Badakhshan	1000	2023	4955	2500
13	Dashttijum	Pyanj	Kunduz	4000	2023	19819	8000
Total Generation					**3455 MW**		

Lack of water sharing policies within the Central Asian countries, the construction of large HHPs will almost likely lead to conflicts with neighboring countries**[1]**.

The upper side of Amu darya and Dashtijum HHPs on the Pyanj river are largest energy contribution in hydropower projects with highest impact on water energy. These projects are located within Afghanistan and Central Asian Countries. The Dashtijum HHP is placed around 280 km away from Tajik capital in southeast of Tajik on the pyanj River. Its planned to use for generation of electricity and irrigation for agriculture lands required water reservoir facility. This project is not only too expensive for Afghanistan which is cost around 3 billion US, but it could also lead Afghanistan to conflict with downstream countries like Uzbekistan and Turkmenistan. Even Pyainj River is not flowing directly to downstream countries it is just a tributary of Amu Darya River. The share and quotas of Amu Darya River allocated for Uzbekistan, Turkmenistan, Kyrgyzstan and Tajikistan, 48.2, 35.8, 0.6 and 15.6 percent respectively[1]. Afghanistan has never went to claim its water portion percent from Amu Darya Basin or engaged in projects that could critically endanger it's relationship with the neighbors.

1.3 WATER RESOURCE OF AFGHANISTAN

Afghanistan is rich in water resources mainly due to the availability of the high mountains series such as Hindokush, Pamir and Baba which are mostly covered by snow. The Hindukhush mountains series at height of above 2000 m are the origin of over 80 percent of country's rivers. These mountains work as natural storage of water in the form of snow during winter and thus support permanent flow in all rivers by melting of snow during summer[10]. The river basins of Afghanistan are shown in Fig. 1.3.

Fig. 1.3: Basin and Watershed of Afghanistan. [10]

Afghanistan is not independence for its water due to landlocked and shares of four out of five Rivers with the neighboring countries. The four major rivers origin is start in Afghanistan by melting snow at elevation of above 2000 m, from the Hindu Kush mountain, (constitutes the volume of Afghanistan water resource and key importance to the country as a natural water storage) then flow into the neighboring countries, whilst very small portion only one third of this huge water being using in Afghanistan.[10]

Afghanistan water flow is divided into five river basins:

a): Amu Darya river basin
b): Helmand river basin
c): Kabul river basin
d): Harirod river basin
e): Northern river basin.

1.3.1 Amu Darya River Basin

The Amu Darya river basin gets origin from High Mountain of Wakhan corridor located in the northeast of country, while that area is also called as Pamir River. It flows toward west and forming most of the border with Union of Soviet Socialist Republics (USSR). Many large tributaries of Amu Darya are enters from north side. Where Kokcha and Kunduz Rivers are major tributaries from Afghanistan. Also during monsoon season the huge flood, the Shirin Tagao, Sarepul, Balkh, and Kholem Rivers are may also add as tributaries to the flow of the Amu Darya. Finally Amu Darya empties into Aral Sea.

1.3.2 Kabul River Basin

The Kabul River Basin flows eastward from the neighborhood of Kabul city and then goes into to Pakistan where finally enters to Indus River. The major tributary of Kabul River is: Panjshir River that enters near to sarobi to Kabul River, while from south is Logar River. Kunar River is the major tributary which gets start from the mountains of Pakistan and enters to Kabul near Jalalabad. The last tributary is Laghman River enters in Kabul near Laghman city.

1.3.3 Helmand River Basin

The Helmand River Basin gets start just near Kabul city mainly from southern slopes of the Hindu Kush Mountain. It flows toward southwest of country until it come to an end in the Human Sistan Basin on the Iranian border where it is lost due to evaporation. The major tributary to Helmand is Arghandab River that drains most of the places in the southeastern Afghanistan. Tirin River is a tributary to HRB from east. Musa Qala, Kaj and Panjao are the tributary from west. Most the mentioned flows are originates from snow melting in the high regain of mountain and all the tributaries have permanent flow during the year expect Musa Qala and Kaj rivers.

1.3.4 Harirod River Basin

The Harirod River Basin originate from high central Plateau and start flows toward west of country forward to the Iran border. Its changes their direction toward north and form border among Afghanistan and Iran. The only major tributary of Harirod River is Kowgon River where, for long distance it travel parallel to Hari River and finally joining near Marwa. In the north it forms border with Iran and at the end disappears in the desert wastes of Turkmen

1.3.5 Northern River Basin

The Northern River Basin is consisting of Murghab in the northwest. It tributary is Kushka and joined the Morghab River in Turkmenistan. The adraskand and farah river are tributary from the west and flows parallel to each other and finally enters to Human Sistan Basin. The Kash river located between the Helmand and Farah rivers in the south and finally same as the two previous tributaries disappear in Hamun. The many other tributaries to the Indus River along eastern border like Matun River.

Two common things that most of the rivers in Afghanistan have it: from origin all have steep gradients but fairly float in the lower reaches. Secondly due to heavy runoff during snow melt and rain transporting huge silts with it.

1.4 CONVENTIONAL METHOD FOR HYDROPOWER POTENTIAL ASSESSMENT

Historically developers were used absorbed discharge data for a specific location to find the potential of river and also for planning purposes. However, in most cases, of the last decides records of water resources only it was available for particular locations. Questions and doubt was raise about the accuracy and reliability of the future assessment based on the specific observation data from past for a location due to involved difficulty of the Hydrological Phenomena. This inaccurate information may have some penalty of cost on regard of miss records of water resources. First thing could be listed as main case of poor hydropower is underestimation, even if the real accessibility is encouraging. Second, assessment based on study for selected areas may also miss more hydro potential events at other locations, which may also direct the developer to wrong plans. Third, the huge collections of recorded data in wide spaces are even not cheaper but also its time taking process. These listed barriers seem to be the slow development of hydropower, especially in the Hindu Kush mountain region, central and southeast of the Afghanistan. Even if the preliminary interior selection of sites relies on hydro potential of location for available geographic as well as for hydrological data.

The onsite work will be allocated, that could be extremely trim down the costs and further analysis and investigation. After completion of investigation phase which implemented in the site will allow the decision maker with the proper basis for accomplishing the final alternative, where the hydropower development will having slightest impact on other activities, existing infrastructure and the environment.

After looking these entire thoughts, if we see to the increasing power demand only less of the suggestions are actually carried out due to all these difficulties and conventional methods. It is therefore recommended to replace the conventional methods with more advanced particular and accurate ArcGIS and remote sensing technology. Also the materials like maps and spatial details provided by the Afghanistan Government Agencies are not updated for many years. Moreover the details which are provided by these Agencies, maps are not looking good enough in quality to carry out spatial analysis and changes happening and terrain causes lots of problems in many cases. Thus, for the above mentioned declaration, is encourage to made or build the database to carry out the analysis and assessment by using ArcGIS and Remote Sensing Tools, which might give more near accurate results.

1.5 ORGANIZATION OF THE THESIS

In the first chapter, general introduction about Afghanistan, hydropower scenario of country along with water resources information is given. Also works are specified and followed by organization of dissertation which will help in navigation through the work. Literature review relating to the work done is given in the second chapter. Third chapter deals with introduction to SWAT model and a brief description of geographic information system (GIS). The fourth chapter presents the study area and the data used for the project. The fifth chapter involves the methodology adopted for model making. Hence calculation of the discharge and model result include in chapter six. The seventh chapter deals with the Conclusion and Recommendations.

CHAPTER 2

LITERATURE REVIEW

The present literature review has been carried out for Farah River Basin to find the hydropower potential and identifying suitable sites for hydro power projects among the basin with the help of SWAT Hydrological modeling, ArcGIS and remote sensing tools.

Carroll *et al*. [2] Observed the prospect of using GIS tools to identify hydropower potential of small scale hydro systems (less than 1 MW) sites in all 50 states in the USA. The effectiveness of such GIS developed dataset was expected for several stakeholders including US Department of Energy, private and public power users and researchers. GIS based resource assessment studies have also initiated in under-developed and developing regions.

Coskun *et al*. [3] Used the remote sensing with satellite images to get the simulated drainage network and prepared a regression based hydrologic model to assume the hydropower potential within the Solaki basin watershed placed in the eastern Black Sea, Turkey. Furthermore, the hydro potential of Solakli Watershed is determined.

To determine the hydroelectric power potential in an extremely poor gauged basin, basin boundary and region, minimum and maximum elevation, slope, information of the watershed are achieved from the Digital Elevation Model (DEM) by using Remote Sensing (RS) and Geographical Information Systems (GIS) tools. A regression model was proposed for the entire basin, by using topographic data like area, mean basin elevation and limited point observations of rain data.

Kusre *et al.* [7] Did assessment of hydropower potential on Umkhen area watershed and used eighteen weather and discharge data which were recorded during the year 1988-1990 for calibration of the SWAT model. Therefore, SWAT model is used to estimate discharges at the identified sites and employed a flow-duration curve (FDC) to provide the percentage of time the stream flow is exceeded over a historical period for a particular river basin.

Assessment of hydropower potential is a requirement for identification of sites and determinations of flows at selected sites for hydro power plants. For such above identification and determination the Digital Elevation Model (DEM) and stream network were used. DEM was used for calculation of head difference and discharge was calculated with help of SWAT2000.

Larentis. *et al.* [8] Showed the approach for extensive survey of hydropower potential sites whether need to be applied in the begging phase of hydroelectric development planning.

The study present the procedures and chain by working with remote sensing and regional stream flow data which was computerized within a GIS based computational program to recognize the hydropower sites on a selected areas. Furthermore, the program allows to recognizing more hydro potential sites along the drainage network that would provide different types of dam and powerhouse layouts, which could be two types' projects: run of river and storage type projects.

The initial results from the application in brazil have been shown hydro spot's limitation and potentialities is giving support to the short and long term planning of the electricity sector in hydropower developed basin in there.

Pandey *et al*. [13] Assessed the hydropower potential of Mat River basin which is located in southern Mizoram, India, by employing a digital elevation model (DEM), Hydrological model and Stream network data in the GIS framework within a SWAT Model. The hydrological model with spatial analysis technologies was developed to assess water availability in the Mat River basin. The obtained result from satellite data, ArcGIS tools and SWAT (Soil and Water Assessment Tool) model were utilized to find the hydropower potential in the Mat river basin. Beside of the hydropower potential assessment, thirty three sites have been identified for construction of hydropower plants.

Rasooli, [16] Used GIS tools for Kabul River Basin (KRB) to present the Hydrology or drainage network, irrigation, population, climate and surface pattern other necessary features of the basin in order to invest and implement infrastructure projects. Digital Elevation Model (DEM) and GIS tools were used to extract watershed properties which involve: area, slope length, stream work density, delineating stream and watersheds etc. while usually this was (and still is) being done manually by using topographic/contour maps.

In this study the handling of DEM to delineate watersheds is referred to as terrain pre-processing. Meanwhile, it created the necessary thematic maps, base maps and other detailed maps for illustrating basin characteristics and features GIS Based.

Rostamian *et al*. [18] Used the SWAT model to calculate Runoff and sediment in two mountainous catchments in central Iran. The soil and water assessment tool was used to estimate runoff and sediment in the Beheshtabad and Vanak watershed. The calibration and validation of model output was employed by SWAT-CUP software. Runoff and sediment data from four hydrometric stations in each basin were used for calibration and validation.

Rezaeeha, [17] Shown through an experiments that the possibilities to integrate the remote sensing (RS) and geographic information system (GIS) tools, by employing combination of digital elevation model (DEM) with satellite images and other detailed information leading to an informative Atlas for identifying the hydropower potential assessment. The goal is to provide a methodology to make this information available interdisciplinary for hydro power potential assessment, and developed a common benefits and advantages to the organizations.

In contrast with the conventional methods, GIS tools are found useful and very cost effective for the identifications of proper sites, environmental planning and ranking of the hydropower projects.

Schmaltz *et al*. [23] Employed the SWAT model for modeling hydrological processes in mesoscale lowland river catchments in northern Germany. The Flat topography, low hydraulic gradients, shallow groundwater and high potential for water retention in peatland and lakes are assessed and considered by SWAT model. The dominating hydrological processes were found to be mainly controlled by ground dynamics and storage, drainage, wetlands and ponds.

Tarife. *et al.* [25] used Geographical Information System (GIS) tools for recognizing and classifying the theoretical hydropower potential sites in Misamis Occidental, which is located in a province in the of Northern region of Mindanao in the Philippines.

GIS based hydrological modeling was used with the input datasets which include Topographical, Meteorological datasets, Digital Elevation Model (DEM), weather data, soil map and land use land cover to find the potential sites. The result obtained from model after simulation, shown the total 62% of the potential sites are classified as micro (5KW to 100KW) hydropower and the remained 38% are classified as Pico (less than 5KW) hydropower.

The study was preformed to provide information for the policy makers, public authorities and investors in the energy sector, help them to optimize the available resources for selection of suitable sites for small hydropower plants with high power potential.

Weiss and Foah, [26] Used three different methods to find the Hydropower potential of a basin or river. (a) The annual precipitation is used as a basic parameter for Area-Potential method to calculate the hydro potential. (b) The Line-Potential method is introduced for calculation of hydropower potential in river by using mean annual discharge and the difference in elevation between start and end of each reach. (c) The third method is Utilizable-Potential method, for calculation of hydropower potential. This method is depending on function of utilizable volume of water, turbine and generator efficiency and net difference in head.

Yevalla. ***et al*****.** [27] Did assessment to find hydropower potential sites, for development of hydroelectricity plants in Nkam Division and environ, which located in Cameroon. The Geographical Information System (GIS), Remote Sensing (RS) techniques, and hydrological models (HEC-HMS) were used in this assessment. A hydrological model (HEC-HMS) was used to calculate the discharge with the given inputs as follows: Digital Elevation Models (DEMs), digital soil and land use maps parameter, for the basin.

The HEC-HMS model calibration and validation were done by using obtained rainfall data from localized Yabassi weather station and discharge values from Yabassi gauge station. The surfaces with 40% hilly landscape with the elevations range between 10 to 30 m, were identified by hypsometric curve, which is favoring for development of small scale hydro systems.

RET Screen software used for estimation of hydropower potential and given the net present value greater than zero, which shows the project is very practical and profitable. Beside of economic issue the project will also do excellent job that will reduce huge amount of CO_2 from atmosphere.

2.1 GAPS IDENTIFIED

1. Farah River Basin is a poorly gauged basin. The discharge and meteorological data of the basin is available only for some years.
2. Study based on hydrological models has not been carried out for the Farah River region in Farah province of Afghanistan.
3. The conventional method of hydropower assessment requires considerable time and effort. So computational tool can be utilized to assess the potential.

2.2 OBJECTIVE OF THE STUDY

1. To delineate watershed of Farah River by using ArcGIS.
2. To calculate discharge of Farah River through SWAT model.
3. To identify sites for hydropower plant projects (HPP) for the Farah River.
4. To calculate the Head of River by using of Digital Elevation Model (DEM).
5. To calculate the hydropower potential by using ArcGIS and remote sensing tools in Farah River Basin.

CHAPTER 3
ARCGIS AND SWAT HYDROLOGICAL MODELING

3.1. INTRODUCTION

Recent development in the computer technology has been offered many advantages in the water resources field. One of such a tool is the Geographic Information System (GIS) with different applications. GIS is also used in conjunction with a variety of hydrologic applications for delineation of drainage pattern, catchment area and assessment of hydropower potential in the river basins.

In the present study, ArcGIS and Remote Sensing Tools are used for assessment and identifying potential sites for hydropower plant developments in the basin's catchment area. The river discharge has been calculated with help of SWAT model by using daily rainfall, soil map, DEM image and land use land cover data. SRTM DEM data is used to calculate the head by help of focal statistical analysis tool in ArcGIS.

The potential power output can be calculated with the water density, head, discharge and gravitational force, and then through needed integration the levels of output power at each site were pointed out. Up to this stage it is using just for initial screening purposes. Further it needed to do the feasibility study deeply to develop the sites for hydropower plant. By identification of potential sites and then turning the place to hydro power project it can saves the atmosphere of earth from hazard of fossil fuel production, while currently the climate changing in the world is eager with it. The key for finding sites for potential establishment of hydropower plant development are knowledge of the topographical setting alongside with the stream network within a river catchment.

3.2 REMOTE SENSING TECHNIQUES

Remote Sensing is technique of gaining information about an object without making any physical contact with the object and accordingly to the different observation with onsite, particularly from the earth. Remote Sensing is used in various fields, such as geography, land surveying, hydrology, meteorology, ecology and etc. it also may used in intelligence, military, economics, developments and civilization applications.[19]

Remote sensing also can be defined as the science of getting information about objects or areas from space, generally from aircraft or satellites. The data is obtaining by sensor of Remote Sensing that is mounted on satellites or aircraft, after reflection from earth.

Huge hydropower potential in world, yet to be discovered is located at inaccessible areas like mountainous region. However, due to complicated and difficult topography profile it's become as a challenge for development of hydro potentials. Presents application of remote sensing integrated with the ArcGIS software is using for identification and assessment of water resources and also for finding and selection of proper site for hydropower projects along the rivers or basins.

Satellite image can be classified to different objects that are modeled as the commission of gather based on the intensity of R-G-B values of pixels. The obtained results are presented and compared with topographic sheets surveyed data. Remote sensing data is use to provides a scientific method for identification and assessment of hydropower. Remote sensing is the process of obtaining and controlling the physical individuality of an area by calculating the reflected radiation at a space from targeted area. Images of earth are collected remotely by special cameras, it can extremely help researcher sense thing regarding the earth. Such as below:[19]

- The images that are taken by satellites and aircrafts show a wide range of area on the earth's, also allowing us to see more than we can stand on the ground.
- Images of ocean floor can be build without necessitating to travel to the bottom of the ocean, only by using of sonar system on the ship
- The satellite can be used to create images of temperature changes in the oceans.

Specific uses of some remotely sensed images of the earth include:[19]

- Remotely sensed image are large forest fires that can be mapped from space, permitting rangers to can see wide range area than from ground.
- Remotely sensor images can be used to tracking clouds to expect the weather or look at erupting volcano, and also support to watch for dust storms.

3.3 GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic information system (GIS) is not a technique but it's a tool. GIS can works as digital database management system that used to manage huge volumes of non-spatial and particularly distributed data from a different of sources that are then applying geo-referenced by latitude and longitude.

Geographic Information System can connect land use and land cover data within topographic data and two other sections in sequence concerning processes and positioning narrated to geography location. After applied to a hydrological system, all explanation related to ground water surface coverage ground water condition may not be include in the image details as well as the beneath man made systems and its properties. The surface water downhill flow may also contribute within the hydrological significance of terrain modeling. Although maps have at all times been the mainly common form of chronological illustration of terrain, GIS provides different way to store and recover the information with the emergence of digital maps. The amount of digital data required to essentially explain the terrain of even a tiny geographic area builds it a memory-intensive and computationally rigorous system.[25]

The attributes that distinguish a days from common computing mapping a drawing system is the link to details database. After recognized a database, then the connection between different sections of information can be simply checked by computer-generated overlays. To make hydrological parameter that depends on the database information generally required extra steps in the hydrological simulation process. The hydrological ArcGIS includes multifarious phenomenon's or physical based connections which link is an important complication. While Geographic information system (GIS) conjunction with hydrological modeling provides digital representation of watershed features.

3.3.1 Advantages of Using ArcGIS

Geographic Information System (GIS) is perfect for initial site survey because it can proficiently analyze and show information based on user-specified measurements. After development of GIS database, it can give us a capable and cost-effective method for analyzing features. On the other hand, GIS software might be limited due to the lack of up-to-date data availability. Secondly, GIS software eliminate the boring method of paper mapping facilities in many conditions the cost of such mapping alone validate a GIS accomplishment. Since the manual combination and association of the information correlated to the factors to be measured are very boring and complex. While the recent computing and decision making technologies offered in the variety of adaptable GIS should be used. It becomes easier to combine the data of a variety of natures. Remote sensing data are used efficiently in GIS for obtaining more information from an object. Geo-coded satellite imagery can be used straightforwardly for on screen digitization for making of various climatic maps as land use land cover use geology stream network map and etc.

Geographic information system (GIS) helps the user in preparing suitable map in authorized supervision of natural resources and environment. Remote sensing systems are using satellite and aircraft to detect image of the earth's and also collect and analyze large areas of sources and environmental information from various platforms.

ArcGIS tools widely have been used in a variety of areas for water resources development and management, like a hydrological modeling, command area studies, floodplain management, water logging and soil salinity studies. GIS were used generally as hydrological mapping tools in early years. Currently GIS play more significant task in hydrological modeling studies. The plain inventory and management tools along with application are used for wide range of complicated analysis and modeling of spatial data. GIS is use to facilitated substantially to share out rainfall runoff modeling necessitates a large parameters to illustrate soil map and land use land cover data. GIS has shared the ability of models in data managing parameter estimation and appearance of model results however, GIS cannot replace hydrologic models in working out hydrological difficulties.

The uses of computer application regarding hydrologic investigation have become so extensive that it gives the beginning source of data for decision makers for the intention of many hydrologic engineers.

3.4 ARCGIS DATA HANDLING APPROACHES

3.4.1 Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) is a planned arrangement of numbers that characterize spatial allocation of elevation beyond some random data in a landscape along with the tearing feature of the area. Digital Elevation Model of Digital Terrain Model (DTM) compacts with the topographic altitude of the earth surface. Traditionally topographic maps were used to know about the ground elevation which known as contours spot Heights etc. the information is available in GIS as similar to conventional form like vector or points. Separate from this data also can be signified as raster and TIN model. While water flows from higher to lower elevation under availability of earth gravity that DEM can apply important role in input of hydrological studies. Using DEM facilitated to build routes on earth surface from upstream points to the catchment outlet. Further substantial variable can be derived from DEM automatically is slop feature drainage with network sub watershed.

One of the abilities of GIS software to water resource management study is the explanation of the topography in a region. Digital Elevation Model and Digital Terrain Model (DTM) afford a digital demonstration of a part of earth's Terrain over a two-dimensional surface. More valuable tool for hydrological model terrain parameterization can be illustrated by DEM and DTM, particularly for analysis of drainage in hilly hydrology area within ground flow and pollutant transport.

3.4.2 Triangulated Irregular Network (TIN)

The triangular mesh pinched on a scattered location of (x,y) points is called a Triangular irregular network. Model have need of only a small percentage in the number of points that a DEM does in array to correspond to the surface scratching with equivalent precision because the points can be placed intentionally on the surface as is the crate and land surveying. Finite element generally used to solve the flow and transport problems in irregular sites in a hydrological modeling.

Thiessen polygons technique is used to create network of triangles by joining points and also the each apex of triangles is known. The land is demonstrated as a plane surface inside a triangle. For the topographic maps data the input data to model can be a spot height. The triangles are undersized on such that the parts of the triangle are the lines of the slope of exchange and the peak at the point someplace the spotlight is recognized. For DEM producing purpose an alternate approach can relies ahead the resolve of considerable crests and valleys points into a gathering of a occasionally placed points linked by lines.

Triangular irregular network (TIN) is known as patchworks line creator of triangles. The mainly classic triangle can also be measured as a planar facet. However pathway of water motion follows the slope of the plane or near site of the edge between the two sides by smooth confidence possibility. The drainage part problem like suppressing and interruption that can be partly sourced by TIN avoids triangles. Due to verity that the triangle complex from points is non-unique numerous algorithms have been proposed to build from one set of points. The mainly extensively used is the covenant on a triangulation based on the minimizing and maximizing the angle of all triangles created by connector lines to the adjacent neighbor points.

3.4.3 Vector or Contour Based Line Networks

Control line mapping is the third form of representing topography, which can be corresponded to digitally as a set of point-to-point divisions of a general altitude. The entire digital map form is stored known as digital line graph.

3.4.4 Raster or Grid Based Data

The huge number of cells or grids to utilize by the first application of GIS in hydrological modeling is used to store up information. The grid is made of regular baselines, and the centre of coordinate illustrated the closed area of every rectangles. In the different scales it can be exist many different attributes of the trains. Although they are available in homogenous type, while a DEM required high resolution will be require the storage huge quantities of unnecessary data. Data storage the diminution occurs in data storage due to the use of various advanced skills is at disbursement of the complexity of data alteration.

The natural problem in hydrological modeling among gridded DEM data is the fabrication of non-physical gloominess's due to sound in the altitude data heartwarming interpellation proposals used to illustrate discrepancy in the altitude among the raster. Finally the consequence can be an unnecessary elimination of drainage conduit in pits. The difficulty is mostly detected at home for virtual flat areas. The pothole regions in the problematical condition conversely by the subsistence of expected acquitted topographic. The methods are adequately stretchy to tolerate truthful stream path delineation even the substantial of genuine depressions.

3.4.5 Arc Info GIS Hydrologic Routine

The Arc Info GIS from ecological system Research Institute (ESRI), located in Redland, California, surrounds the number of gatherings that are functional to hydrologists in calculation to a large quantity of geospatial data processing and coordinate renovation habitual. The majority of these functions are attached within the special modeling software. Grid also can be related to Arc info suite component of software tools. Arc Info is integrated within the great raster or cell based processing toolbox. A new grade of flow direction creates by the flow direction function from

Excel to the steepest descending slope in the region specified an elevation grid as input. The upstream area or unit weighted traffic is computes by the traffic addition function that flow into each cell. The whole upstream area will illustrate by watershed function that is discharged into a user-supplied collection of outlet unit's basin. The slope feature and curvature gathering used to calculates each constituent of the azimuth and curvature slope.

This tremendous software is used within the stellar and Shreve methods to arrange the flow network and also uses to find flow pathway in downstream and upstream from every unit in the DEM and can find the flow path to explain the length of the flow system as well. Great GIS environment for the hydrological society can be provides by the combination of all the creature tools and functions for hydrological works in addition to structure of the programming language in which to embed analytical tools.

3.5. ARC SWAT

SWAT (Soil and Water Assessment Tool) usually used as a river basin scale model developed to quantify the large and complex watersheds affected by the impact of land management practices. SWAT software is support mainly by the USDA Agriculture Research Service at the Black land in Texas, USA, which is also known as public domain software which facilitate model actively. It is use for developing of hydrological models with the subsequent components: weather, surface runoff, revisit flow, percolation, evapotranspiration, reservoir and pod storage, escalation of crop and irrigation, diffusion, reaching routing, ground water flow, nutrient and pesticide loading and water convey. SWAT model is worldwide used and still it continuously under development, where SWAT can be well thought-out for watershed hydrological model transport.[5]

The improvement of SWAT modeling is experienced that spans a period of roughly 30 years with continuation of USDA Agricultural Research Service (ARS) modeling. Early on beginning of SWAT can be marked out to previously improved USDA-ARS models involving runoff, chemical, and corrosion from Agriculture Management Systems (CREAMS) model. The groundwater filling influences on the SWAT is a Basin-scale, continuous-time model that occupation on a daily time tread and is intended to forecast the collision of water management, sediment and agricultural chemical surrender in un gauged watersheds. The model is physically based, proficient of incessant simulation and computationally proficient more elongated time stages. The model contain major constituents include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management data [6].

Watershed in SWAT software, is consist of many sub watersheds, which are then further subdivided into hydrologic response units (HRUs) that include land use land cover data, soil data features and slope. The HRUs illustrate the sub watershed area percentages that are not recognized spatially within a SWAT simulation. On the other hand, a watershed can be subdivided into sub watersheds with the purpose of characterized by field land use, soil variety and water management[5].

3.5.1 Model Operation

SWAT is designed as incessant time model that generally function on a daily time step at basin level. The aim of such a model development is to expect to know the long term collisions in large basins management and also agriculture timing accomplished contained by a year like a crop revolving, planting and harvest data, irrigation and pesticide function rates. It used in agriculture to simulate at nutrients sequence in landscapes whose governing land use and scale basin water. It also has usage in assessing the environmental effectiveness of best management performs and vary management policies. Two stage disaggregation have usage in SWAT software, where topographic based criteria is carried out for a beginning sub basin recognition that can also pursued by supplementary discrimination using land use data and soil data contemplation. Hydrologic Response Unit (HRU) use same area form with land use and soil type, where a essential computational component unspecified to be standardized in hydrologic reaction to land cove changes.

3.5.2 Model Input

Hydrologic Response Unit (HRU) are fundamentally ingredients of each sub catchment that are spatially correlated to each other sub catchment with a exclusive combination of land management, soil, land use and slope, where those are not spatially correlated. This software allow us to model different evaportranspiration(ET), erosion, plant development, surface flow, water balance and etc. for each HRUs and sub catchment, therefore enhance the simulations precision. The smallest entrance area was set to number of HRUs in the each sub catchment as 5%:5%:5%

for soil, land use and slope classes respectively**[5]**. In order to reduce the number of HRUs the classes which cover less than 5% of areas are eliminated even as not overly cooperating on model accuracy.

The SWAT application necessitates for simulation of model some particular data to obtain the realistic outputs. These data can be classified as spatial thematic map data and isolated data at particular location.

Spatial thematic map data includes:[5]

(i) Aerial map
(ii) Digital Elevation Model (DEM),
(iii) Land use land cover map,
(iv) Soil map.
(v) Metrology Data (i.e. daily precipitation data, temperature data, solar radiation, relative humidity and wind speed data's)

3.5.3 Processing of Software

The application of SWAT has the ability to process or run Hydrologic Model after inserting the needed above mentioned input parameter into the SWAT model.

3.5.4 Advantage of Software

The SWAT application is effortlessly available online and facilitates water managers to model feature of catchments and capacity of surface water globally. By using this wide-ranging model we can integrate surface land and conduit ecological progression. This software merges water quality (i.e. weather, erosion, agricultural land management, crop assembly, urban land management, plant development, nutrients cycles, pesticides, soil temperatures, and agro-environmental evaluates), water quantity (i.e. river discharge, surface flow, base flow, drains, irrigation, subsurface flow, lateral flow, reservoir storage and lakes) and climate change studies. It has the capability to simulate the data based on sub-hourly, daily, monthly and yearly for long periods.

SWAT-Check program helps in SWAT to recognize probable model input considerations issues. Sensitivity analysis and Manual or Auto-calibration instrument with automated procedures to describe and change the model parameters and carry out most favorable calibration integrated in to the model that significantly helps modelers. Hence rather than above another standalone and public domain computer program is available that is SWAT-CUP. It work for sensitivity analysis, calibration, validation and uncertainty analysis of SWAT models result.

Fundamental strength of the SWAT model is flexibility of framework that permits simulation of agro-environmental computes and best management performs for the software. By the changing parameters that can be in the greater part of cases being straightly connected to simulations of measures and practices. Modeler are allow to model through management files in crops rotation, sowing and harvesting time, type of farming tools and machinery, irrigation management, terraces and etc.

3.5.5 Limitation of Software

Threats have harmfully impact on model simulation and its use, if they are not addressed properly. For development of simulation many adjustments of the parameters are needed to be made in during the process of building a model. Adjustments are made using the modelers' experiences, greatest knowledge and subjective evaluation of the study area and usually it's not measurable. It can suitable for case studies, those are difficult to enumerate and also can have more impact on overall simulation and outcome of the model. Measured monitoring data is generally expressed and shown in attentiveness's form and it is mandatory to recalculate the data with flow calculated data for the purpose of comparison with model outcomes. Here can be the origin of errors particularly if the observed data will be like flow, sediment and nutrients is not calculated appropriately or sample taken in the low frequency rate.

The unaccountable and mysterious actions in the extremely managed catchments such as water abstraction, pond and reservoirs storages, waste water treatment plants, waste and chemicals dumping in the rivers can insert considerable error to the model outputs. Generally for the land use, soil data, slope and weather data spatial resolution are not set on the similar scale. It could give the conclusion that the data with lowest resolution are showing good results.

Water balance proper modeling and sediment transport in the catchments are extensively exaggerated the combined with attribute data and uncertainties in the soil spatial. Interpretation by the modeler and their model results must lead to productive discussion, which aspires to accomplish and maintain good quality of water in research catchments; this could be the intention point for the Water Framework Directive and other water related legislations.

3.6 MODEL FORMULATION

Recalling with the mathematical model enclosed in the deterministic program. This can represent that preliminary conditions, boundary circumstance and parameters of the model are assumed to be recognized. Every simulation has accurately the same results and this guarantees to as all previous calculations. Sometime the deterministic model is compared to a stochastic model, where the probability distribution is represented through preliminary conditions, boundary circumstance and parameters.

In program, all enclosed mathematical models use constant parameter values, which revisit to time signals. The parameters that illustrate the watershed for a long stage of time may change as a result of human or further development in the basin. In the simulation, the current parameter trend might not be included. The capability to manually change factor among the fragment and decomposition of longer simulations into fragments are limited. A variable-parameter capability arrangement is at this time being developed.

In the program all contained mathematical model are uncoupled. In the first stage program calculates the evaporation and permeation in the second. In the practically evapotransportation amount is depends on the amount of soil moisture. Penetration amount is also depends on the amount of moisture. However, soil water can remove from soil during filtration as water into the soil due to evapotranspiration. For the better results it recommended to simulate at the same time evapotranspiration and infiltration process with mathematical equations, and the two processes are numerically related to each others. Currently the program does not consist of the search coupling of the model process. Small time interval is using in perform calculations to make light of errors due using uncoupled models.

3.7 FLOW REPRESENTATIONS

Flow networks generation is made only by the design of the watershed model and visualize desired network in the best way like to imagine a tree. The upstream trains through major stem branches and branches correspond to the main river tributaries in the basin. The main idea about stream is that they will not be come apart into two streams. For the EA hydrological element only one downstream connection is allows by the basin model, so the separation of effluent is not feasible from one element into two singular downstream elements. The steering element affords limited capability to eliminate several of the flow from the flow and deflect it to diverse locations in the network downstream. As like, an auxiliary outlet might have be in the reservoir element. However for the presentation of the return water in the currently stream network will necessitate a spread hydraulic model.

Gridded data, time series and balancing data are kept in the data storage system SWAT. The handled data by the program like storage and retrieval data is generally transparent to the user. The data related to rain fall and discharge amount can be entered in program manually or can be loaded from created DSS file. In additional SWAT software can has access to the results that acknowledged by the program in the database. For a single watershed data input can be performed, like a base and flow arrivals or for the whole category of related elements at same time. From visual maps of the basin it's obtained the tables and entering necessary data. All the data are carried out in the metric units. The input data and output results are in metric and could be easily and automatically converted when necessary.

CHAPTER 4
STUDY AREA AND DATA USED

4.1. GENERAL

Farah River, selected as purpose of this study. This river mostly located in Afghanistan, which lied into Helmand River Basin and mainly lies between 31° N and 35° N latitude and 61° E and 66° E longitude. The precipitation and elevation inclination for the entire Helmand River basin is for average annual precipitation of about 300 mm in the 4000 m elevation above the sea level mainly in the north-eastern part and about 50 mm of average annual precipitation in the altitude of 500 m above sea level in the south-western part.[10]

Afghanistan portions for the whole basin area are 90% and 95% for the inspired water in the Helmand River Basin. It's annually generated 99% renewable energy form water resources. The estimated population of the Afghan part in year 2015 living around the basin was about 6 million people. As per Food and Agriculture Organization (FAO), Country STAT Afghanistan report about 83% percent people live in rural areas and mostly rely on irrigated agriculture lands.[15]

The Helmand and Farah-Harut Basin in some Afghan hydrological studies often treated as one basin. It was decided to concentrating on the Farah River as study area to delineated watershed using the hydrological data and maps based on Digital Elevation Model (DEM) in ArcGIS integrated with Arc SWAT model. It is global standard dataset that can provides hydrological information for local and global-scale applications in a consist format.

The present study has been carried out in the Farah River mainly located in Helmand River Basin in Farah, Afghanistan as shown in Fig. 4.1. The Helmand River Basin is located in the south-eastern part of Afghanistan while the Farah River located in western of the Helmand Basin. The total covered area of the catchment is 25309 km^2, out of this 25000 km^2 falls in Afghanistan and rest falls in sistan Iran. The total length of the basin is around 560 km, while out of this 540 km length is lying in Afghanistan. Altitude ranges for the entire Farah River Basin start from 468 m to 4123 m above sea level. Its average width is approximately about 40 m. It average discharges recorded as 41.4 cumecs of water at Farah gage station near the Farah city. [9]

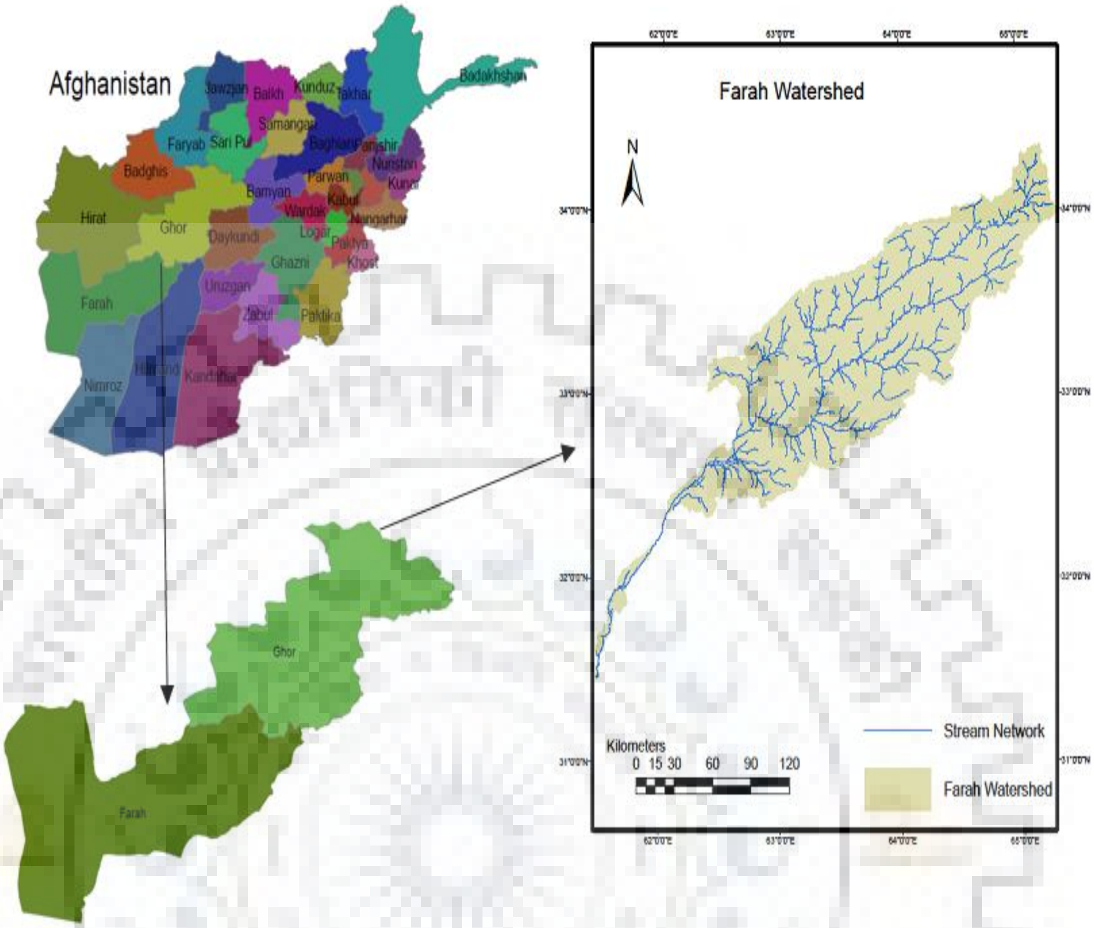


Fig. 4.1: Boundary of Country along with Location map of Study Area.

The Farah River digital elevation model was downloaded from the USGS Earth Explorer. The Digital Elevation Model (DEM) is used with 90 m resolution Shuttle Radar Topographic Mission (STRM) for the current study. For creating of watershed area, the downloaded DEM used in ArcGIS to delineate watershed area for the basin and build up slope map, drainage map etc. with the help of DEM in ArcMap for the watershed area the flow direction and flow accumulation are developed. The entire feature like watershed geomorphologic parameter and delineation is done in ArcGIS 10.3.1 software.

4.2 EXISTING HYDROPOWER PLANTS ON HRB

Two major hydroelectric dams are existing in southern region of Afghanistan. The details are as follows:

4.2.1 Kajaki Hydropower Plant (51.5 MW)

The Kajaki Dam is located in the Helmand province in the southern Afghanistan. It is placed on the north west of Kandahar about 100 miles (161 km) mainly on the Helmand River Basin and usually its managed by the Arghandab and Helmand valley authority. It is dual function, using for producing electricity and also for irrigation of more than 1800 km^2 arid lands. The discharged water from the dam passes through about 500km far from the dam to downstream ward through a canal for feeding farmland purposes. As per the report of the MEW on October 2016 it produces about 51.5 megawatts of electricity.[9]

The height and width of dam is 100 m and 270 m respectively. The gross storage capacity of dam is approx 1,715,000,000 m^3 of water. The dam is mainly used for output control of the dam watershed which feeds the sistan Basin. The capacity of the Kajaki plant is an important aspect for South Electricity System, in the future will have an additional capacity of 100 megawatts to increase to 51.5 megawatts.

4.2.2 Grishk Hydropower Plant (3 MW)

The Grishk hydropower plant is erected on the Helmand River Basin, which is located in Helmand province of Afghanistan. It was built by the United States in 1945 for hydroelectric power and irrigation purposes for nearby villages in this province.

Currently two turbines are installed in this dam each having 1.5 MW capacities, with total capacity of 3 MW. Recently works are started to upgrade the power plant by replacing existing turbines with new turbines which will have the total capacity of 4.2 MW. [9]

4.3 DATA COLLECTION

The monthly observed discharges and daily meteorology data (daily precipitation, daily relative humidity, daily solar radiation, daily wind speed and daily maximum and minimum temperature) of Farah River Basin were collected from Ministry of Water and Energy of Afghanistan. The World soil map is downloaded from Food and Agriculture Organization of the United Nations (FAO) website and with the help of ArcGIS the site of interest is clipped.

ArcGIS 10.3.1 is used for the creating of maps and the images that were downloaded from USGS earth Explorer. The following maps were created in ArcGIS- digital elevation map, contour map, Soil map, land use land cover map and the delineated watershed. With help of these maps the location of Dams was forecasted on basis of parameters like slope, elevation, contour, etc. Using the delineation of watershed of map the area and circumstance of the watershed was computed which came out to be 22000 km^2. Fig. 4.2 shows the downloaded DEM of study area from USGS website.

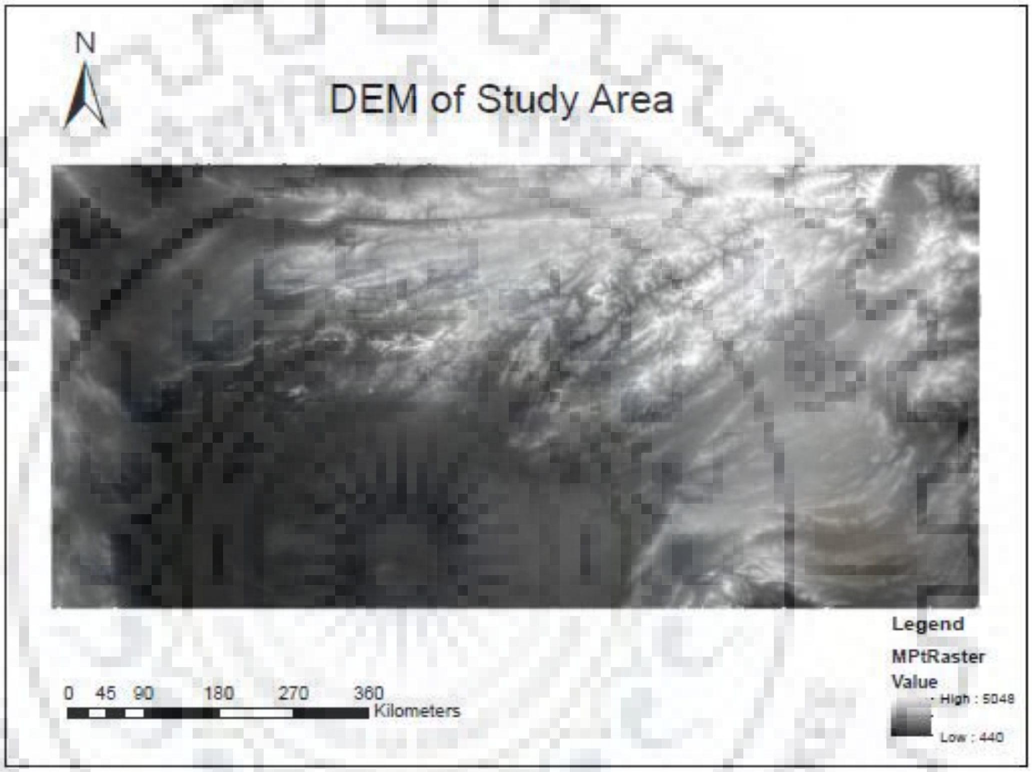


Fig 4.2: DEM of the Study Area.

CHAPTER 5

METHODOLOGY AND MODEL DEVELOPMENT

5.1 GENERAL

In this chapter, an attempt is made to express a proposed method for extracting the parameters required for estimating hydro potential using hydrological modeling.

As discussed earlier, the SWAT model is used for hydrological modeling, which is mainly known as the public domain software, and also it is used to perform hydrologic modeling for the basin to get average discharge for the selected sites. Then by using these values together whit calculated head obtained from DEM to estimate the hydro potential of the sites. For the developing of proposed watershed the 30 m resolution Digital Elevation Model (DEM) is used. Meteorology, geology and tectonic setting of the area are the mostly depended parameters for the drainage network. Whilst for the performing the hydrological analysis, ArcGIS is used to compute the liner aspects, areal aspects and relief characteristics for it.

The procedure of creating input data for the basin component of SWAT has been divided into five analysis steps:

- raster-based DEM analysis
- raster-based watershed and stream network delineation
- vectorization of watersheds and stream segments
- HRU analysis including: land use land cover map analysis, soil map analysis and slope map
- Meteorological analysis

The hydropower potential of a plant can be calculated with help of following two parameters:

- Head
- Discharge

Hydropower potential is a function of head drop and discharge in stream. The theoretical ROR hydropower potential is calculated by using equation (1). [11]

$$P = \rho \times g \times Q \times H \times \eta \tag{1}$$

Where,

P = Power output in Watt (W)

ρ = Mass density of water (1000 kg/m^3)

g = Acceleration due to gravity (9.81 m/s^2)

Q = Discharge (m^3/s)

H = Gross head drop (m)

η = Overall Efficiency of turbine

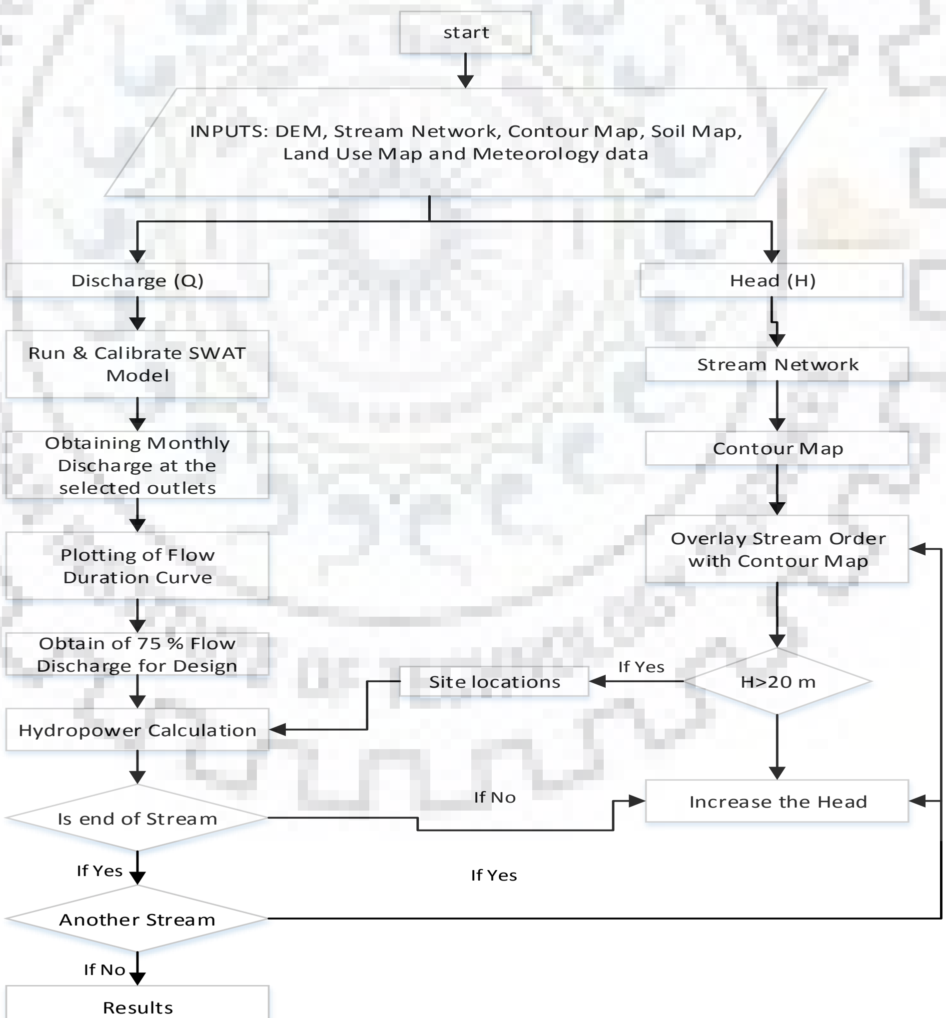


Fig. 5.1: Methodology for Calculation of Hydropower Potential in FRB.

The methodology is shown in Fig.5.1 was employed to do works in this dissertation. This methodology shows the works are divided into two parts (calculation of Head and Discharge) to calculate the hydropower potential in Farah River. The Method for calculation of Head and Discharge are briefly discussed in sections 5.2 and 5.6.

5.2 CALCULATION OF HEAD

This dataset provides data of elevation for the upstream and downstream of each stream. The measurement of the head is that the height difference between the pour point and location of power house and interested point. The power house sites are decided based on the head requirement for a SHP. Therefore, for the steady investigation, the hydraulic head was resulting from the difference among the minimum and maximum altitude data's alongside the rasterzied pour lines. Each flow line was characterized by a height of upstream and a hydraulic head. Therefore the head was calculated for whole Farah River watershed as shown in Fig. 5.2 to be as follows:

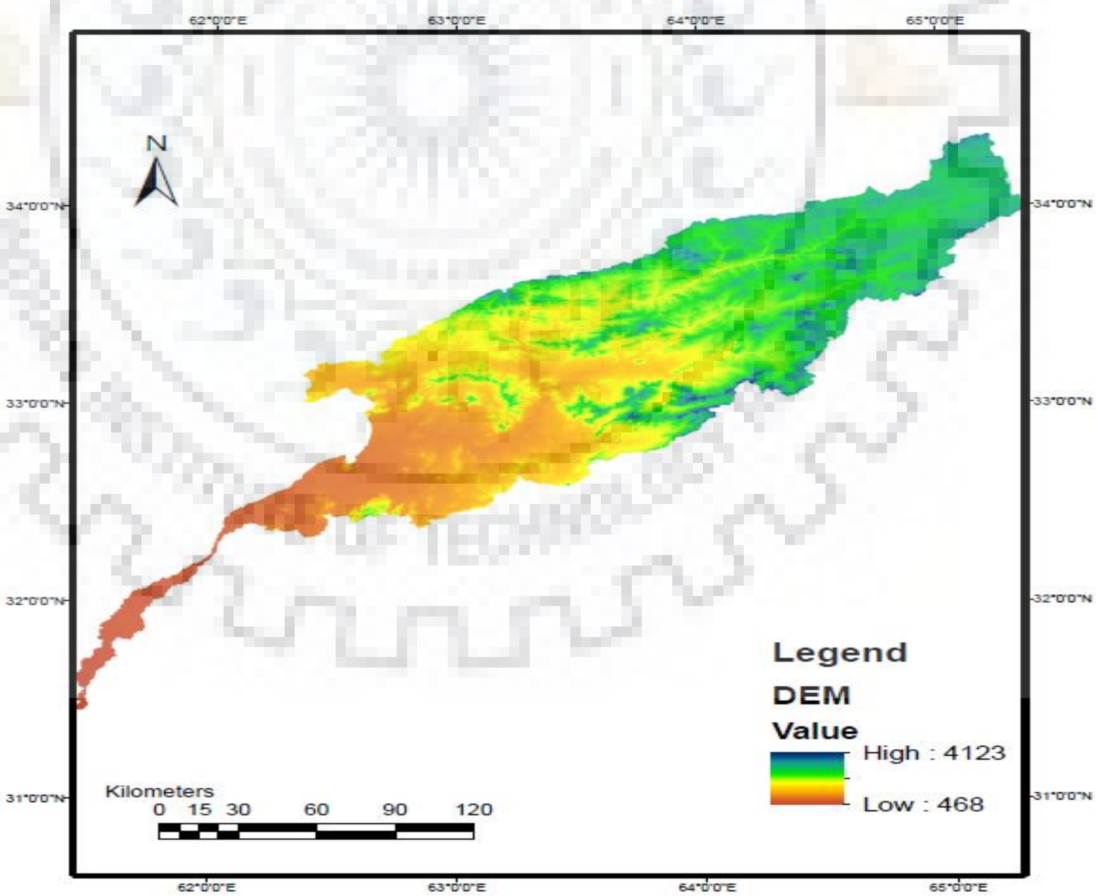


Fig. 5.2: DEM of FRB.

5.2.1 Slope Map

A slope map can be generated from a Digital Elevation Model (DEM) in ArcGIS to determine the steepness of the river for selection of hydropower project. The slope map as shown in Fig. 5.3 created using Spatial Analyst tool as follows:

- Arc Toolbox -> Spatial Analysis Tool -> Hydrology -> Surface -> Slope
- Input Raster : projected DEM Raster of Farah River Basin
- Output Raster: Slope_Dem with tif format
- Table of Content -> properties -> Symbology -> Classified Class = 5 and click Classify
- Break Values: 10, 20 30, 50

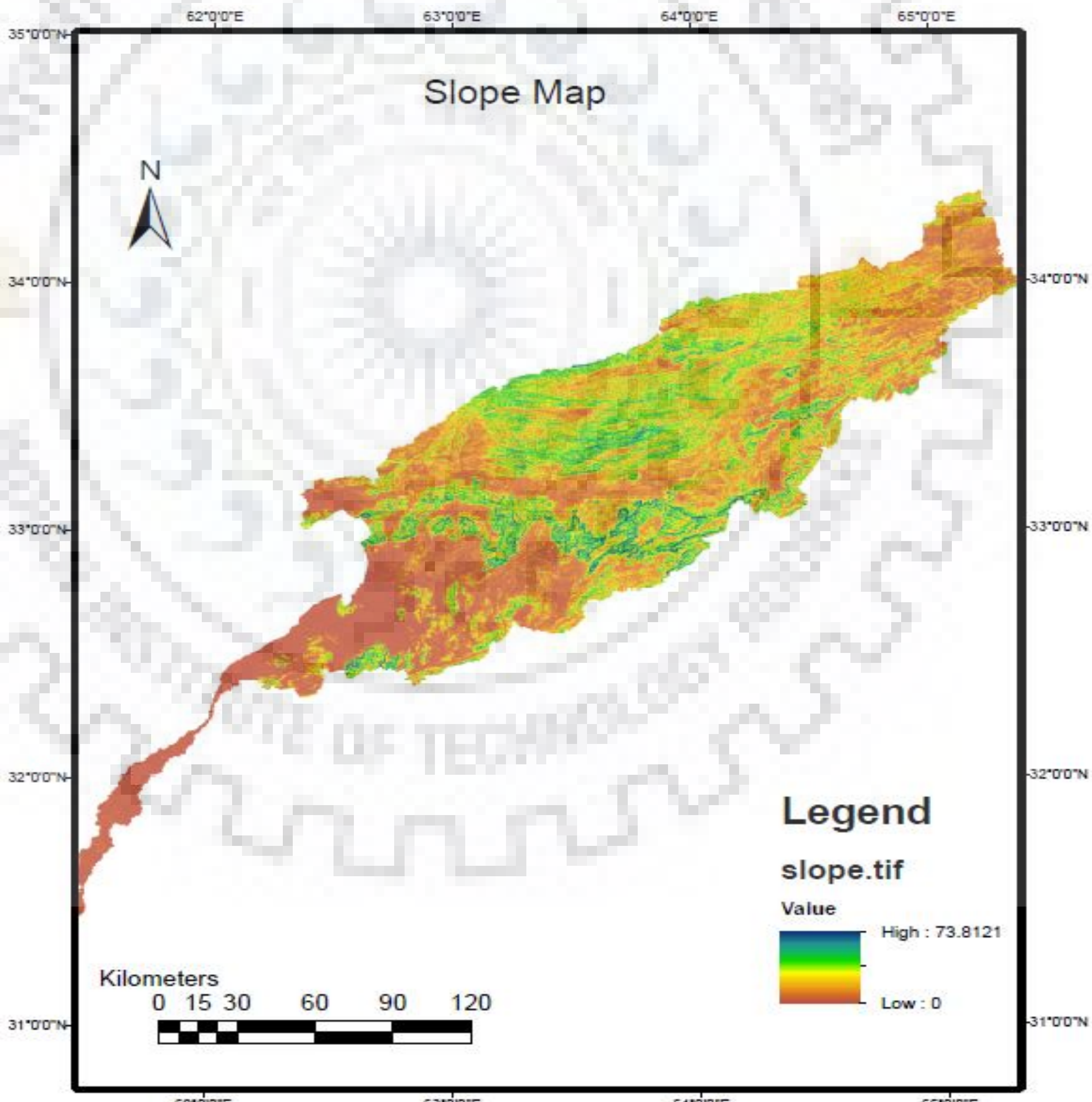


Fig. 5.3: Slope Map of FRB.

5.2.2 Contour Map

The map, which is showing the altitude and surface arrangement by means of contour lines called Contour map. This map is generated to find the height difference between two points. With help of contour map (as shown in Fig. 5.4), the elevation difference between the diversion arrangements and powerhouse locations are determined for Farah River Watershed. The steps for generation of contour map from DEM are listed below:

- Arc Toolbox -> Spatial Analysis Tool -> Hydrology -> Surface -> Contour
- Input Raster : projected DEM Raster of Farah River Basin
- Output Raster: the name is defined as Contour_Dem with tif format
- Contour Interval: 2 meter distance is taken between each contour line.

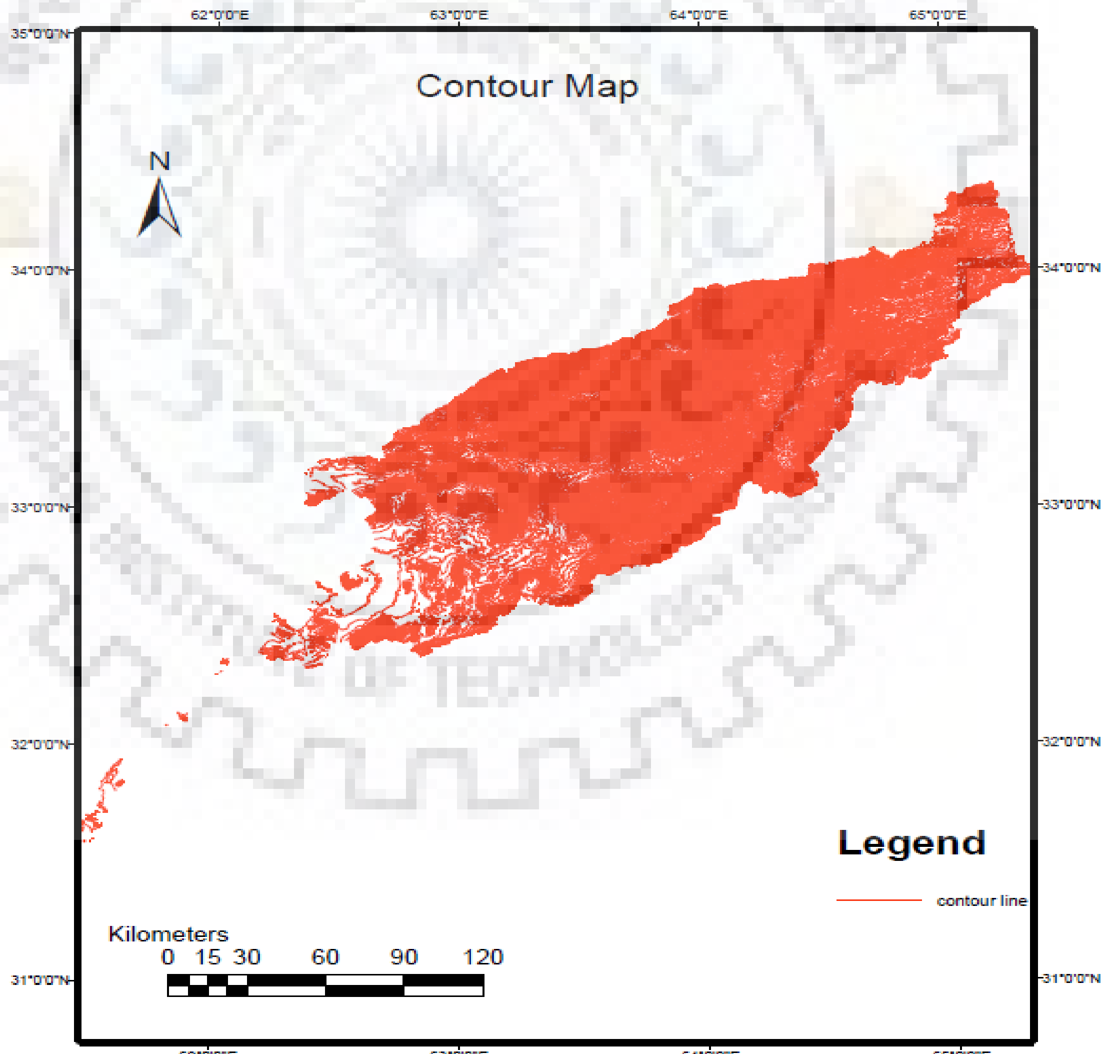


Fig. 5.4: Contour Map of FRB.

5.3 WATERSHED DELINEATION

In each type of hydrological simulation, the first step is to divide the rivers and basins to obtain some characteristics of the catchment area such as area, slope, flow length, river network density etc. Terrain pre-processing is known as the process of using DEM to divide a basin. Watershed is a piece of land that has a single common exit of discharge coming out from it. Mountain ridges in hilly area split river basins from each other. The basin area is separated by the using of digital elevation model (DEM) and topographic maps.

The manual watershed delineation is time consuming process with using topographic maps that necessitate familiarity of cartography, which is complicated to carry out accurate analysis on it. For better visualization and analysis capabilities of watershed, DEM is used in Geographic Information System (GIS) to understand the context of various parameters in the basin. Watershed dividing means that to create a periphery to characterize the involvement area of a particular exit or control point.

5.3.1 Fill Sink

For the creation of flow direction for a given sink, the DEM is important parameter to be used that has no indentations and depressions. The elevation data the sink is generally due to errors in the data it is cased generally by outcome of sampling and rounding of the height to an integer. The number of sinks in a dataset is directly proportional to the cell size. Therefore, using of DEM devoid of sink is required to generate an accurate illustration of flow direction and flow accumulation.

- Arc Toolbox -> Spatial Analysis Tool -> Hydrology -> Fill
- Input Raster: Projected DEM Raster of Farah River Basin
- Output Raster: the name is defined as Fill with tif format like Fill_Dem.tif.

5.3.2 Flow Direction

To calculate a drainage network or watershed, a grid must exist that is coded for the direction in which each cell in a surface drains. The flow of each cell must be known because the final destination determines the flow of water from each cell in the network. The output of the flow direction tool represents the network for the exit of each cell. There are eight outputs associated for the direction with eight adjacent cells, and flow can go by through these eight cells. Fig. 5.5 shows flow direction map. This could be done with the help of flow direction tool by following steps in ArcGIS:

- Arc Toolbox -> Spatial Analysis Tool -> Hydrology -> Flow Direction
- Input Raster: use the generated Fill map of Farah River as input
- Output Raster: the name is defined as flow direction with tif format (Flow_direction.tif).

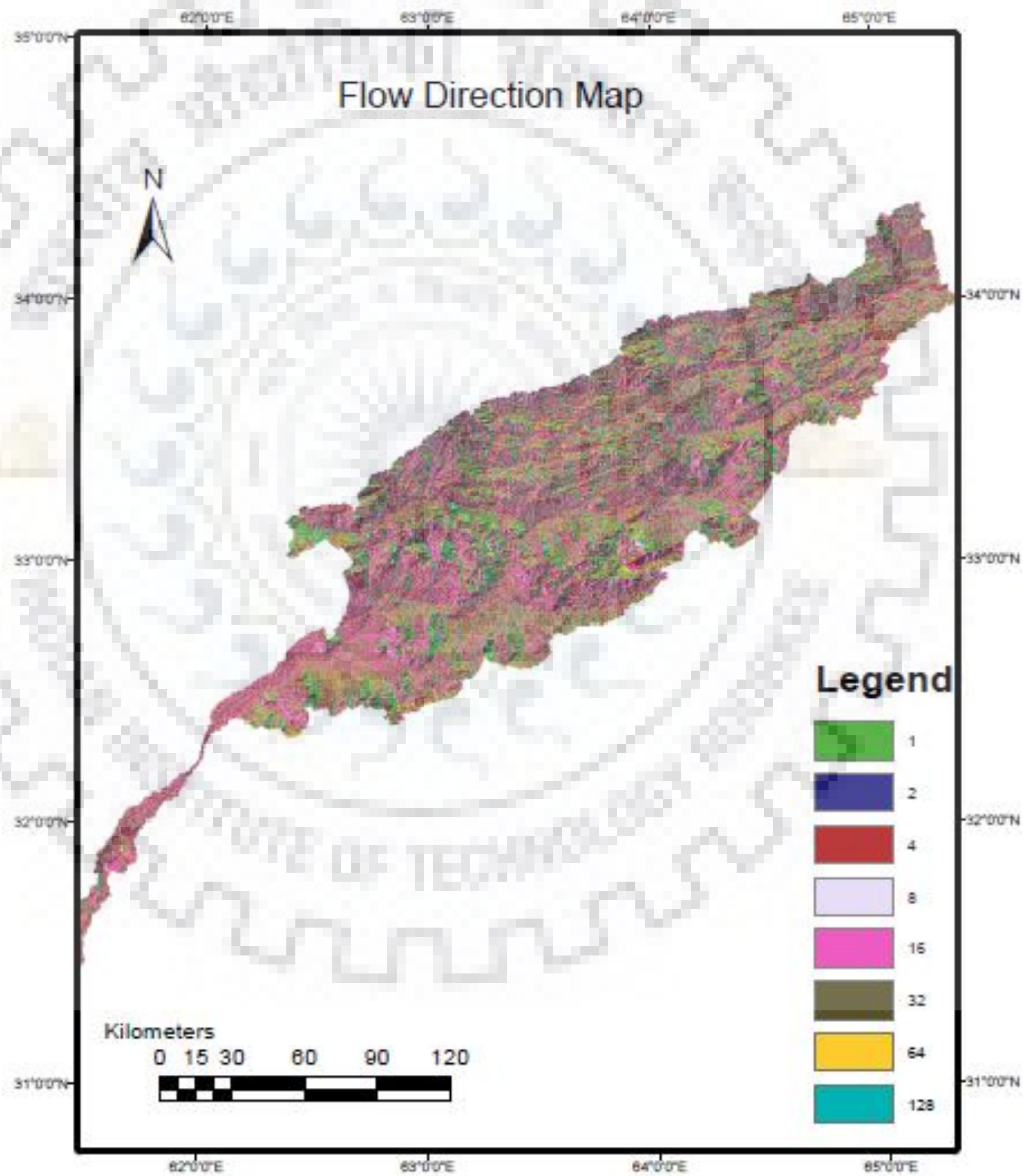


Fig. 5.5: Flow Direction Map of FRB.

5.3.3 Flow Accumulation

It is the tool that calculates increasing number of upstream units of cells the flow into each subordinate incline component in the output rater. Flow accumulation is used to generate a drainage network, based on the direction of flow of each cell and also to determine the flow path of every cell on the landscape grid. High-flow accumulations mainly situated in streams rather than on hillsides or ridges. Fig. 5.6 shows flow accumulation map of the basin.

- Arc Toolbox -> Spatial Analysis Tool -> Hydrology -> Flow Accumulation
- Input Raster: use the generated Flow direction map of Farah River as input
- Output Raster: the name is defined as flow accumulation with tif format (Flow_accumulation.tif).

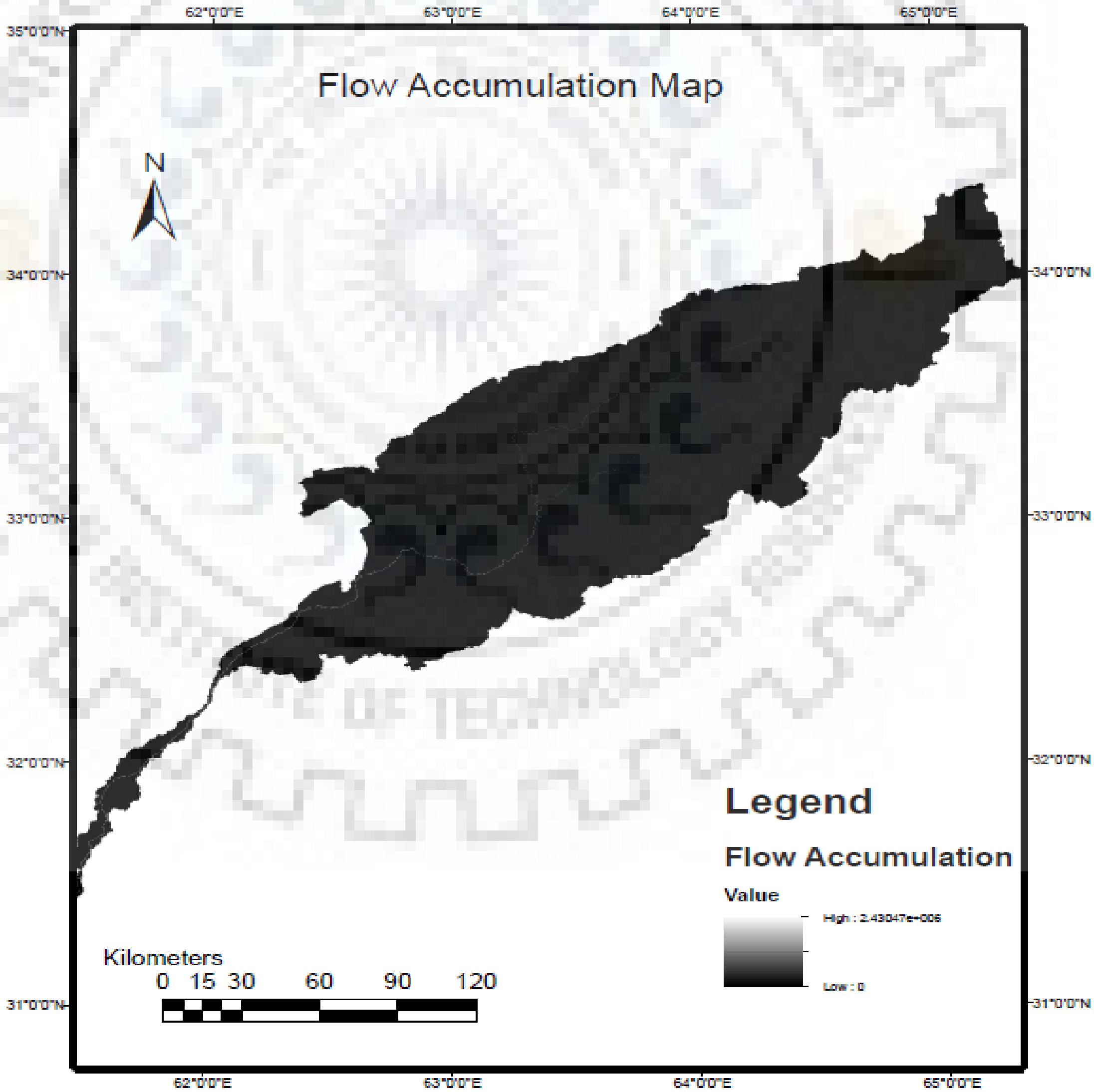


Fig. 5.6: Flow Accumulation Map of FRB.

5.3.4 Snap Pour Point

This tool is adapted when basins are used to segregate the basin to make sure that high cumulative flow points are selected. It aligns the pour point within the particular distance and the maximum flow accumulation unit.

5.3.5 Watershed

This tool is used to calculate the involved area on top of a group of cells in a raster. The pour point and the raster description of the flow to the grid are given as input. It is used to create boundaries to the study area and it also dividing the mentioned area into sub-areas as shown in Fig. 5.7.

- Arc Toolbox -> Spatial Analysis Tool -> Hydrology -> watershed
- Input Raster: used the generated pour point of Farah River as input
- Output Raster: the name is defined as watershed with tif format (watershed.tif).

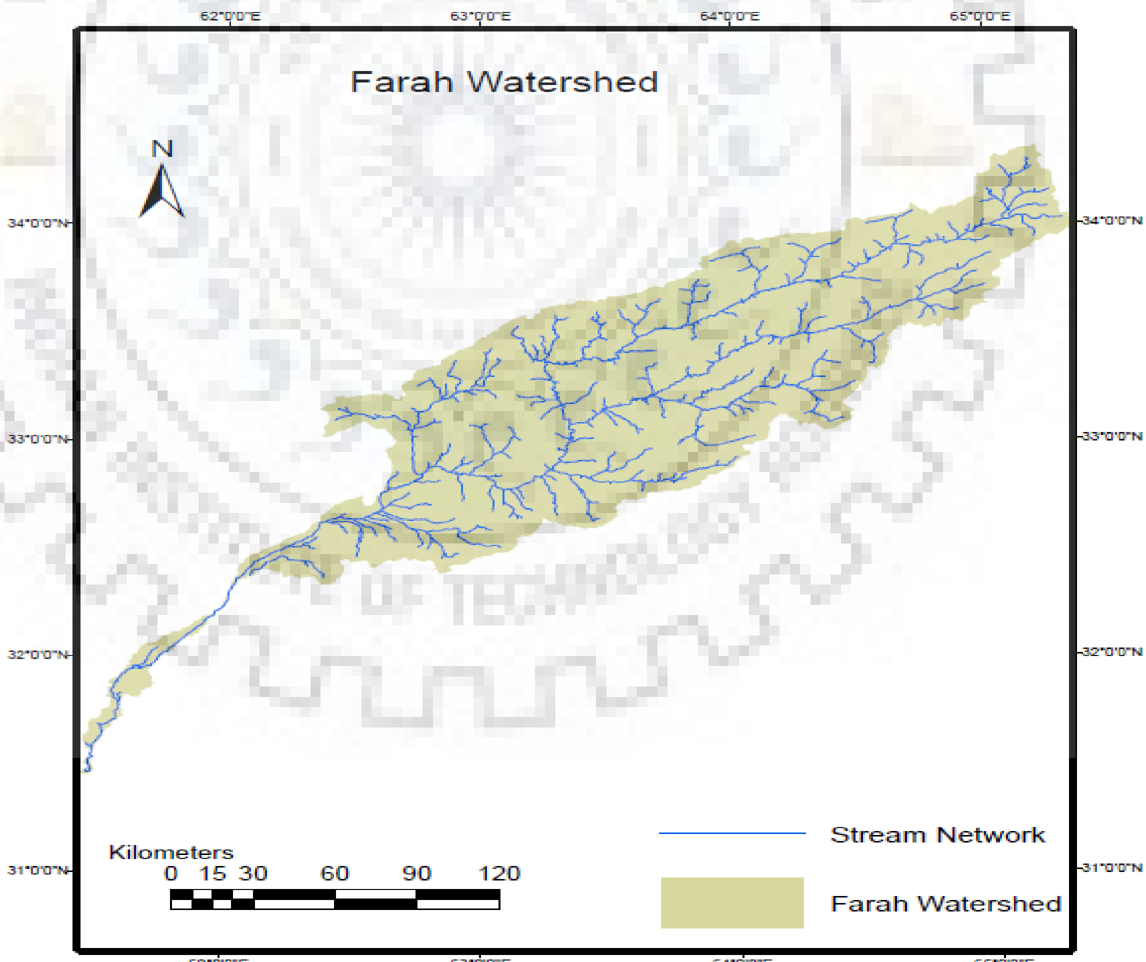


Fig. 5.7: Watershed Map of FRB

5.3.6 Stream Order

The Stream Order is used to determine the different types of river stream in a watershed. The aim of this work is to know about the flow of water in all streams in a particular watershed during a period of year. The Fig. 5.8 shows the stream order for Farah River.

- Arc Toolbox -> Conversion tool -> From Raster -> Polylines
- Input Raster: generated watershed map of Farah River as input
- Output Feature: the name is defined as Stream_Vec and format will be automatically taking shp (Stream_Vec.shp).

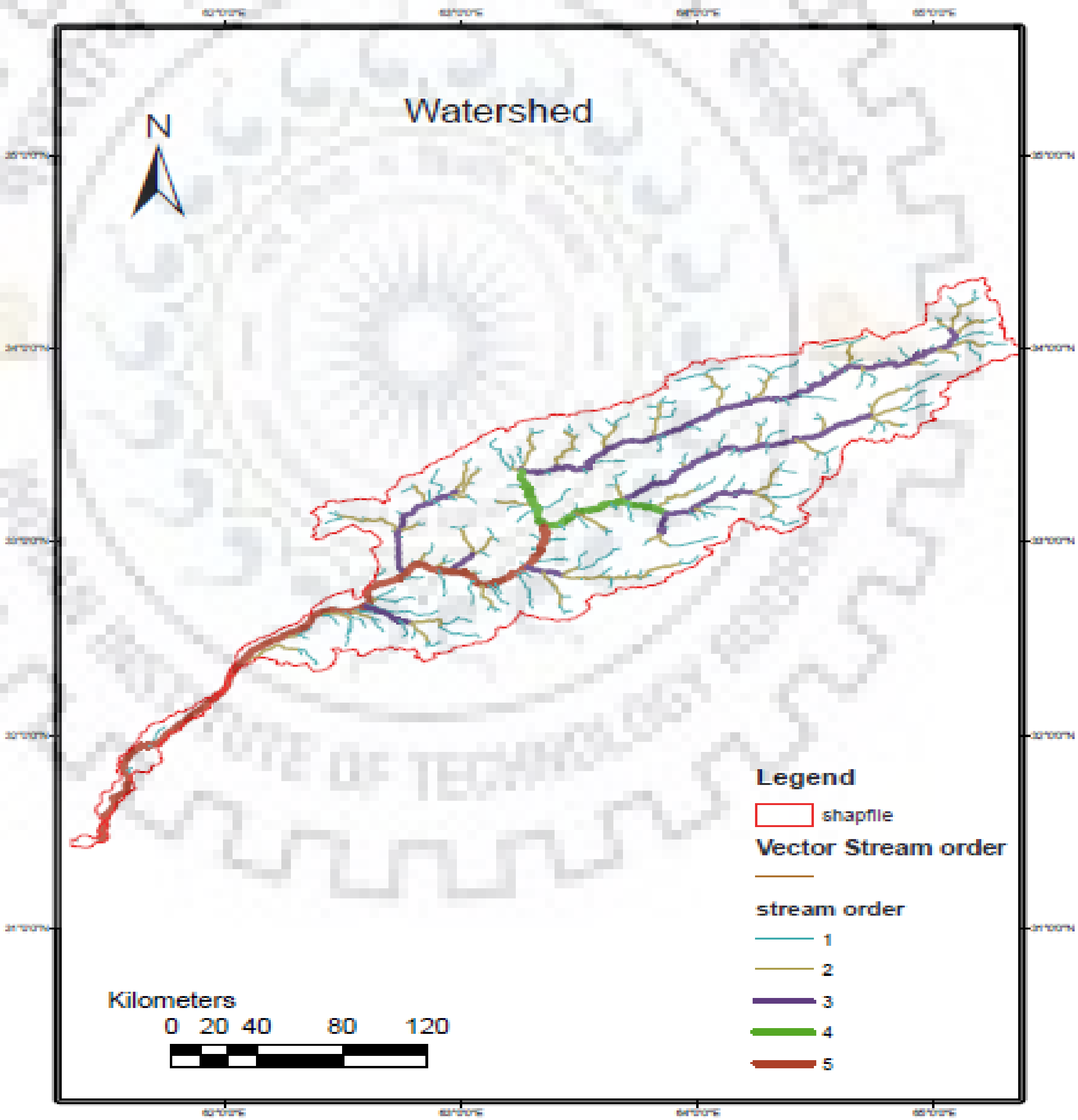


Fig. 5.8: Stream Network Map of FRB.

5.4 IMAGE CLASSIFICATION

Land Use Land Cover (LULC) classification is one of the most widely used applications in ArcGIS. It is a method by which all related spectral signatures in all the pixels in an image are identified. In general satellite imagery are used to process in image classification. It can be used for various applications with different type of data to interpreting and recognizing areas. Classes and areas of interest are represented by the pixel or italic 8 cells in a data set random arithmetical value. Classes can identify urban, water body, rural area, crops and forest area, while color can be assigned for easy viewing of these classes. Generally, the data classification creates a new data set. The most commonly used approaches include unsupervised classification, supervised classification, image segmentation and NDVI.

In the supervised classification, imaging works is starts with the training are drawn on the image and ArcGIS can find all further pictures with the same spectral characteristics. An unsupervised classification starts with automatic function to classify all pictures dedicated on classes with the same spectral signatures according to the given parameter will creates classes. For better result to have from image classification it is recommended that the outcome of supervised or unsupervised classification can be reproduced by any other supervise or unsupervised classification. Each of these methods has its own restrictions and advantages. However, none of them individually can create an acceptable level of accuracy in producing LULC maps. Using the technique of object-based image segmentation, detailed information in the study area can be gathered effectively from the analysis of satellite images and certain ancillary data. In response to this, it was proposed in this study as a way to combine the advantages of these methods and enhance the quality of LULC maps.

For classification of the Landsat 8 images, the study proceeded in following four steps: (i) preprocessing of the images, (ii) random extraction of a training sampling location (an unsupervised classification) (iii) supervised classification of the image into LULC classes and (iv) creation of a final LULC map. Upon completion of all these processes, the accuracy of the classifications were evaluated for each imaging classes and comparisons were made.

5.4.1 Preprocessing of The Images

An improved spatial resolution Landsat 8 images for the study area were downloaded from USGS Earth Explorer website. Landsat 8 images are consisting of 11 individual bands, each representing a single layer of continuous imagery. Given their low spatial resolution (90 m), the thermal bands (bands 8, 9, 10 and 11) were not used. The images' non thermal bands (90 m) were combined into a multilayer image and clipped with a 10 m exterior buffer around the study area boundary. Image fusion (or pan-sharpening) techniques have proven to be effective tools for providing better image information.

The PCA method was used because a major goal of this technique is to reduce data file size yet retain the spectral information of the 7 bands. This algorithm is mathematically rigorous. The coordinate system used in the topographic maps was the Universal Transverse Mercator (UTM) zone 41 with spheroid and datum WGS84.

5.4.2 Extraction of a Training Sampling Location Map (Unsupervised Classification)

Training sampling locations were chosen to encompass a full variety of LULC classes across the entire study area. Since this study encompassed a relatively large watershed (>20000 km^2), with different climatic zones and a complex combination of mountains, hills, and plains. Concurrently, on each Landsat 8 image the Iterative Self-Organizing Data Analysis Technique (ISODATA) was performed. This is a type of unsupervised classification, and based on the natural groupings of pixels. Based on this method, applying a 95% convergence threshold and maximum iterations of 12 resulted in the generation of a raw classification map with 25 classes. This map was used in an important supportive role for identifying appropriate training sampling locations across the entire study area. Based on these homogeneous areas, the 485 training sampling locations were extracted using a stratified random sampling procedure.

5.4.3 Supervised classification

Six classes were used for the supervised classification to generate an LULC map. LU was classified into following 6 categories: (a)Agriculture, (b)Forest, (c)Urban, (d)Barry Land, (e) Forest-evergreen, (f)Water bodies. To obtain the required ground-truth data for supervised classification, extensive field information was collected at the same 485 locations stipulated. In order to obtain the best possible results, these sampling locations were checked with Google earth pro. With this ground truth data a maximum likelihood supervised classification was performed using an area of up to 100 pixels. At this stage, a primary classified LULC map for each of the images with 6 classes was created. In order to increase the accuracy of these maps a v^2 threshold at a 90% confidence level was applied to the results. This process identified 1,205,324 pixels (6% of the total pixels) which had a 10% or greater chance of being misclassified. These pixels were put into class ‘0’ and defined as ‘unknown’ areas. Again a supervised classification was applied to the original 485 locations plus these 26 additional locations. Then a 90% confidence level analysis was repeated and an area of 183,276 pixels was identified as ‘‘unknown’’. Since this area encompassed only small pixel groups and in all represented less than 1% of the total area, this data was left as classified. The resulting image was termed the ‘secondary classified map.

5.4.4 Final LULC Map

In an effort to further increase classification accuracy, an image segmentation algorithm was applied to the Landsat 8 images, using the Bonnie Ruefenacht algorithm. This method classifies raster images based on pixel values and locations. All 7 bands of Landsat images were used in this process. Image segmentation is able to separate objects of varying size, shape and homogeneity. The main task of image segmentation was to create a set of non-overlapping segments (polygons). This algorithm merges groups of pixels into polygon objects (raster to vector format) but it is unable to classify them, thus the need for combining the images with zonal statistical analysis. The zonal statistics present a distribution of each LULC within each segmented polygon. The reason for image segmentation is to use the resultant polygon vector map in combination with the supervised classification raster map and zonal statistics to generate a new classified polygon map. The idea behind this is to eliminate mixed pixels.

The land use land cover image shown in Fig. 5.9 was organized as a result of above steps adopted. The use of Land use pattern that is to oversee the requirement for agricultural and domestic purposes is an fundamental consideration to determine the health of watershed. It gives detail information about the surface condition and groundwater provision of the particular area and can plays a key function in watershed examination. These analyses hold up the watershed development and management. Land cover map give us detail information about the surface condition and groundwater provision of the particular area and can plays a key function in watershed examination. These analyses hold up the watershed development and management.

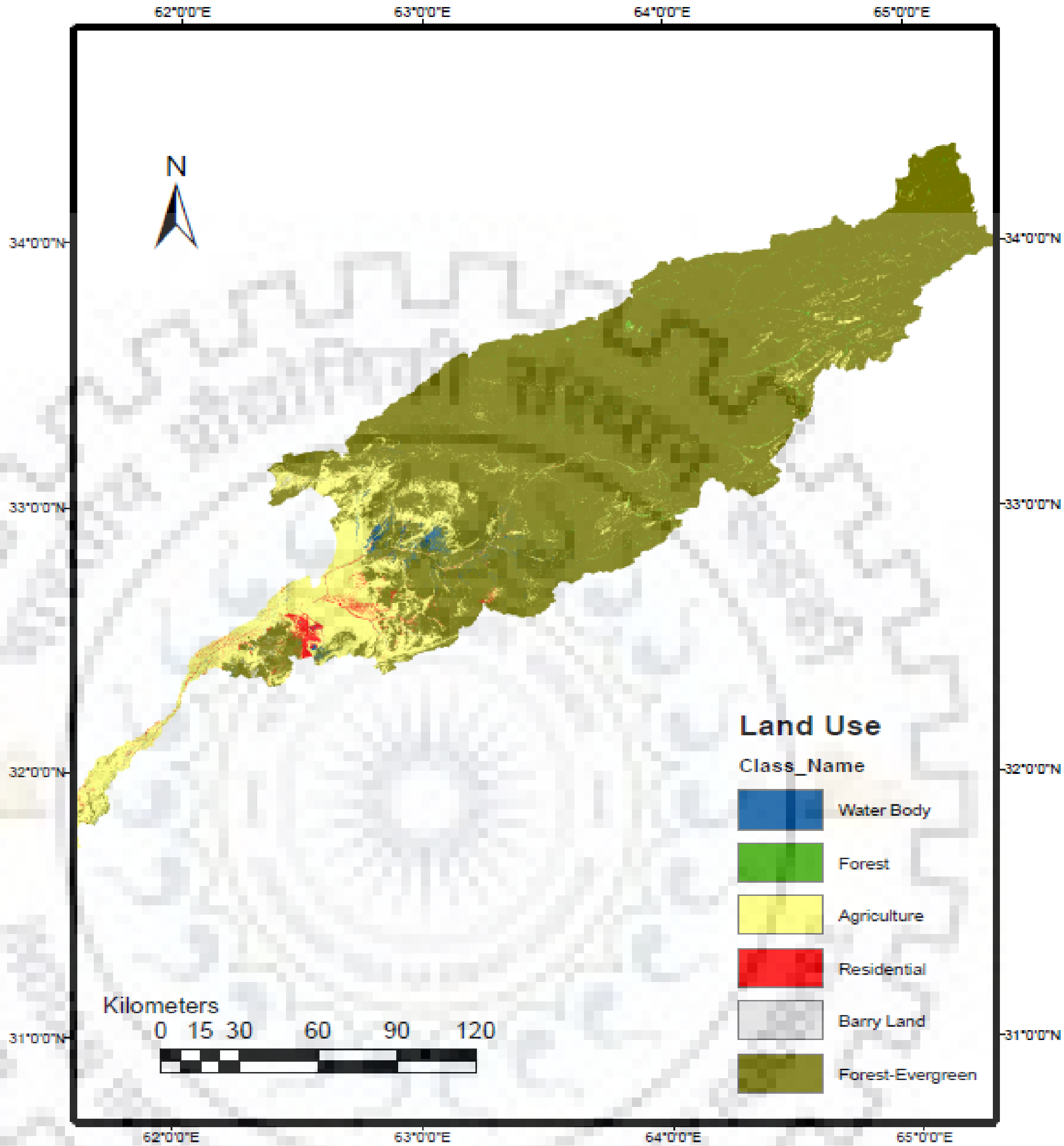


Fig. 5.9: Land Use Land Cover Map of FRB.

5.5 SOIL MAP

The Digital soil map of the World was downloaded from Food and Agriculture Organization (FAO) website. The FAO Digital Soil Map of the World is the digitized version and produced in paper version at scale 1:5 million. It shows 4931 mapping units consisting of soil associations, which are mixtures of different soil types, classified according to the FAO-UNESCO Legend, which defines a total of 106 soil units on the basis of presence of diagnostic properties and

4 non-soil units. The soil associations are characterized in terms of the estimated proportions of the component soil units, the presence of phases (stony, lithic, petric, petrocalcic, petrogypsic, petroferric, phreatic, fragipan, duripan, saline, sodic and cerrado) and the estimated proportions of these soil units in one of 9 texture-slope classes (combinations of coarse-, medium- and fine-textured soils with level to gently undulating, rolling to hilly, and steeply dissected to mountainous topography).

The digital Soil Map of the World was downloaded and opened with ArcGIS 10.3.1. Then some portion of this map is clipped according to the Farah River shapfile of watershed from DSMW image. The DSMW is originally found in vector dataset format, while we need soil map for SWAT model in raster dataset. In order to have the soil map in SWAT model format we need to change the format of it. As shown in Fig. 5.10 the soil map was then changed to raster dataset for the further uses in SWAT model and its present's seven different types of soil in the area of interest. These soils types are: Clay Loam, Loam, Sandy Loam and Sandy Clay Loam. The steps are followed as below:

- Add the DSMW image in ArcGIS with river Shapfile, and then clip it according the Shapfile of area of interest.
- Arc Toolbox -> Analysis Tool -> Extract -> Clip
- Input Feature: World Soil map and Farah River Shapfile as inputs
- Output Feature: Clip_Soil.
- Arc Toolbox -> Conversion tool -> From Vector -> Raster
- Input Feature: Clip_Soil Map of Farah River as input
- Output Raster: the name is defined as Soil_Raster for this process with tif format(Soil_Raster.tif)

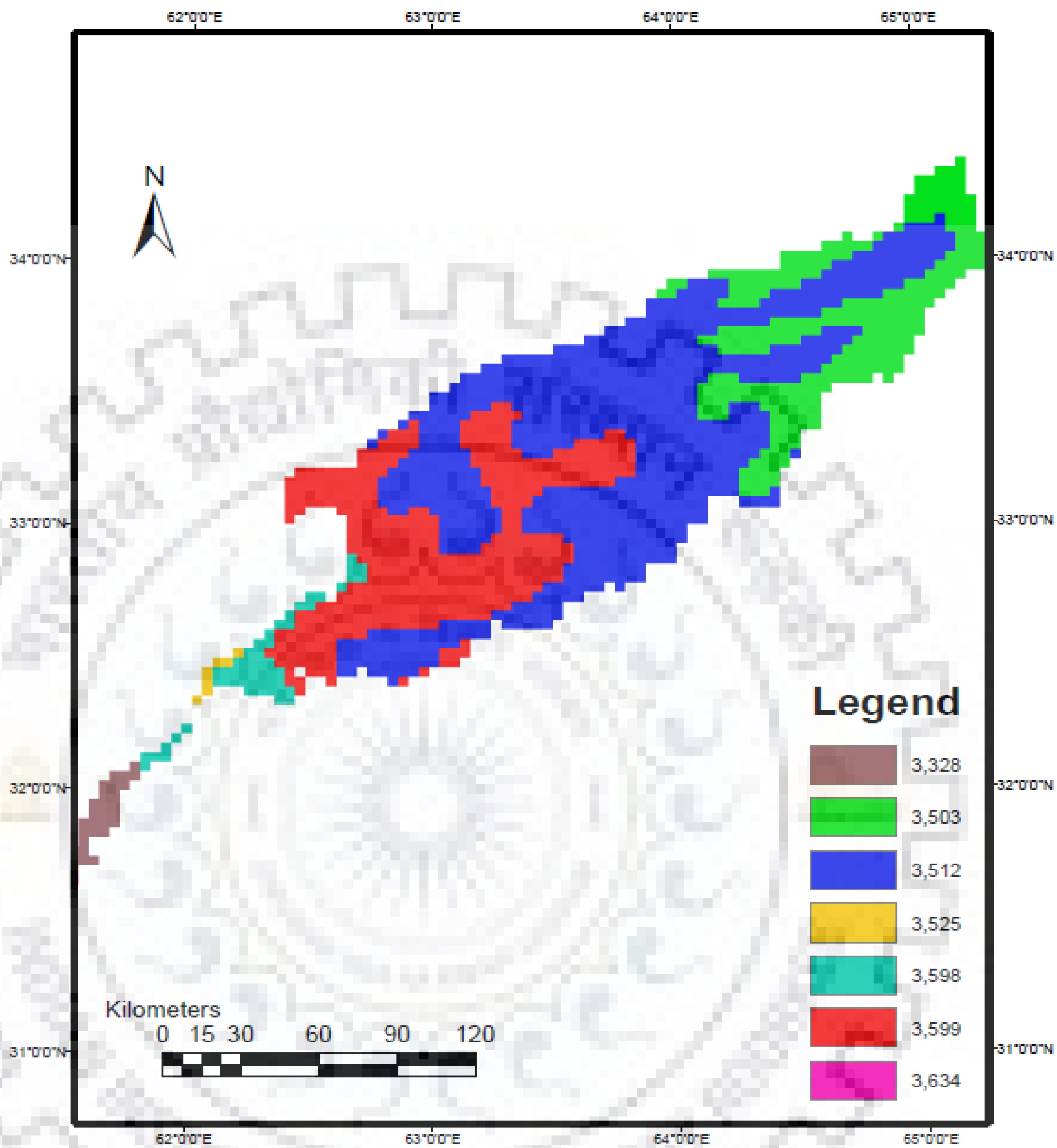


Fig. 5.10: Soil Map of FRB.

5.6 CALCULATION OF DISCHARGE THROUGH SWAT MODEL

The discharge for Farah River was calculated through SWAT hydrological modeling. The model simulation processes and methodology adopted to run the model are briefly discussed and demonstrated in below four steps.

5.6.1 Download and Installation of SWAT Model

The SWAT software is acquired free from Soil and Water Assessment Tool Website and it is available in different versions for ArcGIS 10.1 to 10.5. Since I used ArcGIS 10.3, accordingly SWAT version 10.3 is downloaded. Hence, the SWAT software is still not available for ArcGIS version 10.6. The software was installed in drive C of system and it is linked with ArcMap automatically.

5.6.2 Modification of SWAT Software

The SWAT software initially was developed for United States of America, where it's consisting of limit soil types and weather stations. Therefore, those users who are using this software in Asian Continent Countries and other Continents Countries, they need to bring some modifications in database of the software. The changes are adopted in Usersoil and weather station database of the software. The data which required to be downloaded and replaced it with the existing database of software are as follow:

- **CFSR World Weather Data:** it was downloaded from Soil and Water Assessment Tool website and added to Weather Database of software. The steps are as below:
- Drive C (where the SWAT software is installed)-> SWAT -> SWAT Database -> Weather Database -> import downloaded Access file of CFSR -> click save and close.
- **SWAT Soil Data:** it was downloaded from Indian Remote Sensing and GIS website. This Dataset contains soil map for whole State of India and numerous soil types then SWAT software's. This soil data is prepared by Indian Remote Sensing and GIS website of India for whole world. It covers all the world countries soil types. The downloaded soil data was used to replace the SWAT Usersoil dataset as shown in the steps below:
- Drive C (where the SWAT software is installed)-> SWAT -> SWAT Database -> Access file of SWAT2012 -> open Usersoil and delete all the soil types -> copy the soil types from downloaded soil data and pasted in Usersoil -> click the save button of file and close.
- **Soil WaterBase Data:** it was acquired from Indian Datasets for SWAT2012, which is available in Soil and Water Assessment Tool website. This waterbase data is include a notepad file that is consisting of different soil type codes. The soil waterbase data is required at next stage in HRU analysis part.

- **System Language and Date Format:** the system language format should be changed to United Stated English and the date format should be changed to MM/DD/YYYY.

5.6.3 SWAT Model Input Data

The input parameters for SWAT model should be prepared before starting with simulation process. While the inputs for model include Digital Elevation Model (DEM), Land Use Land Cover map, Soil map and Meteorological data. Each input is briefly discussed as below:

- Projected Digital Elevation Model (DEM): for more details refer to section 5.1.
- Projected Land Use Land Cover (LULC): it is discussed in detail in section 5.4.
- Projected Soil Map: for detail and information refer to section 5.5.
- Meteorological data: these data includes daily rain fall data (given in Appendix I), daily solar radiation data, daily maximum and minimum temperature data, daily relative humidity data and daily wind speed data. The Farah River watershed includes 11 weather stations and the data was collected from Hydrology Department of Ministry of Water and Energy of Afghanistan. The SWAT model has its own format in notepad for the meteorological data and the data format is designed with three decimal degree number as shown in Fig. 5.11a All stations of precipitation, temperature, solar, relative humidity and wind speed have individually one common file in Notepad which contents detail information of all included stations like: ID, Name, Latitude, Longitude and Elevation of each station. These common files as shown in Fig. 5.11b are inserting in SWAT model in lieu of individual station.

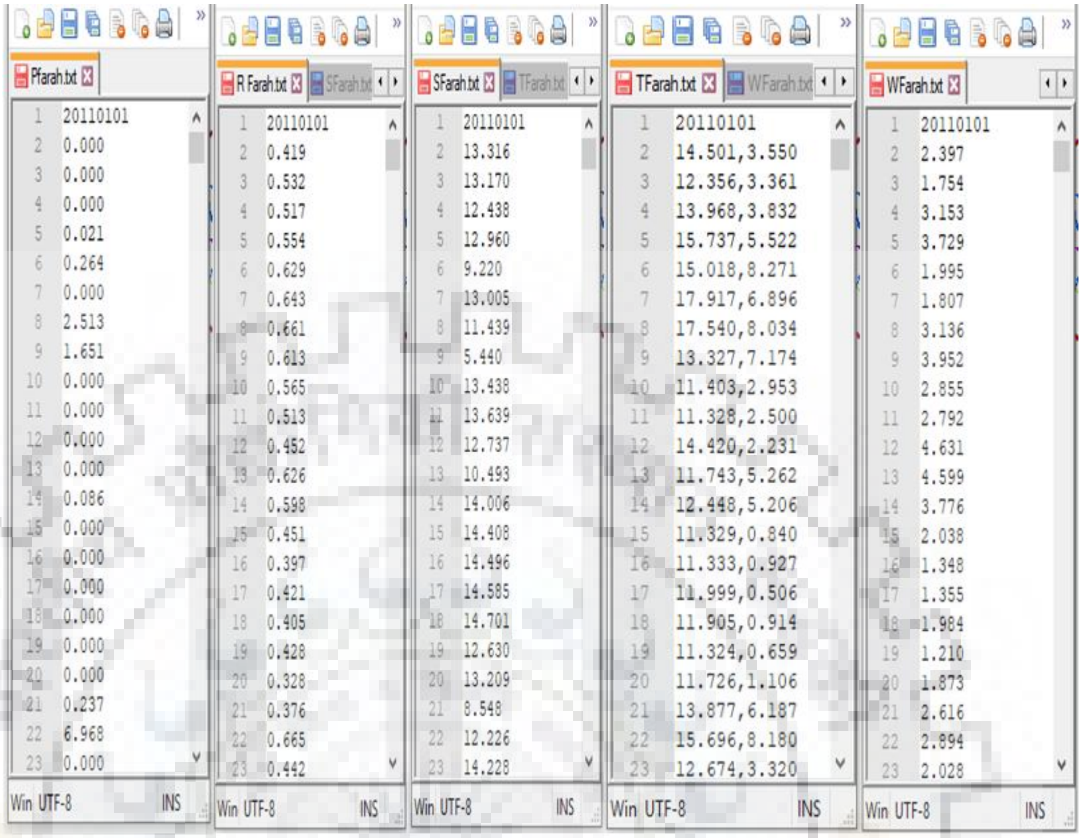


Fig. 5.11a: Meteorological Data inputs Format for SWAT Model.

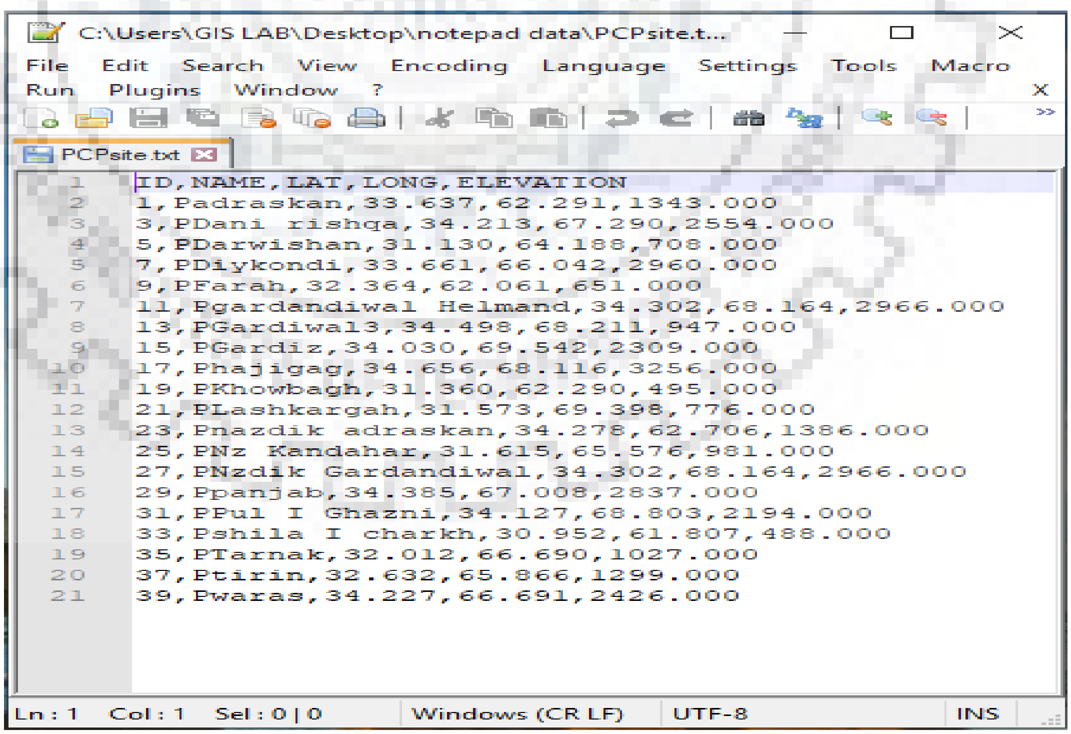


Fig. 5.11b: Main File of Imported Weather Stations into SWAT Model.

5.6.4 Running SWAT Model

The SWAT model will be ready to run after the completions of above 3 steps. For simulation of the SWAT model 5 steps are needed to be filled and these steps are followed as below:

5.6.4.1 SWAT project Setup

At first step, before opening the SWAT model in ArcGIS is to create a new folder in desktop and the created folder location should not be as sub-folder. The Steps are listed below for simulation of model for Farah River:

- Created a new folder in desktop by name of Farah River SWAT project.
- After the creation of the folder, ArcMap is opened and the SWAT tool is check on, then create new project option is clicked.
- A new window is appeared as shown in Fig.5.12 and it required defining the pat for saving the SWAT project.
- The Farah River SWAT project folder is Selected and then clicked ok.

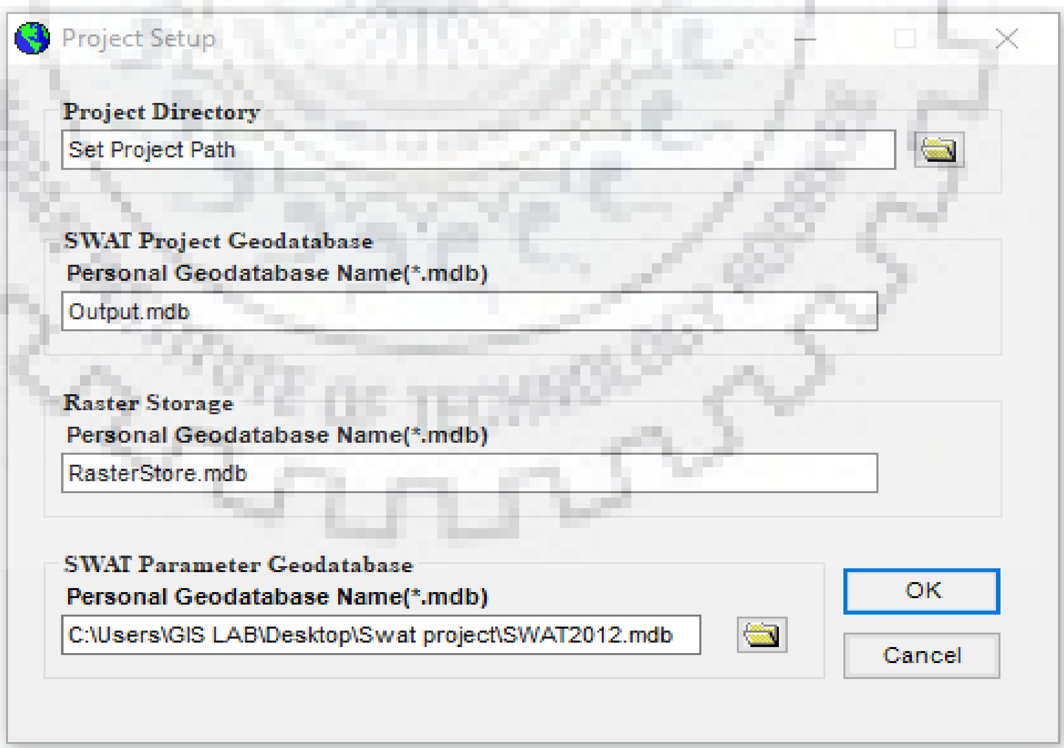


Fig. 5.12: SWAT Mosel Project Setup Window.

5.6.4.2 Watershed Delineator

In this step of SWAT simulation, the watershed for the given DEM of Farah River is generated to show the streams, basin, sub-basins, longest flow path etc. in Farah River. The steps are given below shows the generation of watershed in SWAT.

- The Watershed Delineator on SWAT tool clicked and the automatic watershed delineator is selected accordingly.
- New window is appeared as shown in Fig.5.13 and asked to add a projected DEM raster of Farah River to DEM setup section.

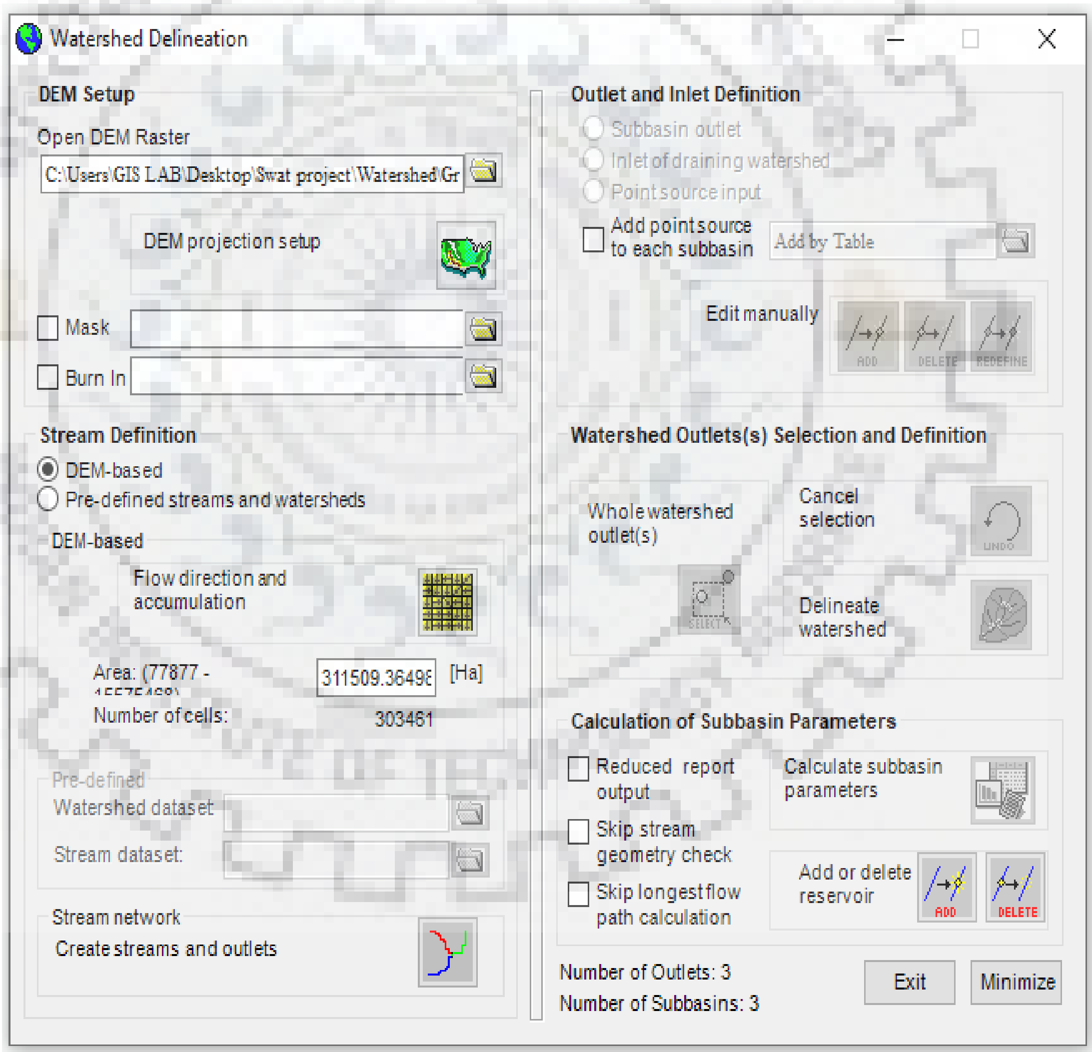


Fig. 5.13: SWAT Model Watershed Delineator Window.

- After added DEM, DEM projection setup is opened to define the unit of Y axis.
- A next step is the stream definition section; the flow direction and accumulation options are clicked and remained by default other options. In the result it given the calculated area in Hectare and cell numbers.
- Stream definition part is followed by stream network section. By clicking this icon, the streams and outlets are generated for watershed of area of interest.
- Next step is followed by inlet and outlet definition section and it allow us to select the watershed outlet. After selection of watershed outlet manually, the watershed delineated option is clicked and watershed is delineated for Farah River as shown in Fig. 5.14.

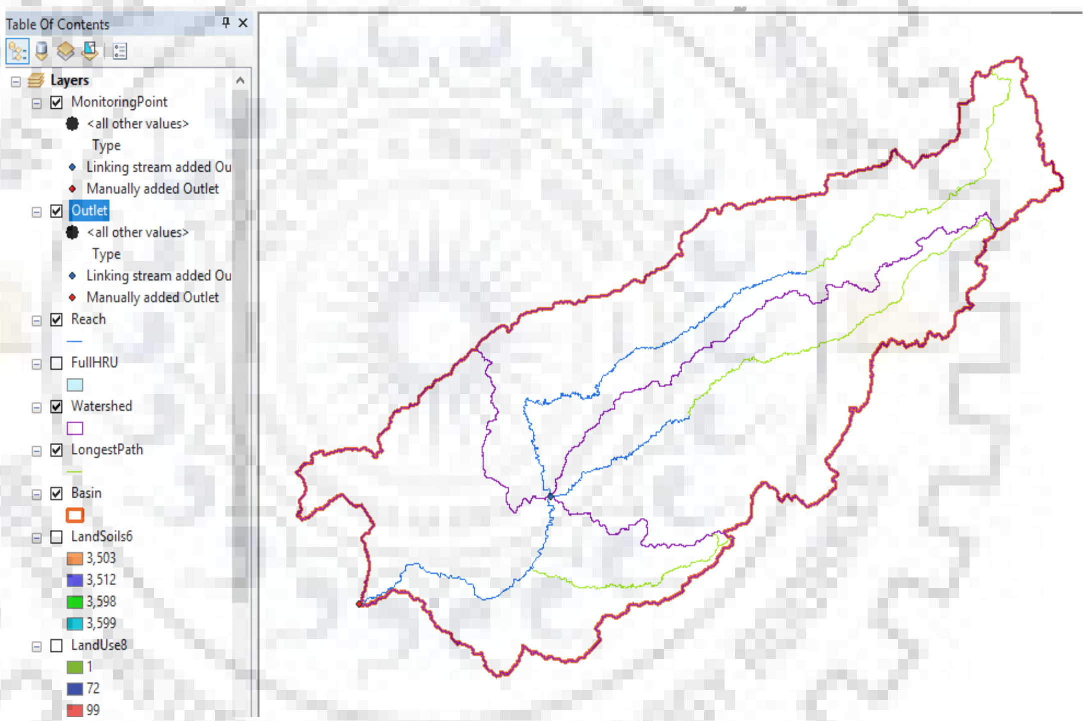
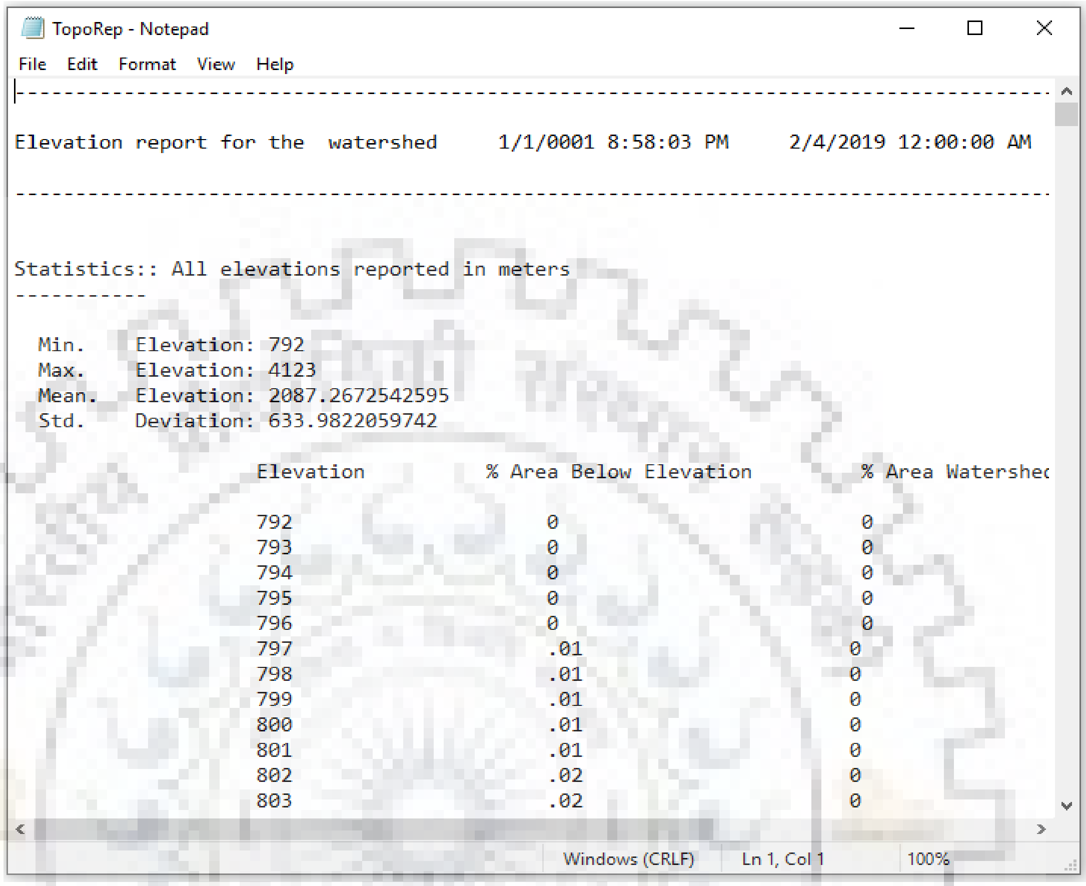


Fig. 5.14: Watershed of Farah River Given by SWAT Model.

- After watershed delineation, the next step is calculation of sub-basin parameters in study area. This option is calculates the sub-basins number, the longest flow path and number of outlets in a watershed. With the finishing of this step, the watershed delineation process for Farah River is completed and clicked exit.
- After completion of watershed delineation process, a watershed report is given by model. This gives information and details about percentage of area available, each subbasin minimum and maximum elevation value for Farah watershed as shown in Fig. 5.15.



```
TopoRep - Notepad
File  Edit  Format  View  Help
-----------------------------------------------------------------------------------------

Elevation report for the  watershed     1/1/0001 8:58:03 PM     2/4/2019 12:00:00 AM

-----------------------------------------------------------------------------------------


Statistics:: All elevations reported in meters
-----------

  Min.    Elevation: 792
  Max.    Elevation: 4123
  Mean.   Elevation: 2087.2672542595
  Std.    Deviation: 633.9822059742

                    Elevation          % Area Below Elevation          % Area Watershed

                    792                     0                          0
                    793                     0                          0
                    794                     0                          0
                    795                     0                          0
                    796                     0                          0
                    797                     .01                        0
                    798                     .01                        0
                    799                     .01                        0
                    800                     .01                        0
                    801                     .01                        0
                    802                     .02                        0
                    803                     .02                        0

Windows (CRLF)    Ln 1, Col 1    100%
```

Fig. 5.15: SWAT Model Watershed Report.

5.6.4.3 Hydraulic Response Unit (HRU) Analysis

Hydraulic Response Unit Analysis section is the critical part of the model, which is including the analysis of land use land cover, soil map and slope of the watershed area. The watershed delineator divided the watershed into sub-basin, while HRU dividing each sub-basin into many parts. Each HRU will have same or different type of soil, land use and slope. Farah River watershed is consisting of 24 HRUs. The steps for generation of HRU are shown below:

- The HRU definition process is started with importing of projected land use land cover of Farah River into the model as shown in Fig. 5.16. It is followed by selection of “Grid Field” option and selected the “Value”. In “Lookup Table part”, a land use code in made in Notepad and imported the same file into the model. This process is completed with clicking on reclassified option.

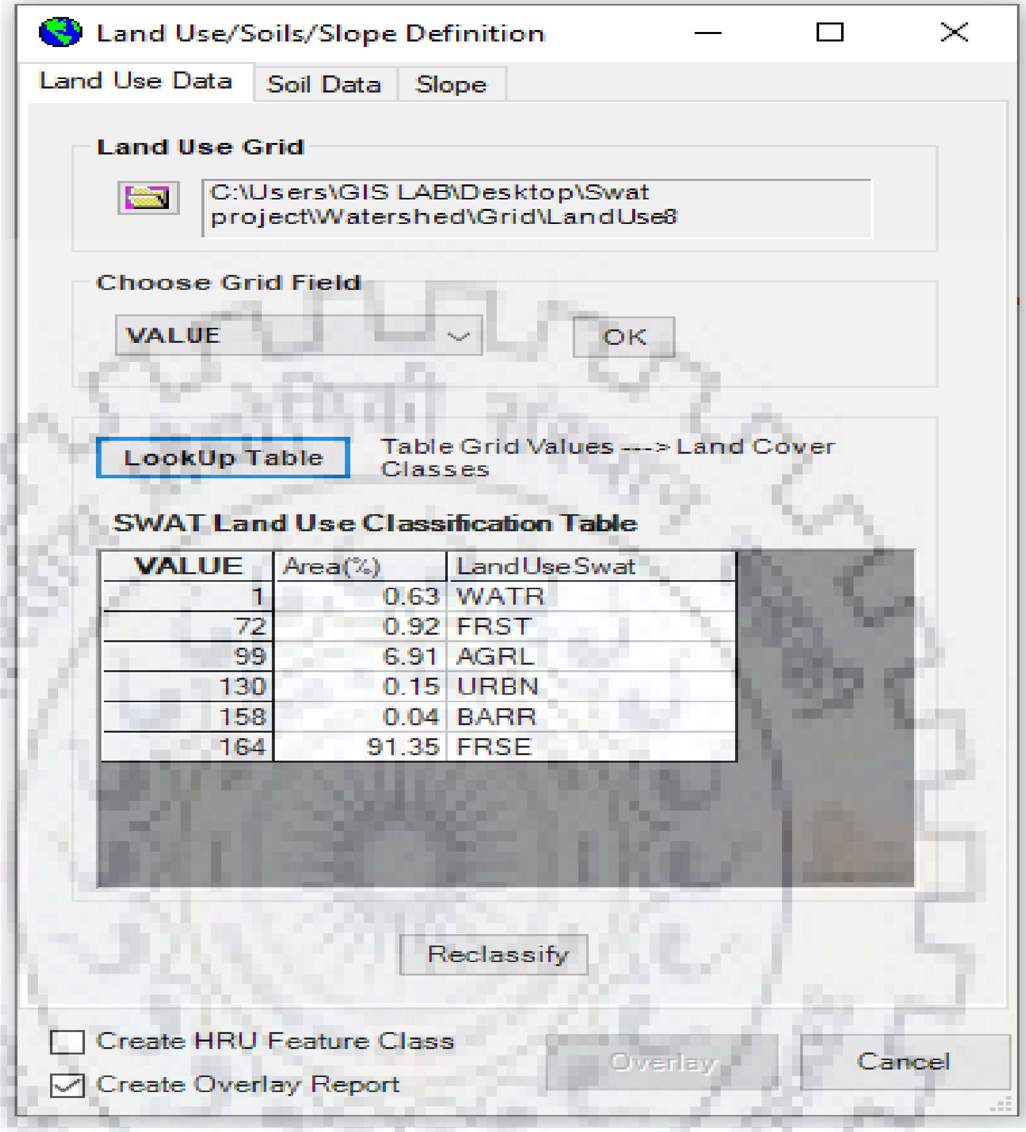


Fig. 5.16: SWAT Model HRU Definition of Land Use Window.

- After land use reclassification, the projected soil map of Farah River is imported to model as shown in Fig. 5.17. Same process is followed for soil map as we used for land use. The “Value” option is selected in “Grid Field”; meanwhile, in Soil database the usersoil option is selected. In “Lookup Table part”, the Soil Waterbase Notepad file is imported, which was already downloaded and discussed in model modification part. This process is completed with clicking on reclassified option.

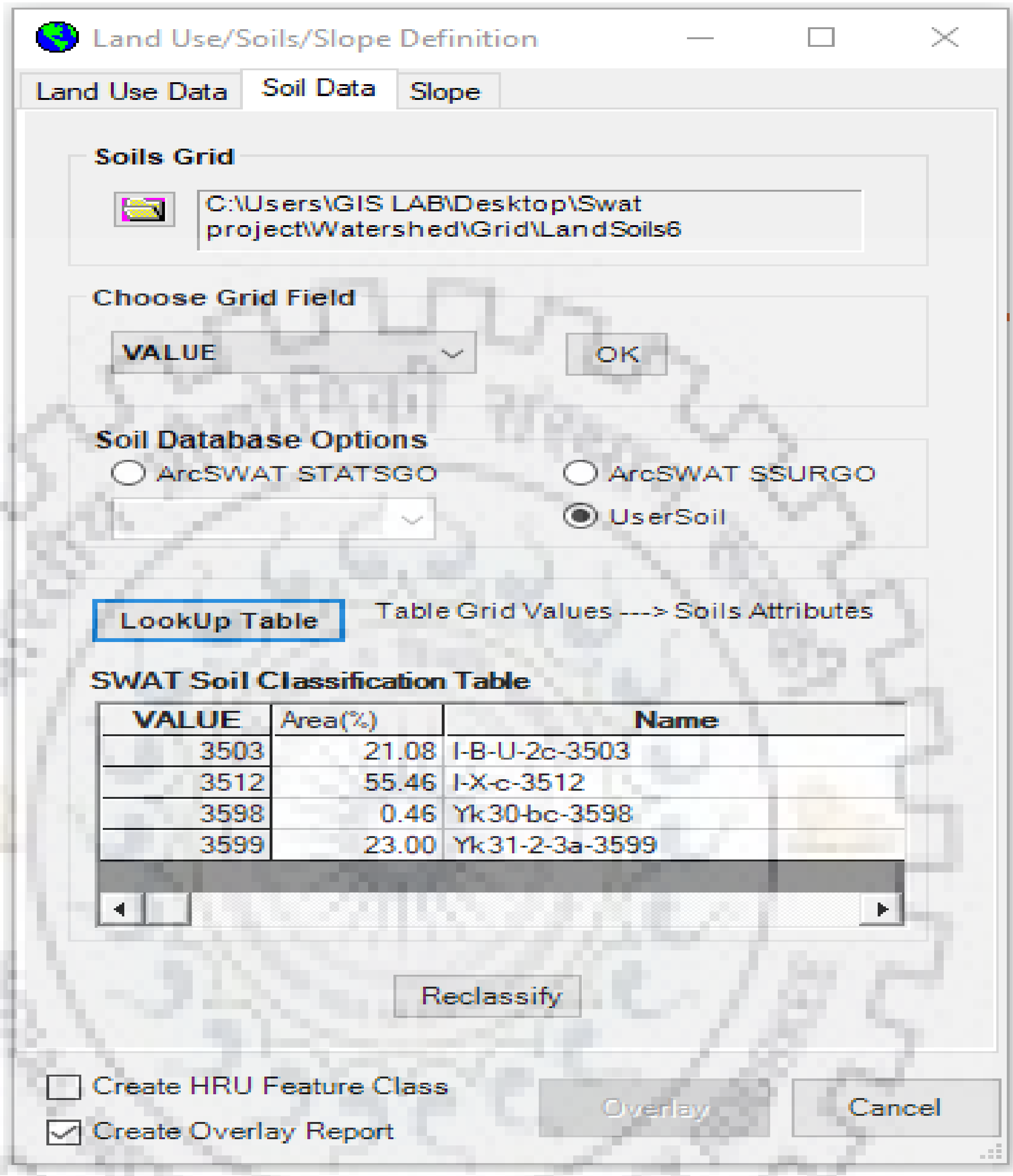


Fig. 5.17: SWAT Model HRU Definition of Soil Map Window.

- The slope in SWAT model is generated automatically from the DEM of Farah River, which was imported at the first step of model simulation. The slope window is shown in Fig. 5.18 showing different parameters to be filled. In “Slope Discretization” portion, the “Multiple Slope” option is selected and at “Slope Classes” portion, 5 classes are selected for Farah River watershed and each Class the upper limited classes are defined accordingly.

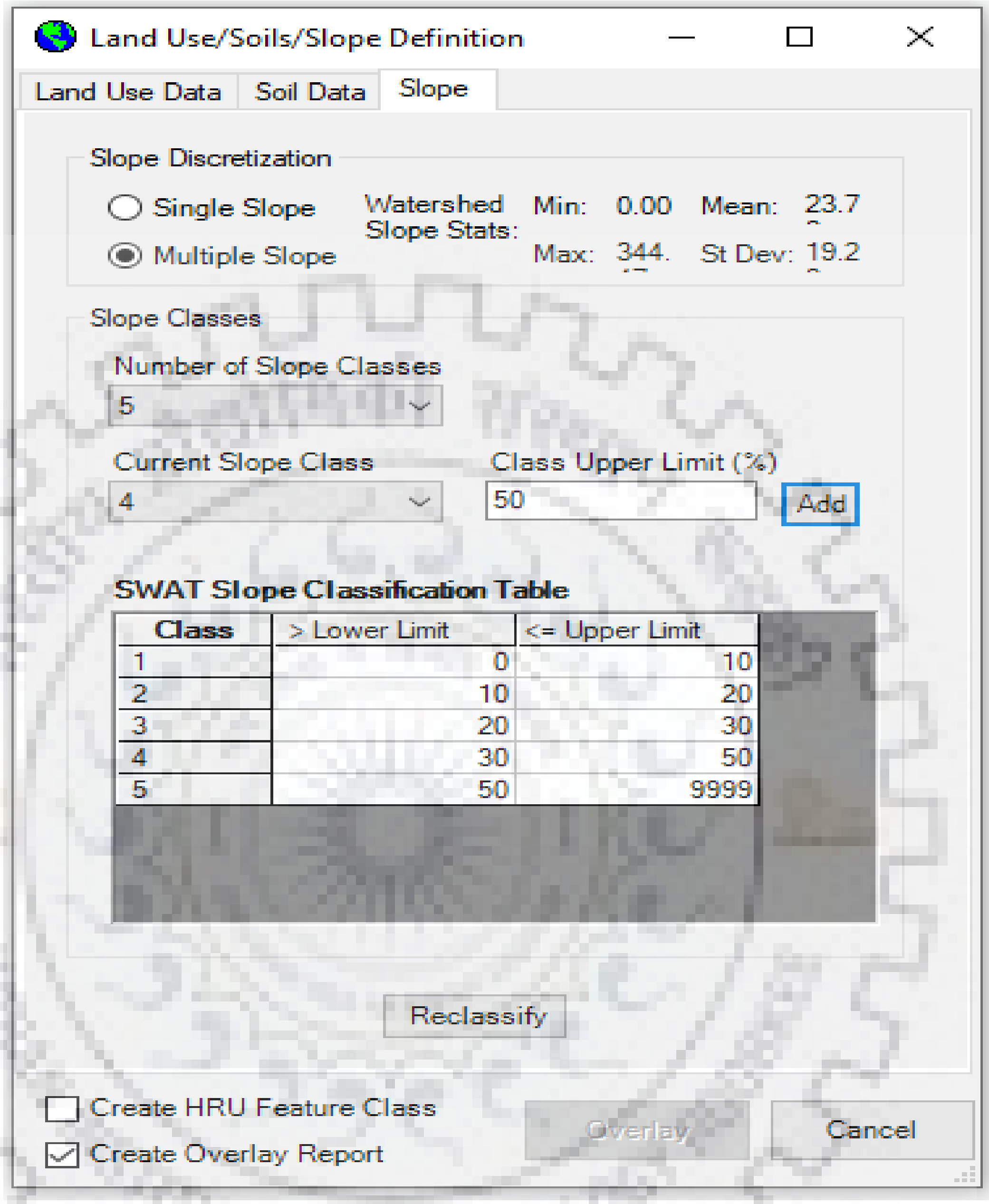


Fig. 5.18: SWAT Model HRU Definition of Slope Window.

- After inserting and reclassifying all these three inputs data in HRU section, the overlay option is clicked to generate the HRU feature for Farah watershed.
- The next step after overlay process is "HRU Definition". The "HRU Definition" window is shown in Fig. 5.19. This process is started with selection of "Multi Slope" and percentage options in HRU Definition and Threshold sections respectively. The land use percentage over sub-basin area, soil class percentage over land use area and slope class

percentage over soil area are taken for Farah River as 15%, 10% and 10% respectively. The "HRU Definition" section is finished by clicking on "Create HRU" button.

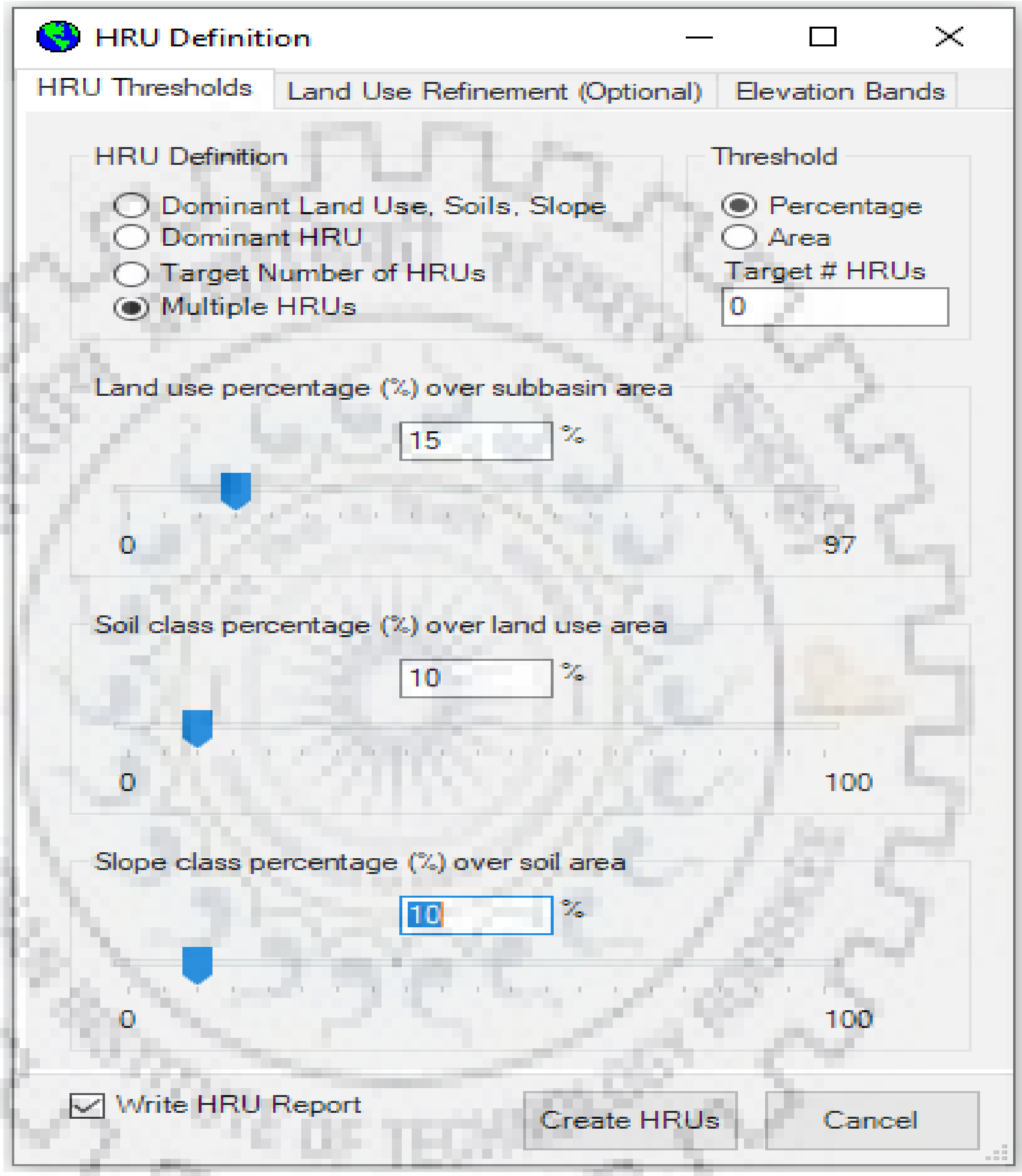
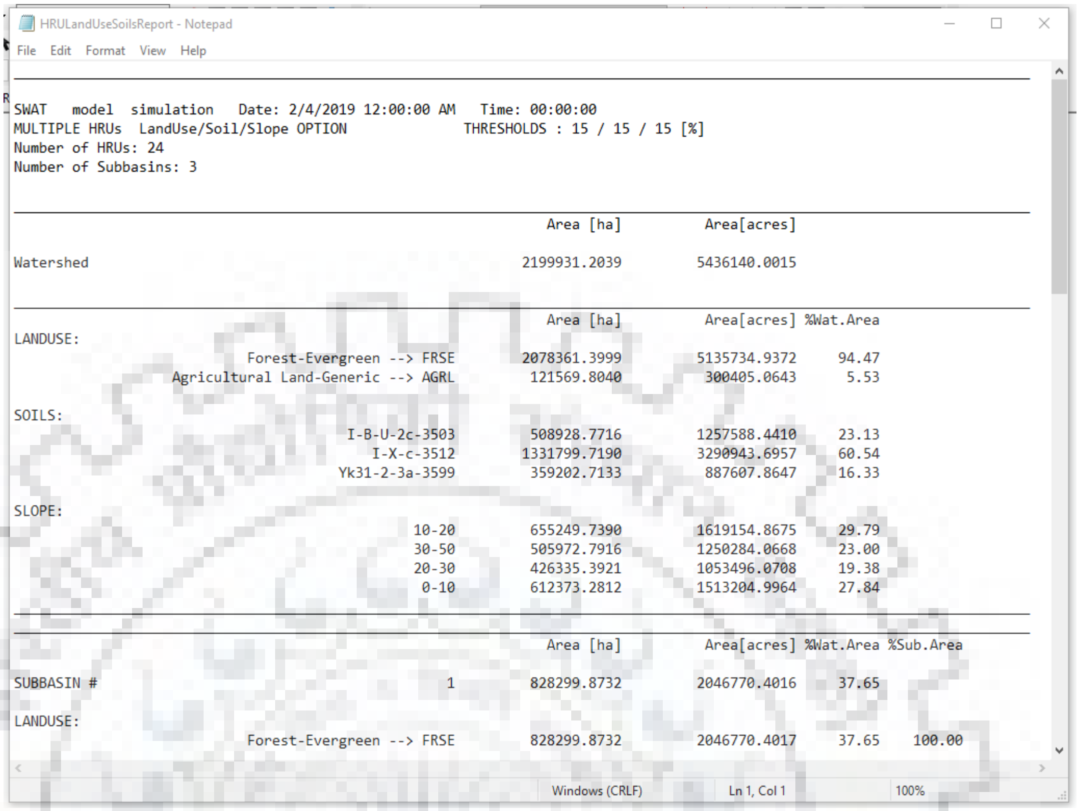


Fig. 5.19: SWAT Model HRU Definition Window.

- With the completion of above processes, model provided HRU Analysis Reports as shown in Fig. 5.20. This report presents more information about each HRU of Farah River watershed.



```
SWAT   model  simulation   Date: 2/4/2019 12:00:00 AM   Time: 00:00:00
MULTIPLE HRUs  LandUse/Soil/Slope OPTION            THRESHOLDS : 15 / 15 / 15 [%]
Number of HRUs: 24
Number of Subbasins: 3

                                                     Area [ha]         Area[acres]

Watershed                                         2199931.2039        5436140.0015

                                                     Area [ha]         Area[acres] %Wat.Area
LANDUSE:
                           Forest-Evergreen --> FRSE    2078361.3999    5135734.9372     94.47
                  Agricultural Land-Generic --> AGRL     121569.8040     300405.0643      5.53

SOILS:
                                     I-B-U-2c-3503     508928.7716    1257588.4410     23.13
                                       I-X-c-3512    1331799.7190    3290943.6957     60.54
                                    Yk31-2-3a-3599     359202.7133     887607.8647     16.33

SLOPE:
                                             10-20     655249.7390    1619154.8675     29.79
                                             30-50     505972.7916    1250284.0668     23.00
                                             20-30     426335.3921    1053496.0708     19.38
                                              0-10     612373.2812    1513204.9964     27.84

                                                     Area [ha]         Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                       1     828299.8732    2046770.4016     37.65

LANDUSE:
                           Forest-Evergreen --> FRSE     828299.8732    2046770.4017     37.65    100.00
```

Fig. 5.20: SWAT Model Final HRU Analysis Report.

5.6.4.4 Write Input Tables

This section dealing with two parts: Weather Stations and Write SWAT Inputs Tables. Each part is discussed briefly in below steps:

- The Weather Stations window shows 6 parameters to be filled for running the model. As shown in Fig. 5.21 in Weather Generator Data section we have to select a weather stations and I had selected the CFSR World (refer to input data section for SWAT model) weather station, which contents 177575 weather stations. Similarly for other sections like Rainfall Data, Temperature Data, Relative Humidity Data, Solar Radiation Data and Wind Speed the main Notepad files of stations are inserted. With clicking on the "OK" button, all the selected data are imported to model.
- When the above data is successfully imported into the model. Model is required to create tables for the inputs data in order to run the simulation for Farah River. While the "Write SWAT Input Tables" has this responsibility to create tables for each imported inputs data. The "Write SWAT Input Tables" window shown in Fig. 5.22. The process is started by

Check on the first table box, then "Select all Button" option is selected and finally the "Create Tables" button is clicked to finish the process.

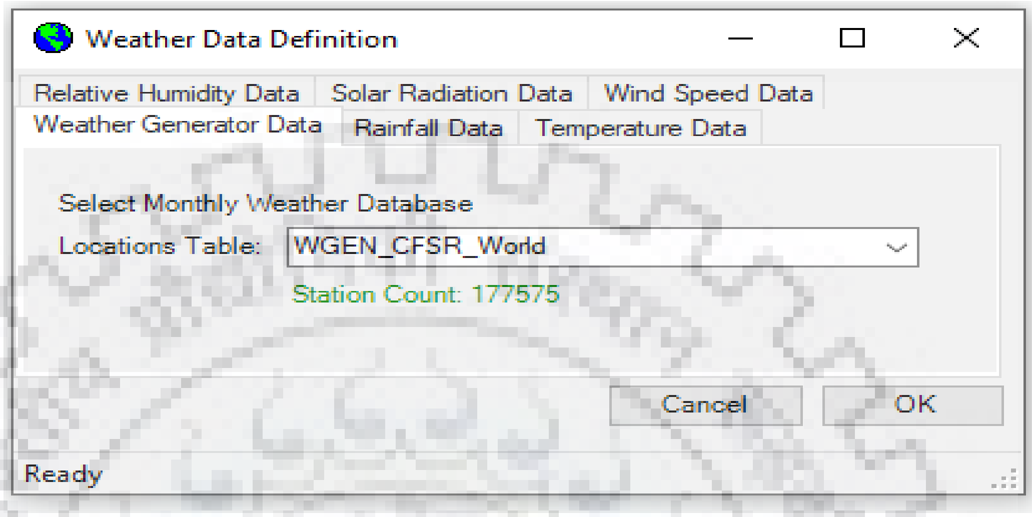


Fig. 5.21: SWAT Model Weather Data Definition Window.

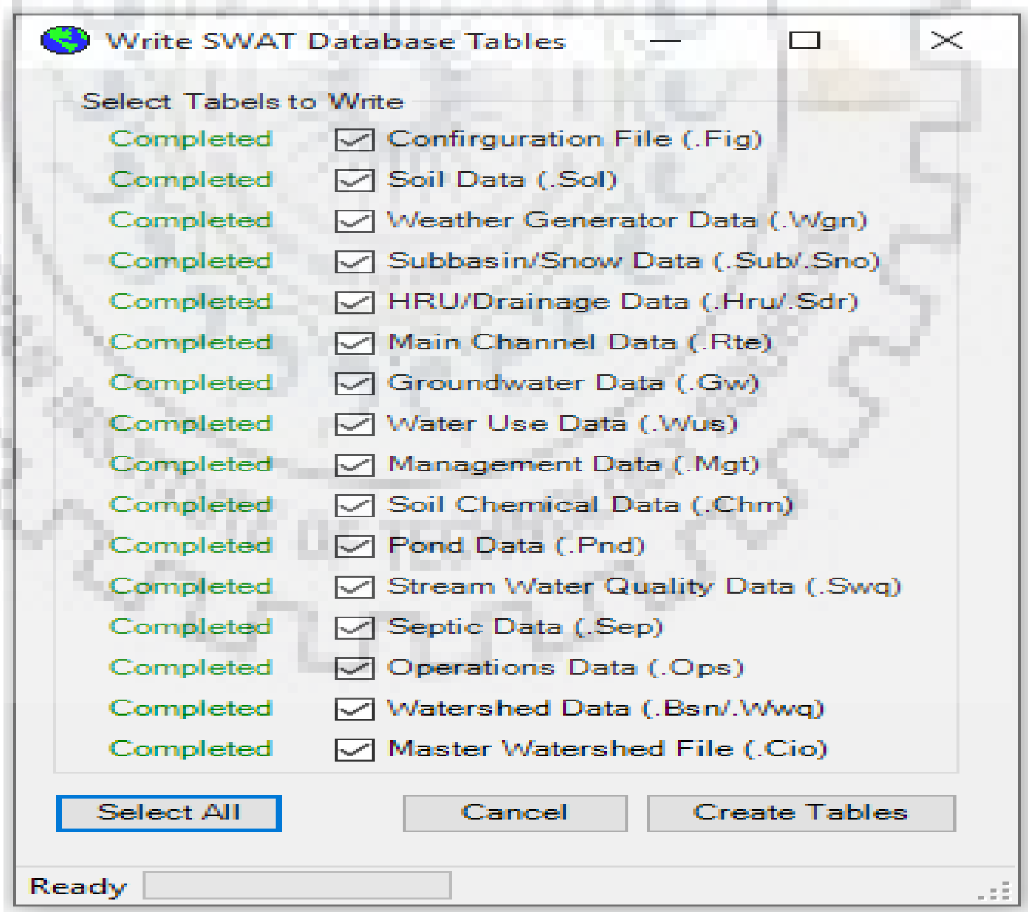


Fig. 5.22: SWAT Model Database Table Window.

5.6.4.5 SWAT Model Simulation

With successes in completion of pervious sections the "Run SWAT" option is activated to run the simulation for Farah River. The SWAT Simulation section is having Run SWAT, Read SWAT Output, Set Default Simulation and Manual Calibration option and each section is discussed in details as follow:

- The Run SWAT window shown in Fig. 5.23, it presents many parameters to be defined. The "period of simulation" section, it needs to give the start and finish date of the simulation. The starting date of simulation in this case was 1/1/2011 and finishing date of simulation was 31/12/2016. The "Printout Settings" deals with outputs data format (daily, monthly and yearly) and outputs data needs to be printed by model after simulation. The important point in this portion is that we have to set 2or 3 years as warm-up period for the model. The output parameters are shown in the window and every developer will check its needed output parameters accordingly. The other parts in this section are recommended to be remained by default. By clicking on "Setup SWAT Run" the "Run SWAT" button is activated to run the simulation. The "Run SWAT" button is clicked and the model start to run the simulation for the given inputs. Meanwhile, the model given massage of "Successfully Completed" when the simulation is completed.

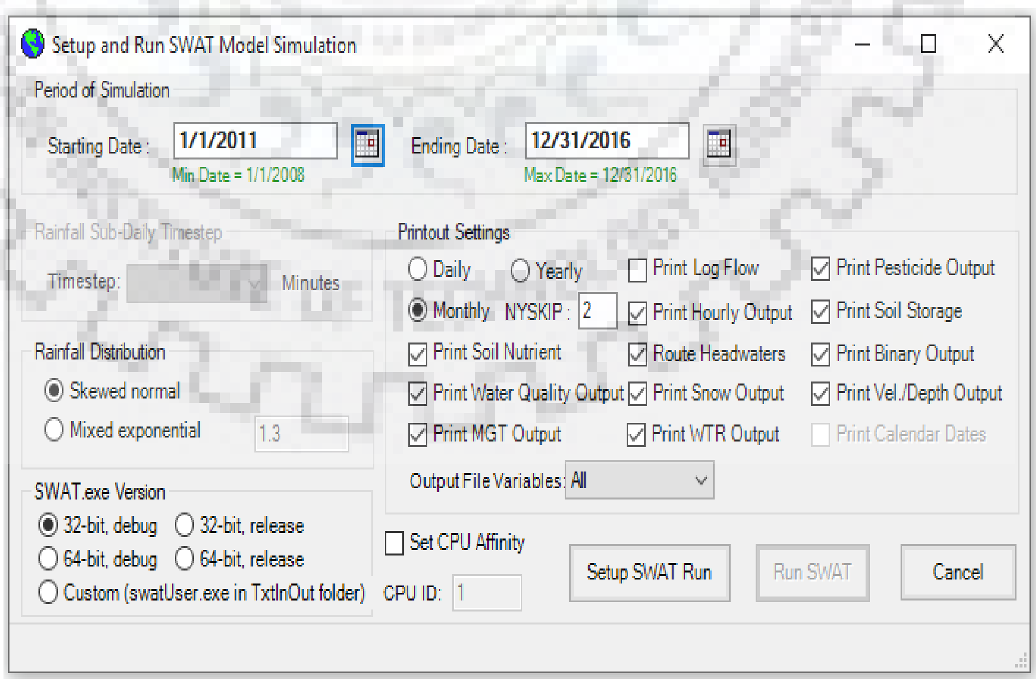


Fig. 5.23: Setup and Run SWAT Model Simulation Window.

- When the model successfully ran, it is required to import and saved the output data of the model in scenario of the created folder for SWAT. The "Read SWAT Output" window as showing in Fig. 5.24, having many output parameters. It is depend on User which output data he/she will need to select.

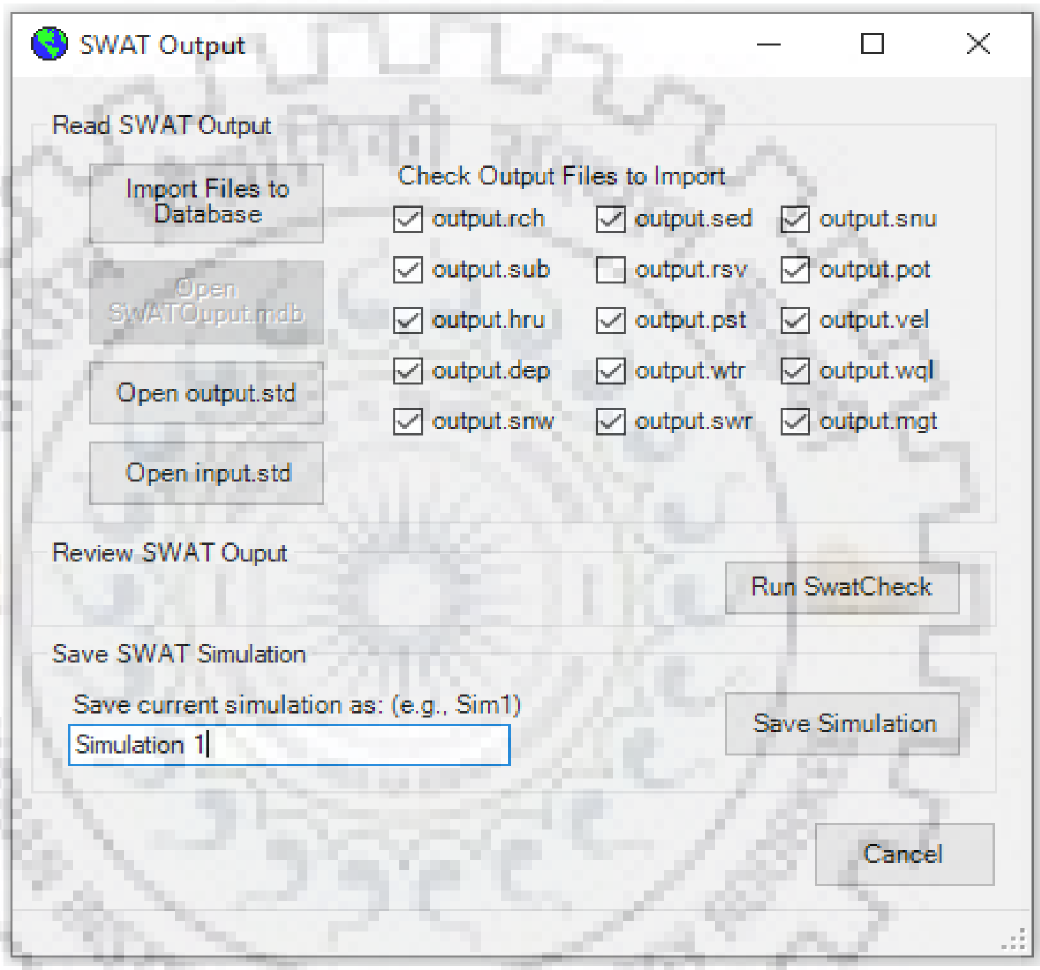


Fig. 5.24: SWAT Model Output Data Window.

- The "Run SWAT Check" option in "Read SWAT Output" is opened to check the outputs data of Farah River watershed directly from model like Hydrology, Sediment, Soil Erosion and etc. as shown in Fig. 5.25.
- All Hydrological models outputs are needed the calibration process to adjust the calculated data through the model with the observed data from site. The Calibration of SWAT model can be done manually by SAWT model with the given equation or with automatic software of SWAT-CUP.

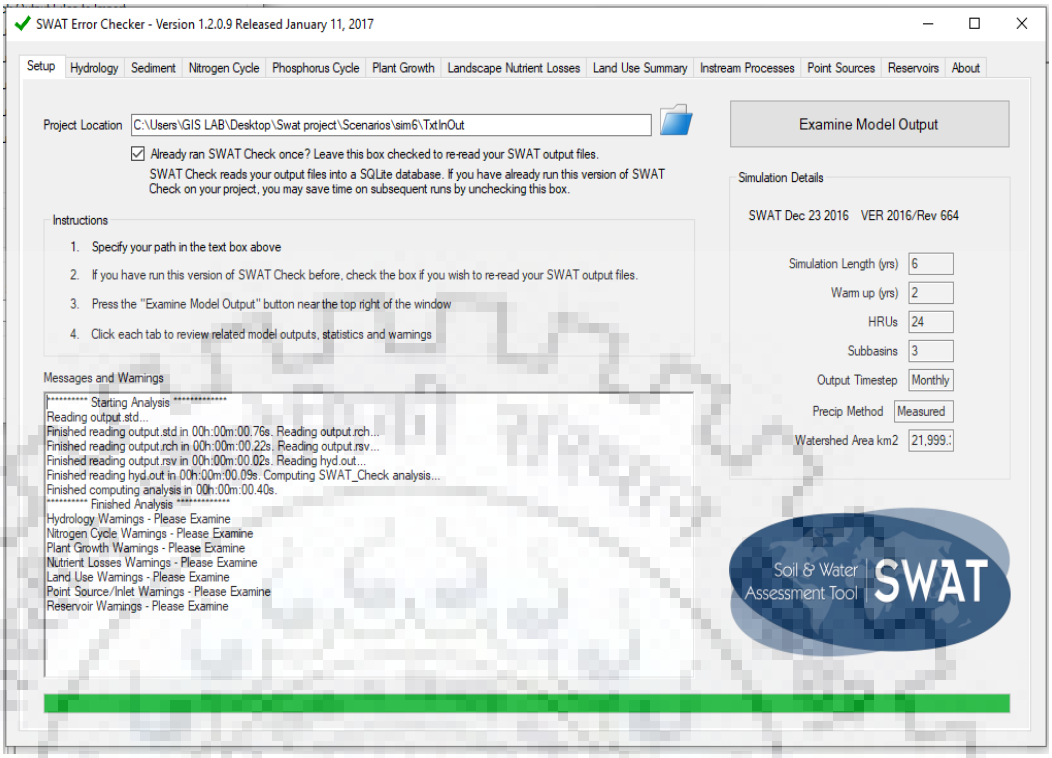


Fig. 5.25: SWAT Check Window of SWAT Model.

5.7 SWAT-CUP

The Calibration and Validation for SWAT model output data of Farah River are done with help of SWAT-CUP software. This software is dedicated only to Calibrate and Validate the output data of SWAT model.

5.7.1 Calibration

This process involves the comparison of model results with the observed runoff data of specific area at selected outlets. In calibration process, the model parameters are adjusted in such a way that the simulated results are matched with observed flow within some accepted limits. In this study, the discharge data of 3 years (from 2013 to 2015) is used for calibration. The calibration and validation have been tested with the coefficient of determination (R^2). The steps followed for calibration in SWAT-CUP software are as follows:

- New folder is created on desktop with the name of Farah River Calibration.

- SWAT-CUP software is opened and “New Project” selected. A window is appeared and needed some parameters to be filled like: Name of Project, Type of project, the area to be saved and file to be imported.
- The “Calibration Input” section is opened to select the parameters and define number of simulation. Four parameters, with 200 simulations have been selected for SWAT output data as shown in Fig. 5.26.

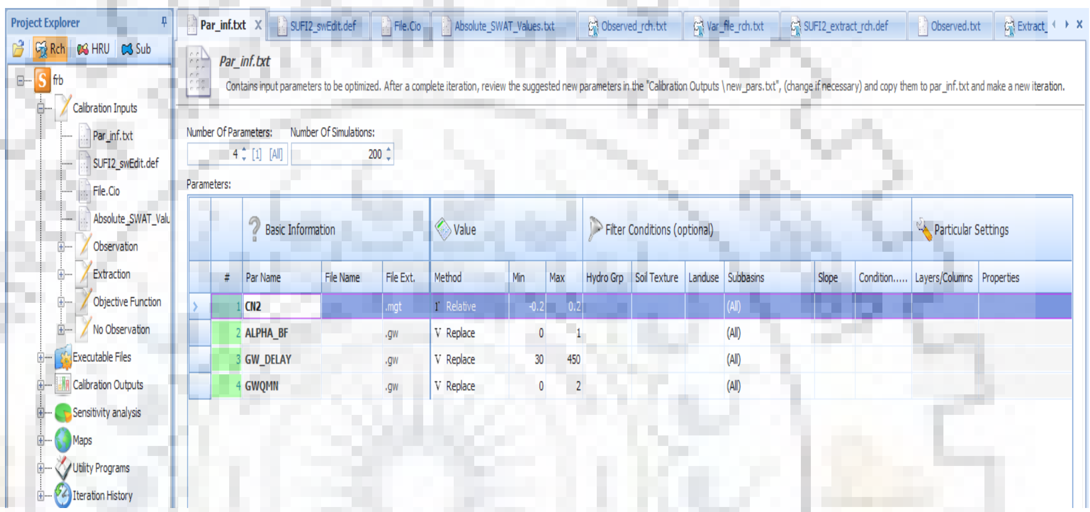


Fig. 5.26: SWAT-CUP Parameters Selection Window.

- In “Conversion” part it need to define the number of Variable, flow out and observed discharge for Farah River. The format of observed discharge as input for SWAT-CUP is shown in Fig. 5. 27.
- In “Extraction” portion the Flow outlet from basin(its outlet 1), number of variables(1 variable, only discharge), variable column number(column 7), total number of basin(3) and reaches(3),total number of HRU(24), start(2013) and finish(2015) date of simulation(exclude warm-up period) and time setup(monthly) are defined.
- In “Objective Function” part the objective function type (R^2), flow outlet (1), variable (1) and observed discharge are defined.
- In “No Observation” the number of variable (1) and number of observed data only (36 months) are defined.
- Save all changes and click the calibration button to start the process of calibration.

- After completion of calibration process, the simulation is saved. The R^2 value is checked which is 0.804 and the graphs of calculated and observed discharge data are compared for accuracy of the works by model.

Month	Year	Number					
1	2013	1	_	Flow_out_	1	Flow_out_1_2013	23.943
2	2013	2	_	Flow_out_	2	Flow_out_2_2013	41.607
3	2013	3	_	Flow_out_	3	Flow_out_3_2013	38.384
4	2013	4	_	Flow_out_	4	Flow_out_4_2013	59.833
5	2013	5	_	Flow_out_	5	Flow_out_5_2013	35.214
6	2013	6	_	Flow_out_	6	Flow_out_6_2013	2.1667
7	2013	7	_	Flow_out_	7	Flow_out_7_2013	4.645
8	2013	8	_	Flow_out_	8	Flow_out_8_2013	3.115
9	2013	9	_	Flow_out_	9	Flow_out_9_2013	2.701
10	2013	10	_	Flow_out_	10	Flow_out_10_2013	2.509
11	2013	11	_	Flow_out_	11	Flow_out_11_2013	7.667
12	2013	12	_	Flow_out_	12	Flow_out_12_2013	6.322
1	2014	13	_	Flow_out_	13	Flow_out_13_2014	44.193
2	2014	14	_	Flow_out_	14	Flow_out_14_2014	42.548
3	2014	15	_	Flow_out_	15	Flow_out_15_2014	94.526
4	2014	16	_	Flow_out_	16	Flow_out_16_2014	135.667
5	2014	17	_	Flow_out_	17	Flow_out_17_2014	93.417
6	2014	18	_	Flow_out_	18	Flow_out_18_2014	17.954
7	2014	19	_	Flow_out_	19	Flow_out_19_2014	4.466
8	2014	20	_	Flow_out_	20	Flow_out_20_2014	3.241
9	2014	21	_	Flow_out_	21	Flow_out_21_2014	1.025
10	2014	22	_	Flow_out_	22	Flow_out_22_2014	4.054
11	2014	23	_	Flow_out_	23	Flow_out_23_2014	8.546
12	2014	24	_	Flow_out_	24	Flow_out_24_2014	11.848

Fig. 5.27: SWAT-CUP Input Discharge Format.

5.7.2 Validation

Validation is the comparison of model output with an independent observed dataset not used in the calibration without further adjustment of model parameters. The validation has been preformed for the SWAT model with the help of SWAT-CUP for the remaining data that is not used in calibration process. The independent observed discharge that is given to SWAT-CUP was year 2016 which contains 25 percent of the total observed data. The validation process in SWAT-CUP is same as Calibration process only the observed discharge will be changed.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 CALCULATION OF DISCHARGE

In the river or basin, the more difficult step is estimation of discharge due to flow of the river that depends on the number of processes that happen in the basin. In the hydrological modeling, SWAT model is used for the calculation of river flows. SWAT model can be used in conjunction with ArcGIS to calculate the main parameters for discharge; such as surface runoff from rainfall, ground water flow, snow melting from glaciers and evaporation of surface runoff.

The discharge for Farah River is calculated using SWAT model. The input parameters for model are DEM data, land use land cover map, soil map and daily meteorological data for 6 years. The DEM for study area is downloaded from USGS website with 90 x 90 m resolution. The Land use and land cover image of river was organized as a result of supervised classification in ArcGIS. The supervised image classification works is starting with the training are drawn on the image and ArcGIS can find all further pictures with the same spectral characteristics. The Farah River's land use represents water bodies, agriculture area, and barren land in mountains as well as area covered by forest. Similarly for generation of soil map, the World soil map is downloaded from Food and Agriculture Organization of the United Nations (FAO) website and with the help of ArcGIS the site of interest is clipped. Meanwhile, Farah soil map presents seven different types of soil as shown in Fig. 5.10. The meteorological data for the study area was collected from Hydrology department of Ministry of Water and Energy of Afghanistan. It includes daily precipitation, daily relative humidity, daily solar radiation, daily wind speed and daily maximum and minimum temperature.

On other hand, the observed discharge data was obtained from Ministry of Energy and Water of Afghanistan, in order to use for evaluation of the SWAT model in Swat-Cup. These data's are given for the period of 6 years from January 2011 to December 2016. The observed discharges are available in monthly basis format and recorded at outlet of the watershed near to Farah city.

The discharge for Farah River has been calculated with help of SWAT model. The model has divided the watershed area into 3 sub basins and the discharge for each sub basin outlets has been calculated. The area of each sub basin evaluated by SWAT model as shown in Fig. 6.1 are 6682 km^2, 7068 km^2 and 8251 km^2 for basin 1, 2 and 3 respectively.

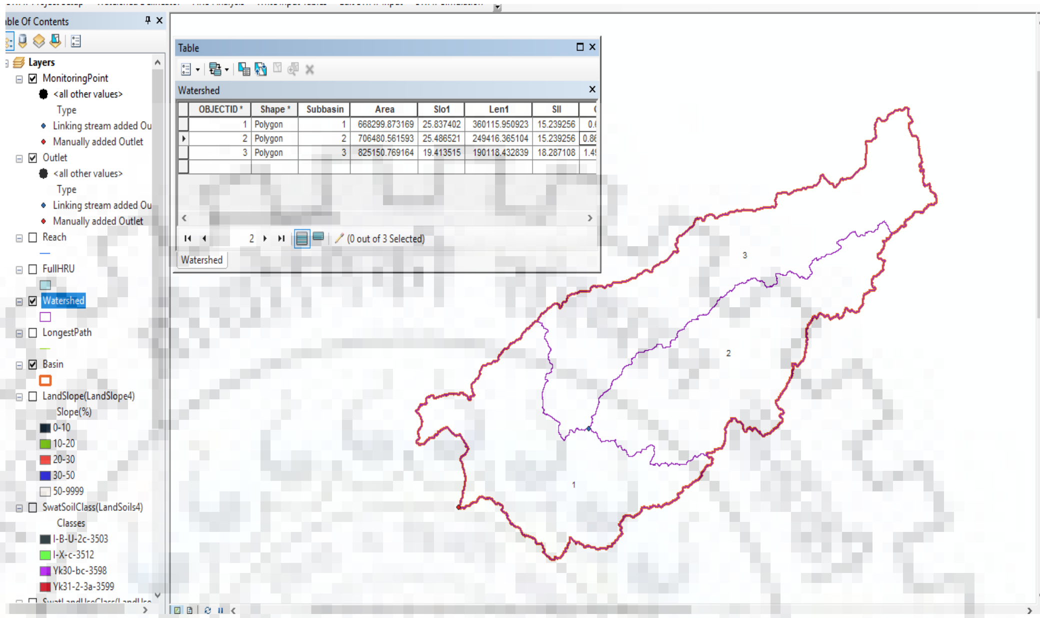


Fig. 6.1: Calculated Area of Sub basin.

By inserting inputs data into SWAT model and model has simulated successfully. The important outputs have been given for SWAT model that are shown in Table 6.1 like; amount of rain fall in watershed, surface run off, return flow, evaporation etc. in Farah River watershed area.

Table 6.1: Hydrological Values of Catchment Given by SWAT Model.

S. No.	Name of Output Parameter	Value Adopted by Model (mm)
1	Annual Precipitation	408.8
2	Surface Runoff	36.81
3	Evaporation and Transpiration	237.2
4	Return Flow	40.32
5	Percolation to Shallow Aquifer	64.48
6	Recharge to deep Aquifer	3.22

6.2 SWAT MODEL CALIBRATION AND VALIDATION

Calibration is the process of modification of model parameters within suggested ranges to match the simulated output with observed data. This process involves the comparison of model results with the recorded runoff data of specific area at selected outlets. In calibration process, the model parameters are adjusted in such a way that the simulated results are matched to the recorded flow outline within some accepted criteria. The calibration can also be done manually through SWAT model or automatic calibration software of SWAT-CUP. The parameters used by SWAT-CUP model for calibration is presented in Table 6.2. In this study, the discharge data of 3 years from 2013 to 2015 is used for calibration. The calibration and validation has been tested with the coefficient of determination (R^2). Validation is the comparison of model output with an independent observed dataset (not used in the calibration) without further adjustment of model parameters. This independent observed discharge is for year 2016 which contains 25 percent of the total observed data.

Table 6.2: Parameters of SWAT-CUP Used for Calibration and Validation in Farah River

Parameter & abbreviation	Calibrated value	Range
Initial CN ll values (CN2)	0.007	-0.2 – 0.2
Base flow recession alpha factor (days) (ALPHA_BF)	0.2475	0 - 1
Ground Water (GW_DELAY)	54.14999	30 - 450
Threshold water depth in the shallow aquifer for flow (mm) (GWQMN)	1.4250	0 - 2

This calibration process is essential to reduce the error generated by the estimation made throughout the simulations used by the Swat model. The calculated discharge data obtained from the SWAT Model has been calibrated in SWAT-CUP with the actual data observed from available gauging stations at the area of interest. The result generated by SWAT-CUP for the comparison of the observed discharge with the calculate discharge is shown in Fig. 6.2.

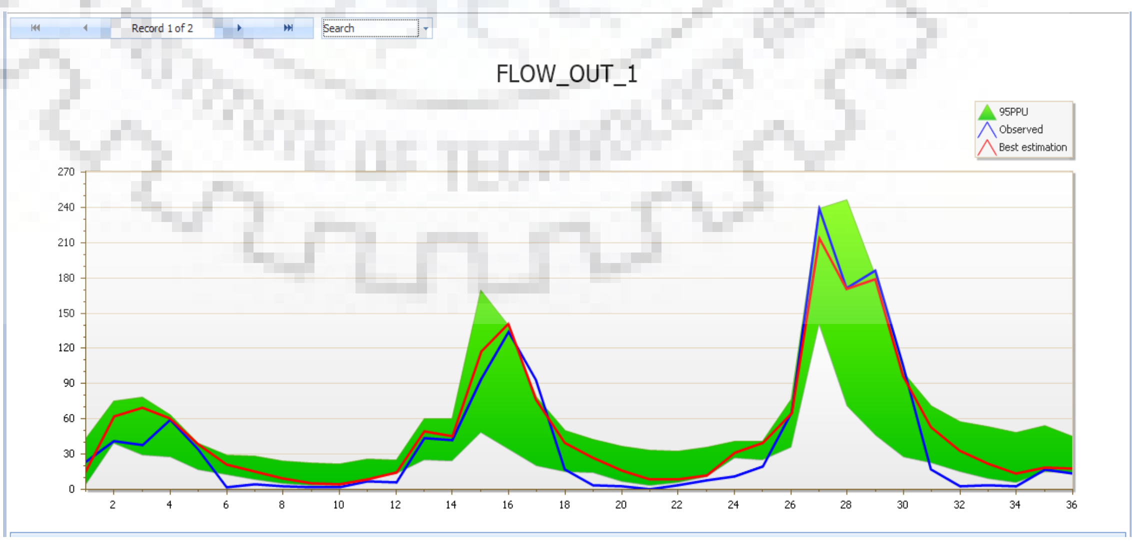


Fig. 6.2: Calibrated data of SWAT Model in SWAT-CUP.

The accuracy of SWAT model is determined by coefficient of determination (R^2) and for the present model it is 0.804 as shown in Fig. 6.3.

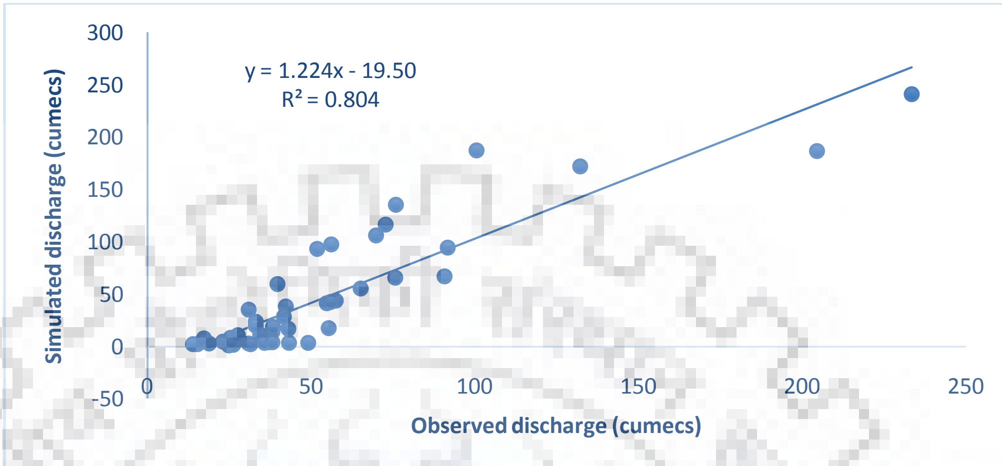


Fig. 6.3: Calibration of Simulated Discharge with Observed Discharge.

The validation has been preformed for the SWAT model with the help of SWAT-CUP for the remaining data that is not used in calibration process. The coefficient of determination (R^2) for model output is 0.815 as presented in Fig. 6.4.

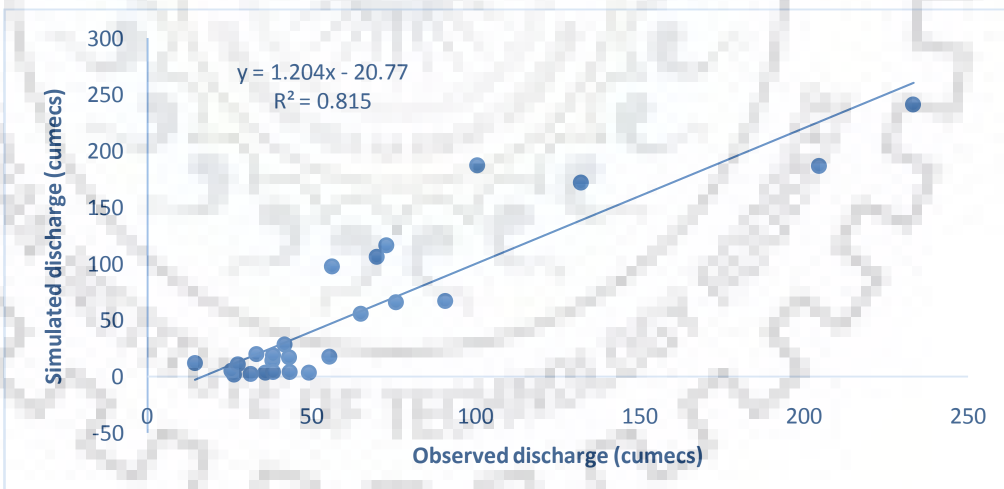


Fig. 6.4: Validation of Simulated Discharge with Observed Discharge.

Bar plots is shown below for the observed and simulated annual flow volumes for Farah River Basin. The Table 6.3 and Fig. 6.5 show a comparison between observed and simulated annual flow discharges for the ARC SWAT Model output. Average discharges for a period of 4 years were then computed from daily precipitation data of the same period.

Table 6.3: Observed and calculated discharges of sub-basin 1 using SWAT Tool

	2013		2014		2015		2016	
	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated
Jan	23.943	16.7	44.193	50.08	20.073	40.11	18.886	18.67
Feb	41.607	62.86	42.548	45.59	65.678	64.93	187.014	172
Mar	38.384	70.13	94.526	117.7	241.322	215.4	55.703	81.69
Apr	59.833	61.35	135.67	142.4	171.967	171.1	116.569	123.4
May	35.214	39.16	93.417	77.03	187.712	180	97.501	82.68
Jun	2.1667	22.14	17.954	40.1	106.047	97.29	28.683	43.84
Jul	4.645	15.89	4.466	27.66	17.821	53.68	4.001	28.44
Aug	3.115	9.739	3.241	16.58	3.457	33.48	2.352	16.71
Sep	2.701	6.042	1.025	9.507	3.966	22.34	1.745	10.28
Oct	2.509	5.24	4.054	9.385	3.574	13.88	4.897	10.19
Nov	7.667	9.573	8.546	12.18	17.274	18.95	11.029	12.89
Dec	6.322	15.31	11.848	31.7	14.007	18.63	67.198	72.36

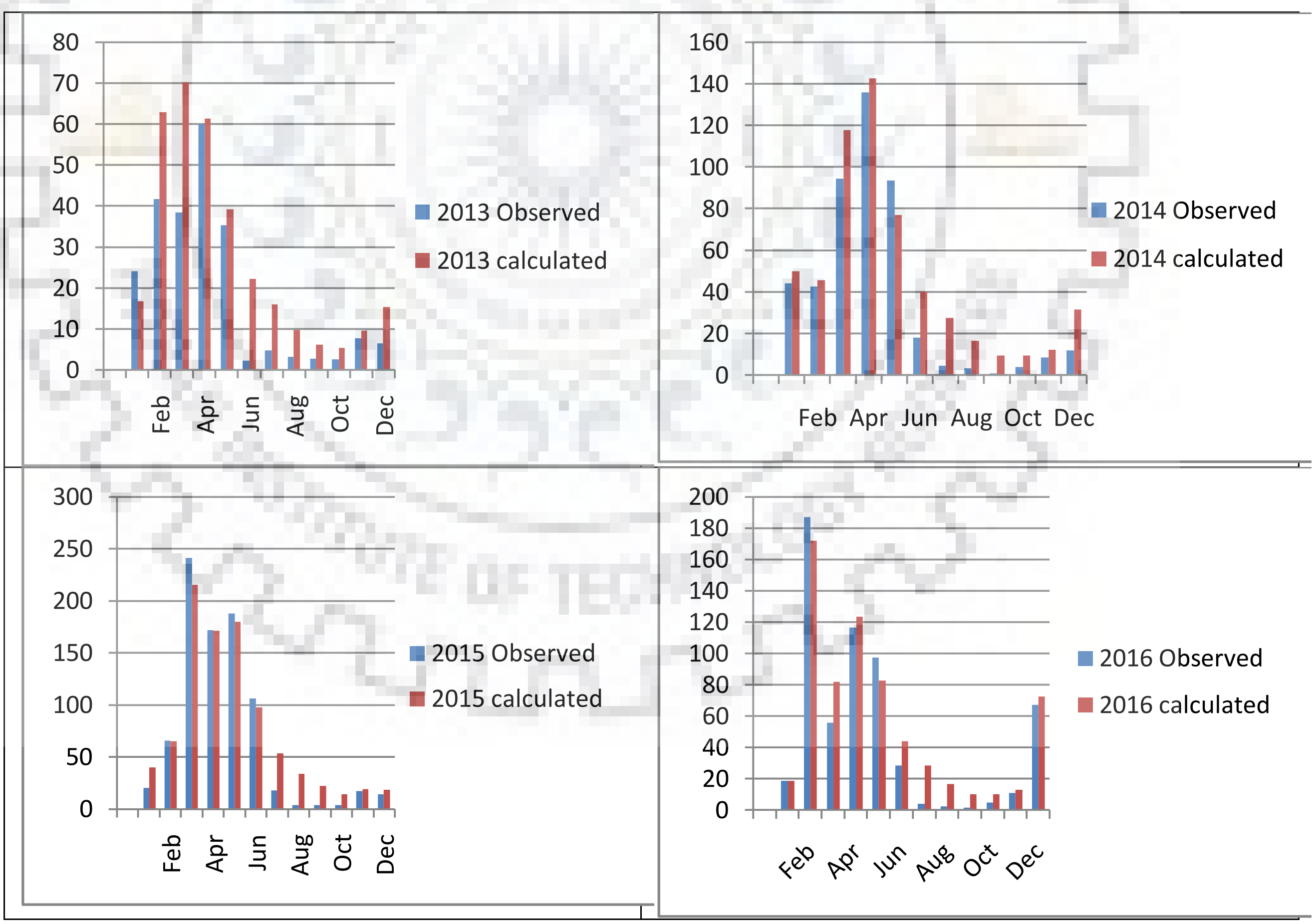


Fig. 6.5: Observed v/s Calculated Stream Flows.

The calculated discharges for sub-basin 2 and 3 through SWAT model are shown in Table 6.4.

Table 6.4: Calculated Discharges Data for Sub-basin 2 and 3

	2013		2014		2015		2016	
	Basin 2	Basin 3	Basin 2	Basin 3	Basin 2	Basin 3	Basin 2	Basin 3
Jan	6.22	10.1	11.91	38.71	9.775	28.32	26.19	14.15
Feb	9.484	47.41	19.06	26.15	9.153	49.7	49.77	96.9
Mar	22.29	41.37	44.98	68.16	89.54	108.2	30.58	47.53
Apr	25.23	33	61.4	76.2	54.2	84.9	50.18	66.4
May	13.41	19.04	33.68	46.74	46.5	90.7	24.28	51.9
Jun	3.032	9.857	12.62	25.11	29.84	53.2	12.26	24.05
Jul	5.279	4.103	9.019	13.497	21.97	26.81	4.026	12.924
Aug	3.917	2.995	3.955	8.652	4.288	18.74	3.649	6.097
Sep	2.97	1.129	2.726	5.435	5.054	9.531	3.156	3.815
Oct	3.1	2.953	4.405	3.67	3.596	5.533	4.993	5.256
Nov	4.844	5.146	4.219	6.828	7.924	6.49	5.9	6.936
Dec	9.288	6.732	5.519	11.06	7.561	9.934	14.596	35.05

6.3 FLOW DURATION CURVE

Flow duration curve is plotted for the SWAT model output discharges as shown in Fig. 6.6. It was found that 75% available discharges comes out to be 15.89 cumecs, 4.41 cumecs and 6.73 cumecs for subbasin 1, 2 and 3 respectively. Thus, it can be taken as design discharge for the estimation of hydropower potential for each sub basins. Meanwhile, during the flows of water in a stream, some amount of water may also lose due to evaporation and absorption on the river. These environmental perspective losses affect the design discharge in a river. Generally these loses are taken about 10% of flow and it was deducted from design discharges. Finally the design discharges for each subbasin are taken as 14.3 cumecs, 3.97 cumecs and 6.11 cumecs respectively.

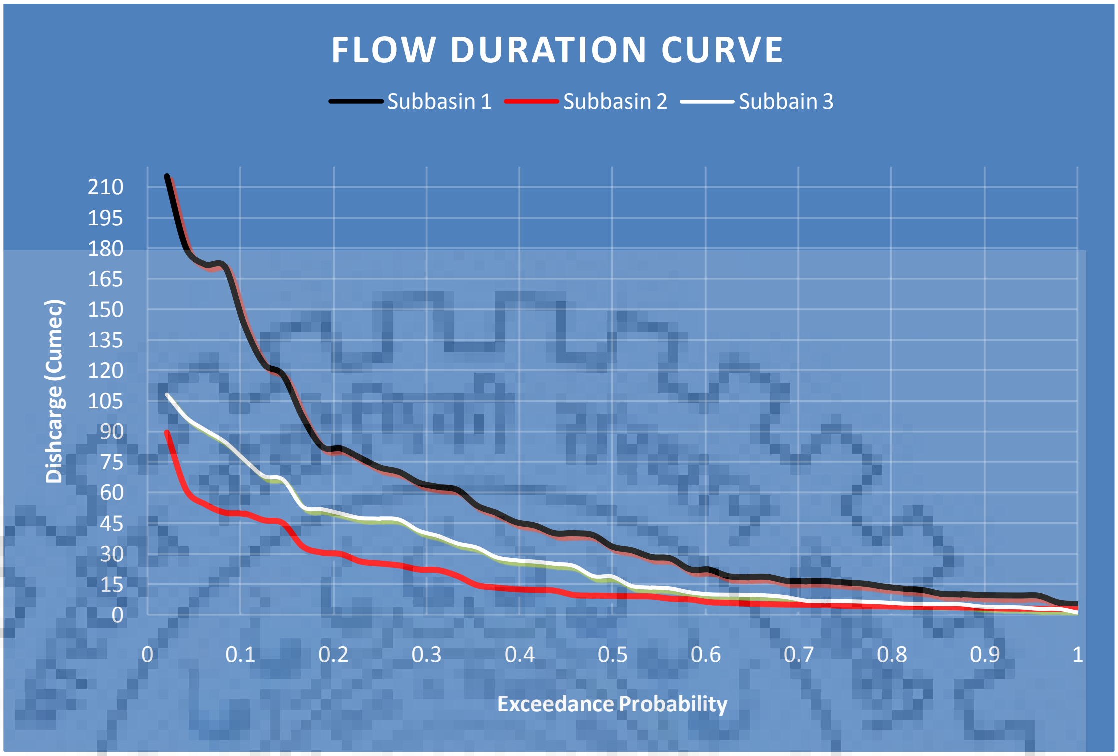


Fig. 6.6: Flow Duration Curve.

6.4 CHARACTERISTICS FOR POTENTIAL SITE SELECTION

For selection of potential sites for hydropower project following conditions were adopted.

- A stream has been selected for hydropower project which should have sufficient water throughout the year to generate electricity. The Farah River watershed shows that the third order stream or more have sufficient discharge for installation of hydro projects and have selected these streams for potential sites accordingly.
- The Farah River has very steep slope in beginning, while its slope becomes to very flat near the end. A site is selected for hydropower project that should have at least 20 m of head between diversion point and power house [13]
- The selected site should have sufficient space between the power house tailrace of one site with diversion point of next hydro project. The minimum distance between two consecutive project should not be less than 500 m [7]
- The maximum distance between the diversion point and power house of a potential site should not exceed 3000 m [13]

6.5 SELECTION OF POTENTIAL SITES FOR HYDROPOWER PROJECTS

The following locations of Small Hydropower plants (SHP) presented in Fig. 6.7 shows the location of weir and barrage along the river. It has been worked out using the ArcGIS techniques by considering the elevations with the help of DEM, contour map, slope map, soil data and land cover patterns of the specific site. Thirty nine different sites are selected along the 650 km length of Farah River. The sites have been selected which had at least 20 m elevation difference and the maximum distance between diversion arrangement and powerhouse building did not exceeds 3000m [7].

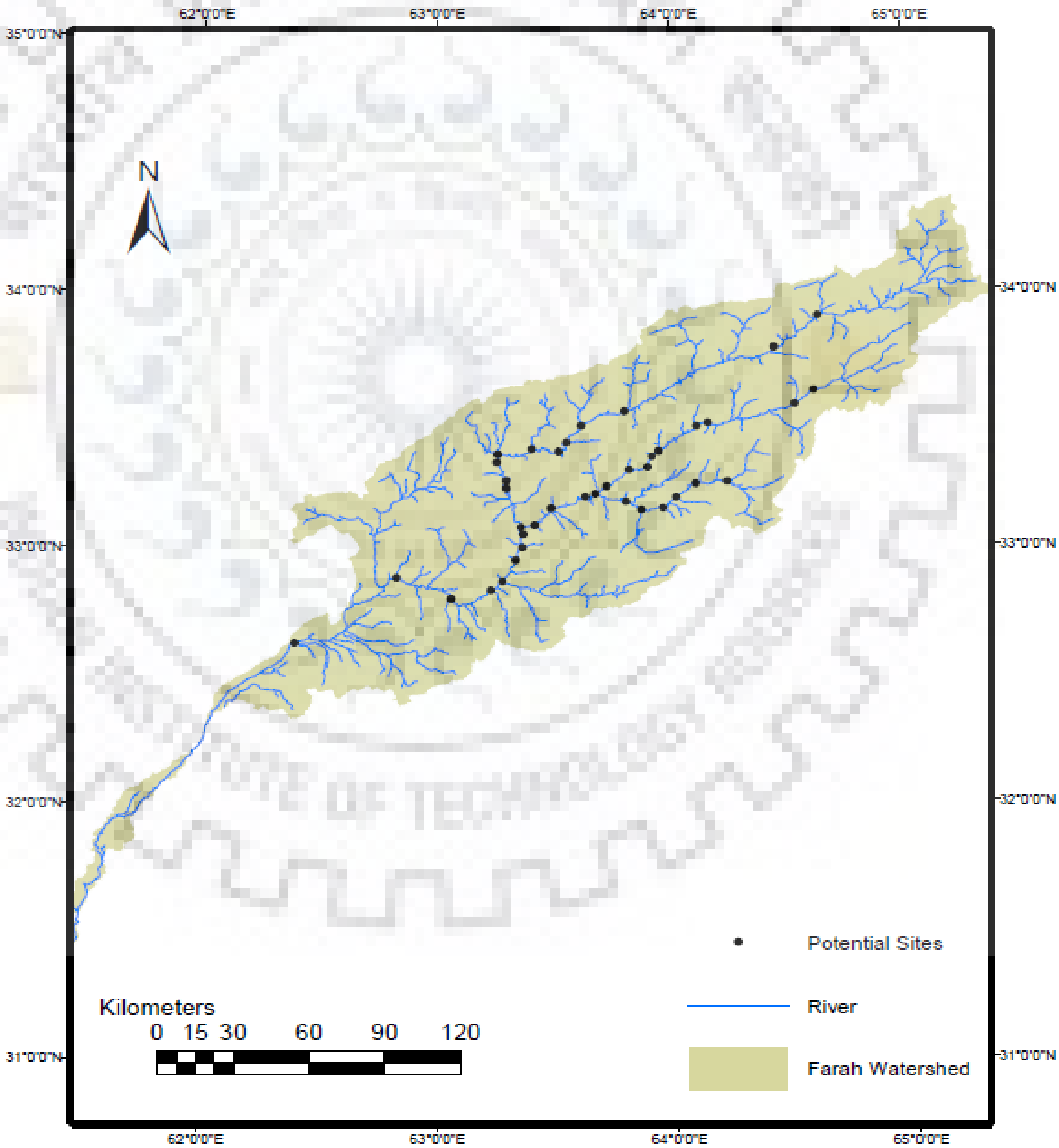


Fig. 6.7: SHP Sites Location.

6.6 CALCULATION OF HYDROPOWER POTENTIAL

The discharge for Farah River has been calculated through SWAT model. The head difference between intake gates and power house locations have been calculated by utilizing the DEM, Contour map and stream order map. Therefore, having head and discharge the hydropower potentials are calculated with the help of theoretical ROR equation for the selected thirty nine sites as shown on Table 6.5.

Pelton turbine is selected for the current study due to low discharge and high head. The efficiency (η) of pelton turbine has been taken from Fig. 6.8 that is 85% for further calculation of hydro power potential [20].

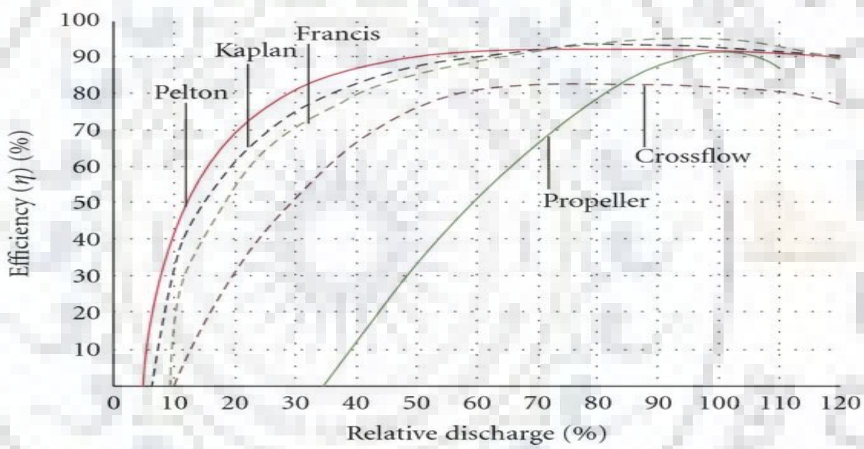


Fig. 6.8: Efficiency of Turbines [20].

The total potential of Farah River is approx estimated 66.04 MW for the proposed thirty nine Small Hydropower Plants (SHP) along the River. Although this amount of water of Farah River is currently goes to neighboring countries without any usage inside the country. Therefore, by construction of these proposed SHPs we can control and manage the water of the Farah River. It also would help to reduce the shortage supply of electricity to Farah city as well as neighboring provinces.

Table 6.5: Hydro Power Potential of Different Sites

Location	Available Head (meter)	Discharge (cumec)	Power Generated (KW)
1	36	1.82	545
2	80	2.4	1600
3	48	4.23	1693
4	30	4.53	1133
5	64	4.72	2518
6	33	4.91	1350
7	51	5.17	2100
8	40	5.45	1820
9	68	5.59	3170
10	37	5.76	1777
11	59	6.11	3006
12	56	1.82	850
13	32	2.13	568
14	40	2.69	897
15	40	2.91	970
16	56	3.19	1490
17	51	3.27	1390
18	60	3.33	1666
19	63	3.43	1802
20	69	3.58	2060
21	60	1.47	735
22	56	1.67	780
23	61	1.83	930
24	57	1.94	922
25	40	2.11	705
26	44	2.25	825
27	41	3.65	1250
28	35	3.73	1090
29	28	3.88	905
30	36	3.97	1190
31	33	10.1	2780
32	62	10.39	5370
33	26	10.65	2310
34	22	11.38	2090
35	20	11.99	2000
36	21	12.31	2155
37	21	13.19	2310
38	24	14	2800
39	20	14.3	2385
Total Hydro Power Potential of Farah River			**66036**

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1. CONCLUSIONS

The study shows that hydrological modeling and ArcGIS approaches are quite useful in the watershed delineation, estimation of hydropower potential and assessment of small hydro power stations. The following are the conclusions drawn from the assessment of hydropower potential in Farah River using ArcGIS and SWAT model:

1. The land use land cover image is generated for Farah River. The land use was classified into 6 classes, viz., Water bodies, Forest, Agriculture, Residential, Barry Land and Forest-evergreen and the covered percentage by each classes in Farah watershed are 0.63%, 0.92%, 6.91%, 0.15%, 0.04% and 91.35% respectively.
2. The soil map was generated for Farah River and it shows 7 different types of soil in the area of interest. These soils types are: Clay Loam, Loam, Sandy Loam and Sandy Clay Loam.
3. The stream order network is created for Farah River watershed and the streams are categorized into 5 different streams and named from 1 to 5. The first and second types are seasonal and temporary streams, while the 3rd, 4th and 5th are permanent.
4. The Farah River watershed area is divided into 3 sub basins with help of SWAT model. The area of each sub basin evaluated by model are 6682 km^2, 7068 km^2 and 8251 km^2 for basin 1, 2 and 3 respectively.
5. The model output is calibrated within SWAT-CUP software with the following parameters: Initial CN ll values, Base flow recession alpha factor (days), Ground water and Threshold water depth in the shallow aquifer for flow (mm). The accuracy of Swat model is determined by coefficient of determination (R^2) and for the present model output, it is 0.804.
6. The Farah River discharge was calculated with the help of SWAT hydrological model for the three sub basin outlets. Therefore, the 75% design discharge calculated as 14.3 cumecs, 3.97 cumecs and 6.11 cumecs for subbasin 1, 2 and 3 respectively, from flow

duration curve organized by the average discharges computed through SWAT model, including 10% deduction of flow for environmental perspective.

7. Thirty nine potential sites were identified in three sub basin within 22000 km^2 watershed area of Farah River.
8. Farah River has capacity of 66.04 MW electricity generations from the proposed thirty nine sites of hydropower projects.

Apart from serving as tool, ArcGIS reduces the time and cost of the sites selection for hydropower projects and subsequently aid future monitoring by providing a digital data bank for the watershed area. The integration of SWAT hydrological with ArcGIS is therefore considered as the best method for the identification and assessment of hydropower potential site as seen from this study. With the integration of SWAT hydrological with ArcGIS tool, thirty nine sites have been indentified for the construction of hydropower projects on Farah River.

7.2. RECOMMENDATIONS

Assessment of the hydropower potential and selection of the suitable sites for hydropower projects have been done with help of ArcGIS, Remote Sensing and SWAT model. The following aspects require some attention:

1. In Farah River basin sediment and soil erosion analysis are not done till date. Accordingly, further studies are recommended to use the SWAT hydrological model with ArcGIS tool for estimation of Sediment and soil erosion in Farah River.
2. In this study the discharge was calculated in monthly basis for Farah River. Further studies may be carried out to calculate the discharge in daily basis.
3. The satellite images used in this study had resolution of 90m x 90m. Further studies may be carried out using data sets with higher resolution.
4. In the present study, due to lack of rainfall data, the SWAT model is ran for the period of 6 years. Further studies are recommended to simulate the SWAT model for long period.

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Appendix - I (Rainfall Data)

2011 Farah Station												
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	3.30	5.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	4.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00
6	0.00	0.00	1.10	0.00	3.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	2.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	31.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	4.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.10	12.10
18	0.00	3.20	0.00	0.00	0.00	0.00	2.43	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	6.00	3.70	0.00	0.00	0.00	2.78	4.56	0.00	0.00	0.00
21	7.90	0.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00
22	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20	7.00	0.00
23	10.9	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.45
25	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.23	0.00	0.00	0.00
26	0.00	0.00	1.30	0.00	0.00	1.20	0.00	1.12	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	5.00	1.30	0.00
28	0.00	7.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.30
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00
31	0.00	0.00	0.00		0.00		0.00	0.00		0.00		0.00
total	62.5	21.1	15.4	7.70	3.30	7.20	2.43	3.90	8.79	7.2	9.4	24.85

2012 Farah Station												
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00
3	2.60	0.00	0.00	5.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.50	2.40	1.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	2.20	0.00	0.00	0.00	0.00	0.00	4.30
6	0.00	0.60	1.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	1.35	0.50	1.10	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.25	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	3.50	2.10	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	12.4	2.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.76
13	0.00	0.00	0.00	3.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	3.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	2.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.50	0.00	3.20	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.80	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	3.80	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.60	0.50	0.00	0.00	1.50	0.00	0.00	0.50	0.00	0.00	0.00
20	0.00	0.00	0.00	4.10	0.00	0.00	2.56	4.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	4.00	3.40	0.00	0.00	0.00	1.00	0.00	0.00	0.00
22	0.00	1.60	6.80	4.00	0.00	0.00	0.00	0.00	0.00	0.00	13.3	0.00
23	0.00	5.10	1.10	2.20	0.00	0.00	0.00	0.00	0.00	0.00	1.30	0.00
24	0.00	0.00	0.00	4.80	0.00	1.30	0.00	0.00	0.00	3.20	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.50	0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.50	1.60	1.70	0.00	1.80	1.20	0.00	0.00	0.00	0.00
28	0.00	0.00	0.90	0.90	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00
29	0.00		0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	21.0		1.50	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.70		0.00		0.00		0.00	0.00		0.00		0.00
Total	26.9	33.6	19.5	51.2	10.5	12.9	4.36	5.70	2.40	3.2	14.6	11.06

2013 Farah Station												
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	2.60	0.00	0.00	5.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.50	2.40	1.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	2.20	0.00	0.00	0.00	0.00	0.00	3.70
6	0.00	0.60	1.70	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00
7	1.35	0.50	1.10	0.90	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.30	0.00	0.00	0.00
10	1.25	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	3.50	2.10	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.90
12	0.00	12.4	2.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	3.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	3.70	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00
15	0.00	0.00	0.00	2.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.50	0.00	3.20	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.80	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	3.80	1.90	0.00	0.00	1.00	0.00	0.00	0.00	0.00
19	0.00	0.60	0.50	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	4.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	4.00	3.40	0.00	0.00	0.00	0.00	0.60	0.00	0.00
22	0.00	1.60	6.80	4.00	0.00	0.00	0.00	0.00	0.00	0.00	13.3	0.00
23	0.00	5.10	1.10	2.20	0.00	0.00	0.00	0.00	0.00	0.00	1.30	0.00
24	0.00	0.00	0.00	4.80	0.00	1.30	0.00	0.00	0.00	0.50	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	5.30
26	0.00	0.00	0.50	0.00	0.00	1.30	0.00	0.00	0.00	0.60	0.00	0.00
27	0.00	0.00	0.50	1.60	1.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.90	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00		0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	21.0		1.50	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.70		0.00		0.00		0.00	0.00		0.00		0.00
Total	26.9	33.6	19.5	51.2	10.5	12.9	1.20	1.00	2.80	2.40	14.6	10.90

2014 Farah Station												
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	7.30	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00
2	0.00	5.80	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.00
3	0.00	0.00	0.00	12.2	0.00	0.00	0.00	1.20	0.00	0.00	0.90	0.00
4	0.00	4.10	0.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	3.90	0.00	6.70	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00
6	0.00	2.50	0.00	0.90	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00
7	6.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.70	0.00	0.00	0.90	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.90	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00
12	2.60	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	16.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	34.4	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00
15	0.00	0.00	12.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	36.4	0.00	0.00	0.00	0.90	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.50
18	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.60
19	0.00	0.00	0.00	0.00	0.00	0.00	1.70	0.00	0.00	0.00	0.00	0.00
20	3.30	0.00	0.00	0.00	0.00	0.00	0.00	2.50	0.90	0.00	0.00	0.60
21	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.80	0.80	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	3.90	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00
28	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.00
29	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.00		0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00		0.00		0.00		0.00	0.00		0.00		0.00
Total	13.2	23.6	62.9	33.7	36.4	7.40	5.40	7.30	4.50	0.00	1.80	2.70

2015 Farah Station												
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.50	3.30	0.00	0.20	0.00	0.00	0.00	0.00	5.40	0.00
3	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.40	0.20	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.90	0.00	0.00	0.00	0.40	0.30	0.20	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.60	0.00	0.20	0.20	0.20	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
9	0.00	0.00	0.60	0.00	0.50	0.00	0.00	0.20	0.00	0.00	1.10	0.00
10	0.00	0.00	0.70	0.00	0.00	0.00	0.20	0.00	0.00	7.90	2.20	0.00
11	0.00	1.30	8.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.50	0.00
12	0.00	1.30	7.50	0.20	0.20	0.00	0.20	0.00	0.00	0.00	0.00	0.00
13	0.00	1.20	0.60	0.80	0.20	0.20	0.80	0.00	0.20	0.00	0.00	0.00
14	0.00	0.00	0.50	0.20	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
15	1.20	0.00	0.00	0.40	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
18	0.00	0.00	0.00	0.20	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	10.7	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	18.5	0.00	0.00	0.90	0.60	0.00	0.00	0.30	0.00	0.00	0.00	5.43
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.30	0.00
22	0.00	6.90	0.00	0.00	0.20	0.00	0.30	0.00	0.00	0.00	0.00	0.00
23	0.00	13.7	0.00	0.30	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	1.00	0.00	0.00	0.30	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.50
26	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	2.30
27	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.30	0.20	0.00	0.00	0.60
28	0.00	0.00	5.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00		0.00	0.00	0.00	0.00	0.20	0.20	0.30	0.00	0.00	0.00
30	0.00		0.00	0.30	0.50	0.00	0.30	0.30	0.30	0.00	0.00	0.00
31	0.00		0.50		0.00		0.00	0.00		0.00		0.00
Total	21.6	24.4	25.7	17.8	4.80	3.30	2.40	2.10	1.80	7.90	14.5	8.83

2016 Farah Station												
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.00	11.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
2	0.00	0.00	0.00	0.70	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	26.1	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.60
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.40
10	0.00	0.00	12.8	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.20
11	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.30
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.20	5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
18	0.00	0.00	0.00	0.00	0.00	0.00	3.20	0.00	1.20	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	4.40	0.00	0.00
20	0.00	0.00	0.00	0.00	0.20	2.40	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.20	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.20	3.10	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	6.70	0.00	0.00	0.00	0.00	0.20
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.80	0.00	0.00	0.00
29	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.20
30	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00		0.00		0.00		0.00	0.00		0.00		0.00
Total	26.1	4.30	18.3	11.7	1.90	2.60	9.90	0.00	2.00	4.80	3.10	9.90