SMALL HYDROPOWER: FEASIBLE LOCATION, POTENTIAL AND INSTALLATION IN ODISHA

A
DISSERTATION

Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of

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In

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WATER RESOURCES ENGINEERING

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NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

CERTIFICATE

This is to certify that the Dissertation entitled "**SMALL HYDROPOWER: LOCATION, POTENTIAL AND INSTALLATION IN ODISHA**" submitted by **SANOJ SAHU** to the National Institute of Technology, Rourkela, in partial fulfillment of the requirements for the award of **Master of Technology** in **Civil Engineering** with specialization in **Water Resources Engineering** is a record of bonafide research work carried out by her under my supervision and guidance during the academic session 2014-15. To the best of my knowledge, the results contained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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I consider the completion of this research as dedication and support of a group of people rather than my individual effort. I wish to express gratitude to everyone who assisted me to fulfill this work.

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Dated (Sanoj Sahu)

ABSTRACT

Odisha is undergoing a serious power crisis situation at present scenario. Although this power shortage can be satisfied by non-renewable energies, these have many environmental problems and are too costly to install and maintain. Hence this project is concentrated on small hydropower which is a renewable energy, have no environmental issues and relatively cheaper. In this project, RS and GIS techniques have been used to find the feasible locations for small hydropower plant (SHP) installations. The digital elevation model (DEM) and hydrologic data (discharge data) have been used to estimate the small hydropower potential of the state. In the present analysis around 40 feasible locations for SHP installation were found which constituted around a potential of 33MW. Due to this around 109489 tonnes of coal can be saved that were to be used in thermal power plants and a considerable amount of greenhouse gas emission can be restricted. A large number of rural population can be benefitted who were earlier being deprived of electricity.

KEYWORDS- RS and GIS, Small hydropower plant, DEM, discharge data

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LIST OF ABBREVIATIONS

RS- Remote sensing

GIS- Geographic Information System

SHP- Small Hydropower Plant

DEM- Digital Elevation Model

ROR- Run of the River

FDC- Flow Duration Curve

GRDC- Global Runoff Data Centre

NRSC- National Remote Sensing Centre

WRIS- Water Resource Information system

AHEC- Alternate Hydro Energy Centre

CHAPTER 01

INTRODUCTION

1.1 Power scenario in India

There has been a regularly expanding requirement for more power era every nation of the world. India is bestowed with enormous measure of hydro-electric potential and positions 5th regarding exploitable hydro power potential on worldwide situation. Through the progressive schemes started after independence of our nation, power improvement has been given the most emphasis. At the time of freedom we had barely 2.3 million KW whereas now remains at 15000 MW more or less. According to insights of Central Electricity authority the total installed capacity of India is 169749 MW, out of which the share hydropower is 37368 MW i.e., 22% of aggregate limit. The increasing population and industrial development requires more power production. Keeping in mind the end goal to give satisfactory base to compelling development of economy and to meet the shortage of power, Government needs to set up small hydro power projects across the nation. Power Potential Studies of a hydroelectric project is an essential procedure in the commissioning of the hydroelectric project. It is done for appraisal of the accessible power potential of a river/basin taking into account a certain set of head conditions and inflows available at the site in years of different degree of reliability, in different periods of a year and the estimation of generating capacity (KW), which is required to be provided in power station in order to generate the assessed quantity of energy (KWh).

Besides, the power potential assessment provides the basis for the planning of layout and design of the scheme and estimation of cost and evaluation of the financial aspect of the scheme. India is poised for expansive organization of hydropower in present conducive policy and investment environment. Concern for carbon emission and growing energy demand is making hydropower development more favorable. The Government of India has installed many such projects in the Himalayan tracts of the country which includes the states of Jammu and Kashmir, Himachal

Pradesh, Uttarakhand and many north-eastern states. Moreover, many other projects are under screening for feasibility analysis and are waiting to be commissioned.

But, in case of Odisha, no such work has been done. Odisha is under a serious power crisis at present scenario. While the state's power demand is 5132MW, the power production is only 3056MW. There are still 3919 un-electrified villages in the state. Many of the rural citizens are without access to electricity and much of the population is suffering from sporadic outages. These deprived communities can be provided with electricity by installation of SHPs for their regular household needs.

1.2 Definition and advantages of small hydropower plants

SHP are hydropower plant which serves industry and local communities in small scale. In India, the development of SHP projects up to 25MW capacity has been vested to ministry of new and renewable energies. SHP has many advantages which are discussed below-

a) Energy efficient source

Small hydropower requires very less amount of discharge and the power production can be transferred to nearby communities.

b) Reliable energy source

SHP produces a continuous power in comparison to other small scale renewable technologies. The peak energy production season is during the winters.

c) No reservoirs required

SHP requires very little or no impoundment. The water passing through the turbine is again diverted back to the stream.

d) Cost effective energy solution

Construction of SHP requires very less investment compared to its counterpart. The maintenance required is also very less.

e) Integration with local power grid

If the site provides excess energy, it can be sold to power companies

f) More environment friendly

SHP requires no greenhouse gas emission. It also alters the natural flow of a river to a very small extent

g) Increase in oxygen content in lower course

The turbines of SHP spins oxygen into the water which increases the DO level downstream of the river. This is very good for fish stock preservation.

1.3 Classification of small hydropower plants

a) Based on layout

1) Run of river schemes

These schemes comprises of turbine which operates on the basis of availability of water in the river. The generation ceases when the river flow reaches below some fixed amount or the minimum technical flow for the turbine. Medium and high head schemes requires weirs to divert water into the intake and is then conveyed to turbines via penstocks. Penstocks are costly and hence requires careful and economic design. Hence an alternative is to convey water by low slope canal along the side of the river to an intake/forebay and then in a short length penstock. In case the topography and morphology of the terrain does not allow the easy layout of a canal, then low pressure pipe can be an economical option. At the exit of the turbines, the water is released to the stream by means of a tailrace. A typical ROR based SHP scheme is shown in diagram 1.1 (a).

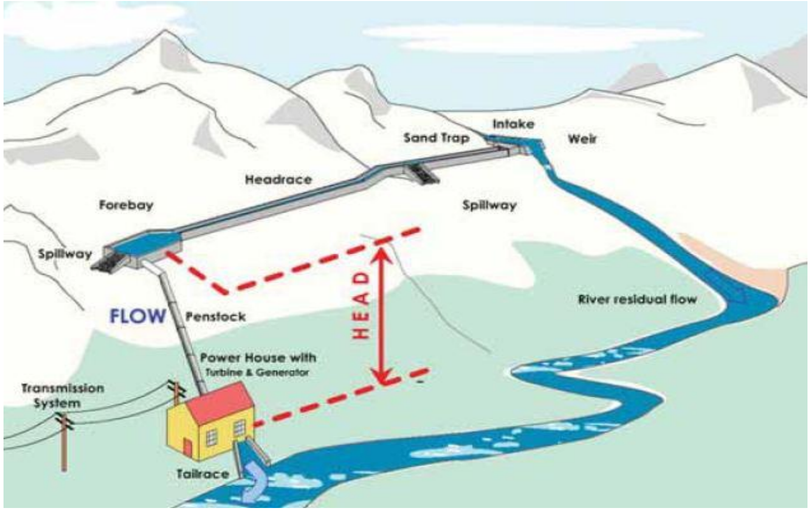

Figure 1.1: ROR based SHP scheme

2) Schemes with the powerhouse located at the base of a dam

If a dam/barrage is already constructed for purposes such as- flood control, irrigation, drinking water supply, recreational, etc, - it may be possible to produce hydropower from such schemes using discharge compatible with ecological flow of reservoir.

The main problem is to fit the turbine while linking the headwater and tail water through a waterway. The solution is clear if the dam has a bottom outlet the solution is clear as shown in the figure 1.2 (a). A siphon intake can be used if the dam is not too high as shown in the figure 1(b).

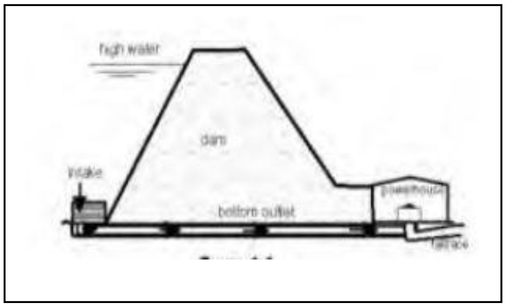

Figure 1.2(a): Dam based SHP scheme with bottom outlet

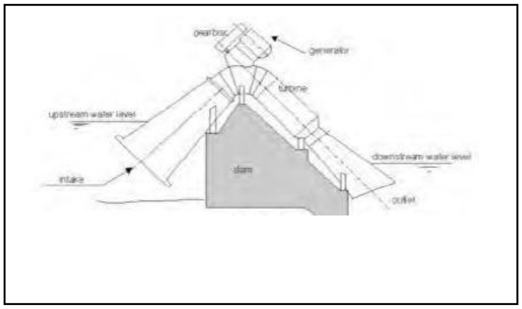

Figure 1.2(b): Dam based SHP scheme with siphon

The turbine can be installed on top or d/s of dam. The unit can be conveyed prepackaged to the works, and introduced without significant alterations of the dam.

3) Schemes integrated with an irrigation canal

The potential sites in a irrigation canal are the canal falls. Canal falls are provided along a canal, where the level of the canal needs to be stepped-down as a fall structure to match with normal ground level. Although the potential head available at these sites are less (0.5m to 15m), the energy potential may be considerable due to large and dependable flows. In India there are large numbers of irrigation canals and these have quite good number of falls. Many of these sites have been used for generation of hydropower and many are still in planning and construction stage. A typical diagram of this scheme is shown in the diagram.

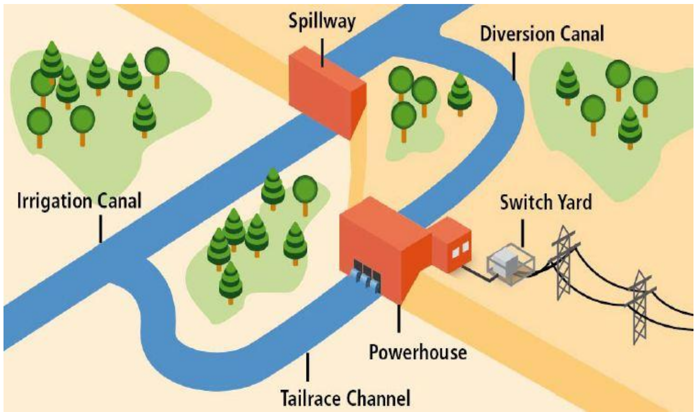

Figure 1.3: Canal based SHP scheme

b) Based on generation capacity

The Ministry of New and Renewable Energy classifies the small hydropower plants on the basis of generation capacities as follows-

i) Micro Hydro (<100KW)

ii) Mini Hydro (101-2000KW)

iii) Small Hydro (2001-25000KW)

1.4 Working of small hydropower plants

A part of river discharge is diverted from the natural waterway or the reservoir created due to the construction of dam. This water is conveyed through open channel to a forebay located at a height of the natural stream. The water from the forebay is transferred to the turbine located in the powerhouse via the penstock. The energy of the falling water rotates the turbine which in turn rotates the generator and ultimately produces electricity. This is the basic concept behind the working of a typical SHP.

1.5 Objectives of study

The main objectives of the present study are:

- To identify suitable streams and feasible locations for SHP projects in Odisha using GIS and RS techniques.
- To develop flow duration curve (FDC) for these feasible locations from which Q_{75} can be derived which is used in further analysis.
- To calculate the power potential of these locations.
- To discuss the suitable type of hydraulic machines (turbines) and different type of appurtenances and works required for such projects.
- To calculate the equivalent amount of coal saved and greenhouse gases emission stopped.

1.6 Organization of the dissertation

The thesis has been organized in chapter wise with a view to meet the above objectives.

Chapter 1 concentrates on the introduction of the work related to SHPs. The importance and the objectives of the present work have been explained.

Chapter 2 presents significant state-of art contributions to various aspects of SHPs such as their site location, potential evaluation, installation in different study area.

Chapter 3 focuses on geographical location, the characteristics of the study area, and the types of data required for the analysis.

Chapter 4 covers the GIS based methodology used in this analysis to locate feasible locations for SHP installations. The chapter also discusses about the turbines, works and various appurtenances required for SHP installation.

Chapter 5 incorporates the results and discussion on the present study.

Chapter 6 provides the summary, important conclusions and specific contribution made in the present work.

Chapter 7 discusses about the future scope of the project.

CHAPTER 02

REVIEW OF LITERATURE

Many rivers across the world have hydropower potential varying across a large magnitude. Before harnessing the hydropower from river, we should know the feasible locations and the hydropower potential available. Generally many of these sites are located in remote places. Visiting each and every site locations for feasibility study is expensive, time-taking, tedious and labour intensive. RS and GIS technique provides many advantages over the conventional methods of site locations. Thus the study and use of RS and GIS in site locations has occupied a large portion of the literature on site locations of SHP.

Monk et al. (2009) developed a model named RHAM (Rapid hydropower assessment model) which takes input as DEM and regional hydrologic data and gives output as total hydropower available on all streams in the study area. It can also estimate the project costs, environmental and social factors etc.

Kusre et al. (2009) assessed the hydropower potential using hydrological modelling (SWAT) and GIS technique in Kopili river basin of Assam (India).

Site location analysis for small hydropower was done by Yi et al. (2009) using geo-spatial information system. Their study area was upper part of Geum river basin of South Korea.

Gunnar (2010) evaluated potential sites for small hydropower plant located in Biobio north irrigation system in Chile.

Jha (2010) used the hydro-meteorological data and incorporated GIS and a hydropower model to estimate the total run of river hydropower potential of Nepal.

Buehler (2011) analyzed the potential for small hydropower installation in the country of Dominican Republic using GIS and RS techniques.

Hammons et al. (2011) worked on extraction of hydropower from river Congo based on low head generation technology without the use of a conventional dam.

Punys et al. (2011) developed computer aided tools small hydropower plant resource planning and development. This tool has been successfully used by countries such as Canada, Italy, Norway, Scotland and the US to re-assess hydropower capacities based on spatial information of their water stream catchments.

GIS based procedure was used by Larentis et al. (2011) for hydropower potential spotting. They developed a GIS based computational program named ‘Hydrospot’ which can locate potential locations in the study area by using the RS and hydrologic data.

Meijer (2012) did systematical estimation of the world’s micro, small and large hydropower capacities based on a GIS based model developed by him. In order to estimate the global hydropower potential a systematical method was developed by him to simulate input data and check whether there is hydropower at a specific location. The world is divided into cells with a resolution of 3”. The two basic components for hydropower calculation- head and discharge need to be evaluated for each cell for potential calculation. The discharge is calculated with help of the DEM datasets combined with the GRDC Runoff fields’ dataset. The slope was calculated from a global 3” DEM. Hydropower is calculated within each cell using the Input Variables ‘turbine efficiency’, ‘minimum discharge’ and ‘minimum head’.

Hall et al. (2012) assessed natural stream sites for installation of hydroelectric dams in the pacific north-west region of USA. They developed a model to give output as capacity potential, number of dams in the stream, dam dimensions, inundation etc.

Feizizadeh et al. (2012) used GIS to calculate the theoretical surface hydropower potential of the Tabriz basin in Iran. GIS based hydrological modeling is performed on equiareal raster cells using topographical and meteorological datasets. Topographic data, monthly evaporation, and precipitation data was used in the analysis. According to their study, Mehran Roud river branches has the highest potentials

Bose et al. (2013) identified suitable locations of micro hydropower stations using geo-spatial techniques in the state of Andhra Pradesh. His study area was Kakataya main canal, a major distributary to river Godavari.

Assessment of hydropower potential of small streams was done using spatial database integration by Izeiroski et al (2013). Their study area was the northern watershed of Prespa lake (Greece).

Fayzul et al. (2014) developed a merit matrix-based algorithm for stream reach identification for new run-of-river hydropower development.

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CHAPTER 03

THE STUDY AREA AND DATA COLLECTION

One of the purpose of the project is to find suitable sites for small hydropower installations in Odisha. Hence the study area of this project is the administrative boundary of Odisha. To find the potential locations, we need to know the elevation data which will ultimately give the head available. Another aim of our project is to find the small hydropower potential of the state. A pre-requisite for this calculation is the discharge data.

The chapter begins with the description of study area followed by the details of data collection.

3.1 The study area

The geographical coordinates of Odisha lies between the latitudes 17° 46' 48" to 22° 43' 48" North latitudes and 81° 22' 12" to 87° 31' 48" East longitudes. There are many hilly tracts located in the districts of Malkangiri, Koraput, Kalahandi, Kandhamal, Rayagada, Nabrangpur, Mayurbhanj, Keonjhar etc. The state is also endowed with many natural streams having considerably good discharge values in those areas. These two geographical conditions in combination provides best sites for small hydropower development. The administrative map of Odisha is shown in figure 3.1.

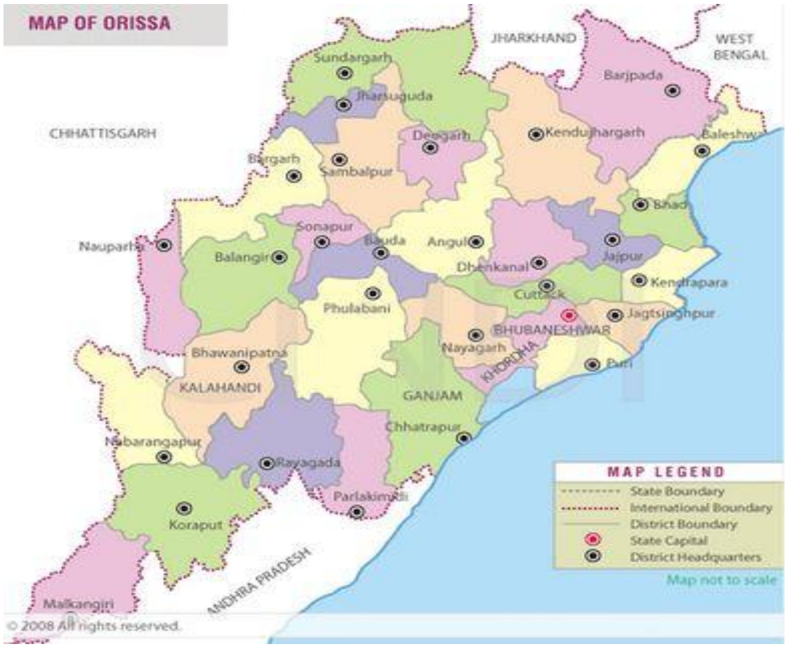


Figure 3.1: Map of Odisha

The climate of Odisha is a tropical monsoon type and having maximum precipitation in July, August, and first half of September.

3.2 Data collection

For my analysis, required two types of data were required as follows-

1) Elevation data

The elevation data is obtained in the form of CartoDEM version 1.1R1 which is a remote sensing data. These data are maintained by NRSC. These data have a horizontal grid spacing of 30m. These data can be obtained from the URL: http://bhuvan.nrsc.gov.in/ . The DEM is used to develop the flow direction, flow accumulation and slope map of Odisha. Ultimately it is used to find out the head available at different locations.

2) Discharge data

The discharge data is required for calculation of hydropower potential and development of FDC for the potential sites. The discharge data are collected and maintained by WRIS. In this analysis daily discharge data is required for past six years. Hence daily discharge data for the years 2006-2011 were downloaded from the URL: http://www.india-wris.nrsc.gov.in/ .The gauging stations under consideration are Saradaput, Kotta, Anandapur, Champua, Sukma, Kantamal, Kesinga, Srikakulam, Gudari, Gunupur, Kashinagar, Khairmal, Tikrapara, Altuma, Jenapur, Pandigaon.

CHAPTER 04

METHODOLOGY

4.1 Theory

The potential energy of the falling water can be converted into mechanical energy and subsequently into electrical energy by using hydroelectric power plants. According to the authors of *Renewable Energy: Technology, Economics, and Environment*, theoretical water power, P_{th} between two points on a river can be calculated using equation 4.1 as shown below-

$$P_{th} = \rho g Q(Z_{HW}-Z_{TW}) \tag{4.1}$$

Where ρ = density of water (1000kg/m^3); g = acceleration due to gravity (m/s^2); Q =discharge (m^3/s); Z_{HW} = head water elevation; Z_{TW} = tail water elevation.

But the theoretical power is never developed as there is always some head loss associated within a hydroelectric plant known as transfer losses. The actual condition can be defined by Bernoulli's equation as shown in equation 4.2-

$$z_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + (1 + \varepsilon)\frac{v_2^2}{2g} = constant \tag{4.2}$$

Where z = datum head; $\frac{p_1}{\rho g}$ = pressure head; $\frac{v_1^2}{2g}$ = velocity head; ε = loss coefficient.

We can see from the equation that there is always a head loss when the water is conveyed through two points. Hence the net usable head, H, is always less than the gross head as shown in equation 4.3-

$$H < (Z_{HW}-Z_{TW}) \tag{4.3}$$

Also the efficiency (η) of the turbine and generator is never 100%. From the previous installations of SHPs worldwide, we can assume that the efficiency of a SHP ranges about 80%. Hence the actual equation of power developed from a SHP is given by equation 4.4 as follows-

$$P = \eta \rho g Q H \tag{4.4}$$

4.2 Location based on head available on streams

To first locate the feasible locations based on head, we need to find streams with adequate flow. More is the order of the stream, more probability is there that adequate flow is available. Hence to ensure the sufficiency of flows only streams with a minimum stream order of 5 is considered. The stream order is based on Stalher's criteria. The uppermost stream are assigned stream order number 1. When two Nth order stream meets, the resultant stream becomes (N+1)th order stream. Similarly, when a higher order stream meets the lower order stream, the resultant stream becomes the higher order stream.

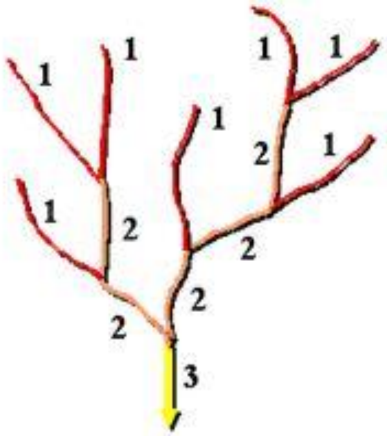


Figure 4.1: Assigning stream order

The above figure 4.1 illustrates an example of assigning stream order according to Stahler's criteria. The uppermost order stream are assigned stream order number 1. When two 1 order stream meets, the resultant stream order number is assigned stream order number 2. When a 2nd order meets a 1st order stream meets the resultant stream is assigned the greater stream order number, i.e 2. Similarly when two 2nd order stream meets the resultant stream order number is 3.

After finding 5th order stream, we have to find feasible stream reach. A stream reach is a certain distance of stream. In our analysis we have considered the distance of stream as 500 m.

We know that more the slope of the river bed more is the head available for a certain length. A stream reach is considered feasible if the slope is > 2%. Thus with a stream reach of minimum slope of 2% will have head available between two ends equal to 10m. The feasible location for SHP installation will be the downstream end of the stream reach.

4.2.1 DEM analysis

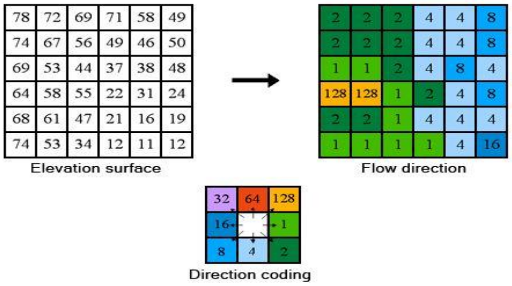
In this analysis ArcGIS software has been used to analyze the DEM and generate flow direction, flow accumulation and slope map. It is also used to delineate watershed of feasible locations, hydro-observation station etc.

a) DEM of the study the area

DEM basically provides the elevation data. It is used as the input in ArcGIS software to generate various maps based on different basin characteristics. DEM is a remote sensing data. It is a raster whose grid values signifies the height of the surface.

b) Flow direction map of the study area

The flow direction map represents the direction of flow out of each cell. The input required is the DEM of the study area in the form of raster. The flow direction is based upon eight direction (D-8) flow model. In this model, there are eight valid output directions relating to the eight neighbouring cells into which flow could travel.



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

Elevation surface

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

Flow direction

32	64	128
16		1
8	4	2

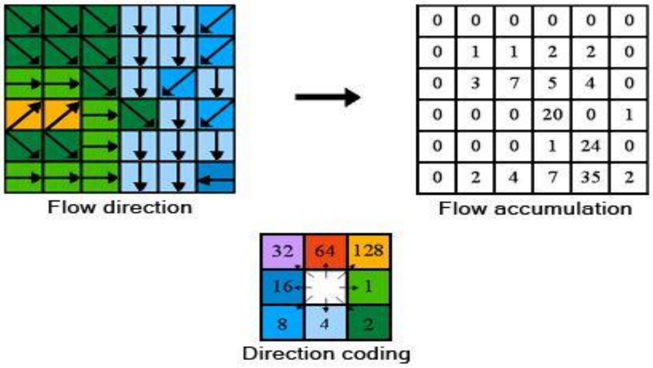
Direction coding

Figure 4.2: Assigning flow direction value

In the figure 4.4, we can see a raster of elevation surface. Let us consider the 1st grid whose value is 78. Its adjoining cell have values 72, 67, 74. The minimum value among these is 67. Thus the maximum slope is in the direction joining the cell 78 and 67 i.e the south-east direction. Similarly the value is assigned for every cell of the elevation surface. The resultant raster formed is the flow direction raster.

c) Flow accumulation map of the study area

The Flow Accumulation tool in ArcGIS software calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. In the figure 4.6, the top left image shows the direction of travel from each cell and the top right image shows the number of cells that flow into each cell.



0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

32	64	128
16		1
8	4	2

Figure 4.3: How flow accumulation tool works

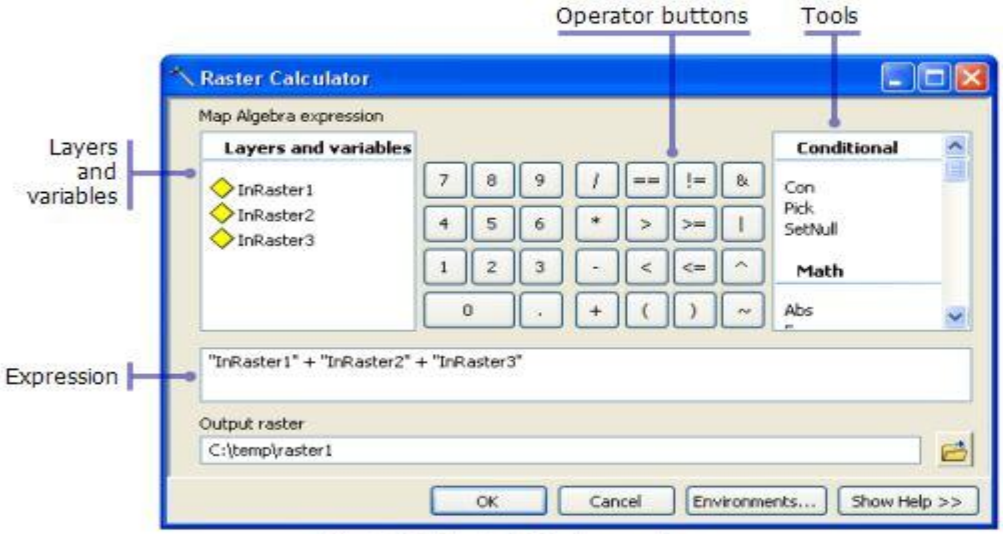
In a simplified manner, we can say that the flow accumulation value of a cell represents the number of cells accompanying flow to that cell.

d) Slope Map of the study area

Slope calculates the maximum rate of change in value from that cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight adjacent cells identifies the steepest downhill descent from the cell.

e) Overlapping stream map and slope map using the raster calculator

Raster calculator is a tool to perform map algebra. This tool can be used to overlap different maps, show feature with distinct properties etc. A snap of raster calculator tool is shown in figure 4.9.



Map Algebra expression: "InRaster1" + "InRaster2" + "InRaster3"

Output raster: C:\temp\raster1

Raster Calculator tool dialog box example

Figure 4.4: A snap of raster calculator tool

In this analysis the expression used in raster calculator is-

(“stream map”==1) & (“slope map”>2%)

This expression results a new raster layer with stream segments having slope >2%. And from this layer the map of feasible location based on head available can be derived.

4.2.2 Head calculation

To determine the head available for the potential SHP installation, a contour map of a sample area is needed as shown in the figure 4.11. The contour map can be created with ArcGIS software.

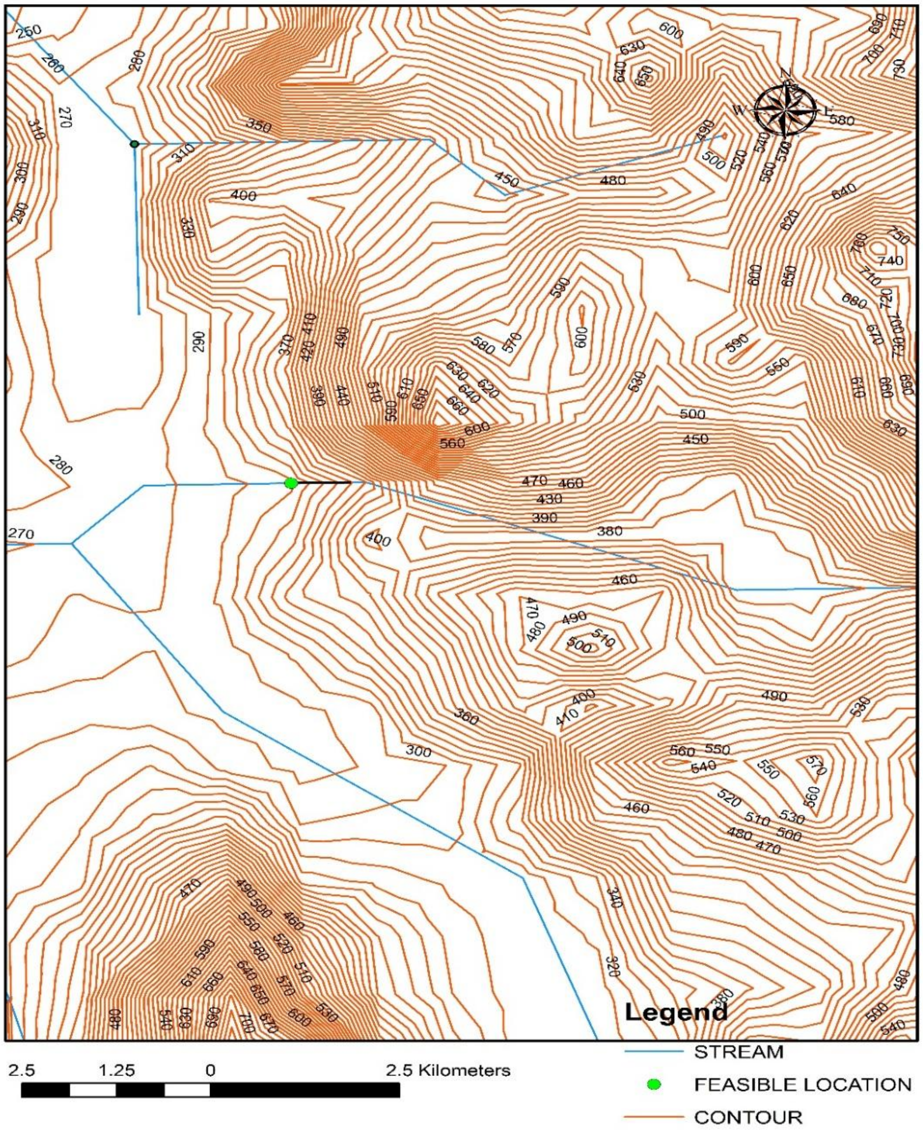


Figure 4.5: Contour map of a sample area

The contour interval of the above map is 10 m. The blue line represents the stream and the black line represents the feasible stream reach of 500 m length. The number of contour lines passing through the feasible stream reach is 5. Thus the head available between the ends of the feasible stream reach in the map is 40 m. The feasible location will be the downstream end of feasible stream reach. Through the use of contour lines, head available can be calculated for all potential locations in the study area.

4.3 Location based on discharge

After finding feasible location based on head, the task is to find the discharge available at these locations. As most of these areas are on ungauged site, no discharge data is available. Hence we need a methodology of discharge calculation. Also flow duration curve (FDC) is needed to be developed for each point for further analysis.

4.3.1 Discharge Calculation

Many times situation arises when the discharge observations are not available at all for streams and flow assessment has to be made for planning and the preparation of project report of a possible project site. Depending on the availability of data of other sites or basins there are various methods. But in this analysis I used a method suggested by AHEC (alternate hydro energy centre) which is described below.

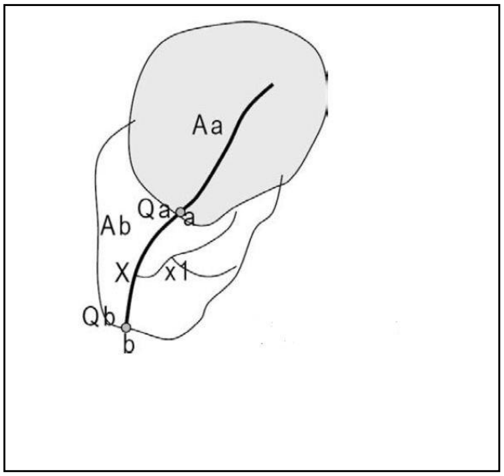


Figure 4.6: A typical catchment area

The above diagram shows a catchment area. The points a,b are gauging stations at which discharge is measured. Now the discharge at areas of interest –x, x1 are calculated by using the following formula-

$$Q_x = Q_a + \frac{Q_b - Q_a}{A_b - A_a} * A_x \qquad (4.5)$$

$$Q_{x1} = \frac{Q_b - Q_a}{A_b - A_a} * A_{x1} \qquad (4.6)$$

Where,

Q_x,Q_{x1}- discharge at points x and x1 respectively

Q_a, Q_b- discharge at points a and b respectively

A_x,A_{x1}- catchment areas of points x and x1 respectively

A_a,A_b- catchment areas of points a and b respectively

4.3.2 Flow duration curve

It is a plot of discharge against the percent of time the flow was equaled or exceeded. The daily discharges for the locations are arranged in descending order and assigned their respective ranks "m". Let the total number of discharge data available be "n". Now the percentage probability (Pp) is calculated by the Weibull method-

$$P_p = \frac{m}{n+1} \tag{4.7}$$

Then the discharges are plotted against their respective percentage probability and the FDC is obtained. The discharge with percentage probability X is given by Q_X. A typical FDC isshown in figure

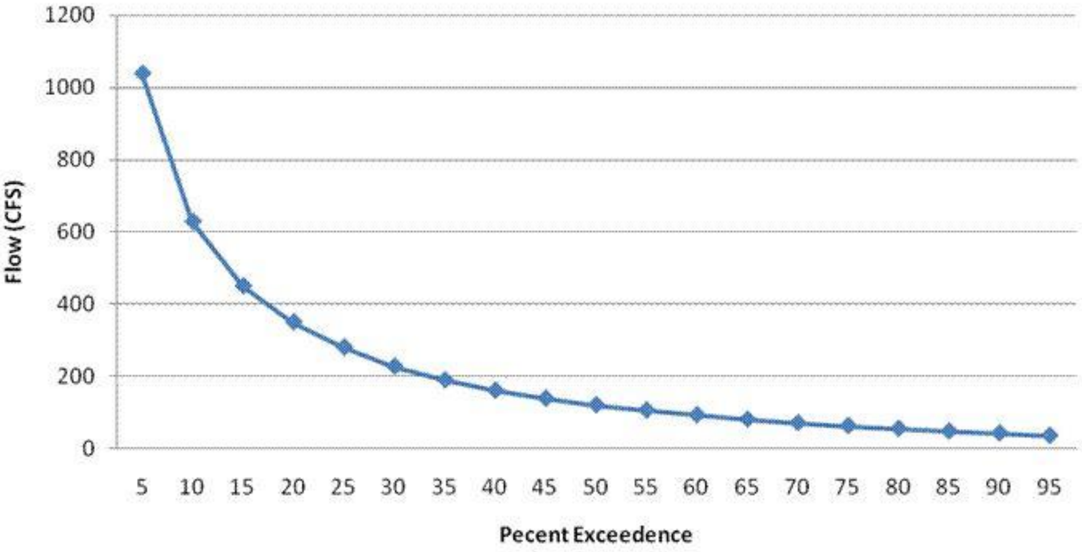


Figure 4.7: A typical flow duration curve

In this analysis FDC has been developed for every year for past 6 years for the period 2006-11 for each location. Thus in the graph we have 6 sets of FDC. The Q_{75} (discharge with percentage probability 75%) for each year is noted down and then the average of these 6 Q_{75} is taken. This average Q_{75} is used in the further analysis.

4.4 Installations

A small hydrower development requires different type of structures and appurtenances, the design of which depends upon the site conditions, type of scheme, access to construction materials etc as shown in the figure 4.14.

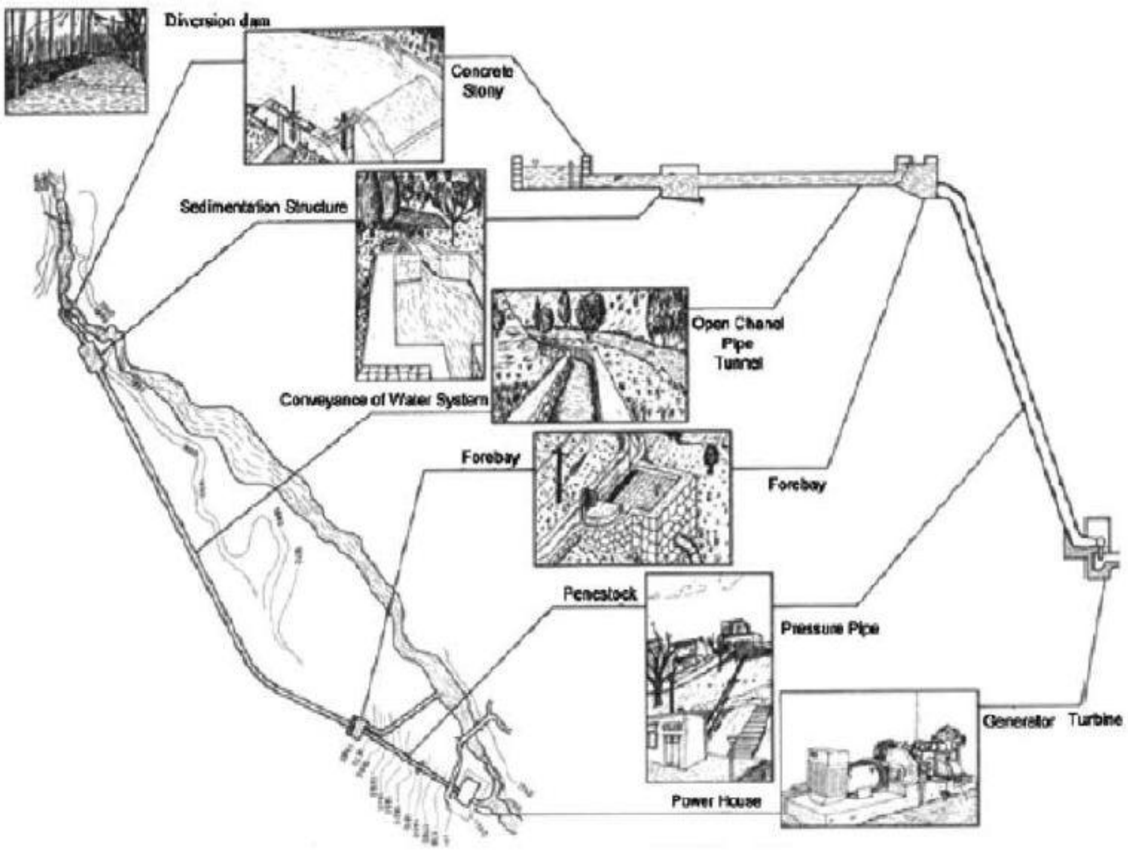


Figure 4.8: Schematics of a typical SHP

The following structures and appurtenances are common in a typical small hydropower plant-

1) Weir

A weir is a masonry or concrete structure built perpendicular to river axis. The main function of the weir is to act as a diversion dam and to create a small reservoir upstream. The weir can be sharp-crested, broad crested, ogee type. The concrete and gravity dams can be designed like a simple gravity dam. Nowadays the inflatable weir has come into use, which uses a reinforced rubber bladder instead of concrete, steel etc. The main advantages of this weir are lower initial cost, simple operation and minimal maintenance. The weir is inflated with air or water under pressure through a compressor or pump connected to it. Similarly the weir can be deflated so that it lies flat on foundation at the times of flood. A typical concrete weir and inflatable weir are shown in the figure 4.15(a) and 4.15(b) respectively.

Figure 4.9(a): Concrete weir

Figure 4.9(b): Inflated weir

2) Sedimentation structure

The river water contains a lot of sediments that can be detrimental to penstock and the blades of turbines if conveyed directly. Thus there is a requirement for the construction of sedimentation structure which restricts the movement of sediment load any further.

Sedimentation structure is based on the principle of lowering the turbulence and flow velocities. This results in the settlement of the sediments. This lowering is obtained by an enlargement of the canal section as it results in decrease of velocity.

Design

The length of the sedimentation tank is governed by the discharge of the intake its chosen efficiency. The length should be sufficiently large so that all the grains have the time to deposit before leaving the tank. This occurs when the deposition time t_D equals the transfer time 't_t'. These are defined as h/v_D and the latter as L/v_t respectively. Thus the minimum length required to deposit a grain diameter d is given by equation 4.8.

$$L \geq \frac{Q}{v_D . B} \tag{4.8}$$

Where B = width; L = length; Q = discharge; v_D = deposition velocity.The width B should be smaller than 1/8 times the length L and also be smaller than twice the flow depth h. For spherical particles and under ideal conditions (pure water, no turbulence and no wall effects), v_D is defined by Newton or Prandtl formula. It is a function of form drag of the particle which in turn depends on Reynold's number. For practice, the empirical formula as shown in equation 4.9 is generally used as a general in still water flow conditions-

$$v_D = \frac{100}{9.d}\left(\sqrt{1 + 1.57 \cdot 1O^2 \cdot d^3} - 1\right) \tag{4.9}$$

Where d = grain size diameter (in mm).This expression is valid for a grain-to-water density ratio of 2.65 and T = 20°.

The deposition velocity decreases for turbulent flow conditions, and the following expression as in equation 4.10 becomes more appropriate

$$v_D = v_{DO} - \alpha \cdot v_T \geq 0 \tag{4.10}$$

in which v_{D0} is the deposition velocity in still water and α is a reduction factor expressed as a function of trap water depth h (m) as shown in equation 4.11-

$$\alpha = \frac{0.132}{\sqrt{h}} \tag{4.11}$$

But the critical transfer velocity (v_{cr}) has to be defined for final and suitable design. The limit between the suspension regime and deposition regime is defined by this critical velocity. The following formula (equation 4.12) is valid for a Manning-Strickler roughness value of K = 60 m1/3/s (K = 1/n, average value for concrete) and for a grain-to water density ratio of 2.65 –

$$v_{cr} = 13 \cdot R_n^{1/6} \cdot \sqrt{d} \tag{4.12}$$

Typical values for v_{cr} ranges from 0.2-0.3 m/s.

3) <u>Open channel</u>

The flow in a canal is a function of its slope, its cross-sectional profile, and its roughness. Natural channels are generally irregular in shape, and their surface roughness varies with distance and time. Hence the application of hydraulic theory to natural channels is much more complex than for artificial channels whereas the cross-section is regular in shape and the surface roughness of the construction materials - earth, concrete, steel or wood - is well documented, so that the application of hydraulic theories yields reasonably accurate results.

The flow in open channels of small hydro scheme is in generally rough turbulent zone and the Manning equation (equation 4.13) can be applied-

$$Q = \frac{A \cdot R^{2/3} \cdot S^{1/2}}{n} \tag{4.13}$$

Equation 4.13 shows that for the same cross-sectional area A and channel slope S, the channel with a greater hydraulic radius R, conveys a larger discharge Q. Hence for a given cross sectional area, the section with the least wetted perimeter is the most efficient hydraulically. Semicircular sections are consequently the most efficient sections. But a semicircular section however is expensive to build and difficult to maintain, unless built with prefabricated materials. The half hexagonal section is the most efficient section for the trapezoidal section . But this is true only if the water level reaches the top level of the bank. A certain freeboard has to be provided to prevent over spilling of the banks and water level fluctuations. Minimum freeboard for lined canals is kept around 10 cm, and for unlined canals this should be about one third of the designed water depth with a minimum of 15 cm. The Manning’s coefficient for various material are given in table 4.1.

Table 4.1: Hydraulic parameters for common canal cross-sections

Type of Channel	Manning's n
Excavated earth channels	
Clean	0.022
Gravelly	0.025

Stony, cobbles (or natural streams)	0.035
Weedy	0.030
Artificially lined channels	
Brass	0.011
Steel, smooth	0.012
Steel, painted	0.014
Steel, riveted	0.015
Cast iron	0.013
Concrete, well-finished	0.012
Concrete, unfinished	0.014
Planed wood	0.012
Clay tile	0.014
Brickwork	0.015
Asphalt	0.016
Rubble masonry	0.025

4) Penstock

The main function of penstock is to transfer water from forebay to the powerhouse. It is a tedious and difficult task to determine the economical arrangement for penstock. Depending on factors such as the penstock material, the nature of the ground, the temperature and the environment, penstocks can be installed over or under the ground.

A flexible and small diameter PVC penstock can be laid on the ground. The pipes can be provided with good insulation by surrounding them with sand and gravel. Small pipes installed in this manner do not need anchor blocks and expansion joints.

Larger penstocks are usually buried. Buried penstocks must be carefully painted and wrapped to protect the exterior from corrosion and further maintenance should be minimal. Also the buried penstock do not constitute a barrier to the movement of the wildlife.

Design

A penstock is generally characterized by materials, diameter, wall thickness.

i) Materials

The material is chosen according to the ground conditions, jointing system, accessibility, weight and cost. Different materials and their properties are shown in the table 4.2.

Table 4.2: Different material's characteristics

Material	Young's modulus of elasticity E(N/m^2)E9	Coefficient of linear expansion a (m/m ^{0}c)E6	Ultimate tensile strength (N/m2)E6	n
Welded Steel	206	12	400	0.012
Polyethylene	0.55	140	5	0.009
Polyvinyl Chloride	2.75	54	13	0.009
Asbestos Cement	n/a	8.1	n/a	0.011
Cast iron	78.5	10	140	0.014
Ductile iron	16.7	11	340	0.013

ii) Diameter

Friction losses are the main head loss in a pressure pipe. The head losses due to turbulence passing through the trashrack, in the entrance to the pipe, in bends, expansions, contractions and valves are minor losses. The friction losses in a pipe can be computed by using the Manning formula (equation 4.14) as follows-

$$\frac{h_f}{L} = 10.3\,\frac{n^2Q^2}{D^{5.333}} \tag{4.14}$$

Where h_f is the head loss; L is the length of penstock; Q is the discharge through penstock; D is the diameter of penstock.

The above equation can be rearranged to find the diameter as shown below-

$$D = \left(\frac{10.3 \cdot n^2 Q^2 \cdot L}{h_f}\right)^{0.1875} \tag{4.15}$$

iii) Wall thickness

The wall thickness required depends on the pipe material, its ultimate tensile strength (and yield), the operating pressure and the pipe diameter. The wall thickness is given by equation-

$$e = \frac{P \cdot D}{2\sigma_f} \tag{4.16}$$

Where e = wall thickness (in mm); P= hydrostatic pressure (in kN/mm^2); D = internal pipe diameter (in mm); σ_f = allowable tensile strength (in kN/mm^2).

For steel pipes the above equation is modified as-

$$e = \frac{P \cdot D}{2\sigma_f} + e_s \tag{4.17}$$

Where e_s= extra thickness to allow for corrosion (in mm).

5) Turbines

The turbine converts the potential energy in the water into the mechanical energy which is required for rotation of the blades. This occurs by one of the two fundamental and basically different mechanism.

i) A force is applied by the water pressure on the face of the runner blades, which decreases as it moves through the turbine. Turbines operating in this way are called reaction turbines. The turbine casing must be strong enough to withstand the operating pressure.

ii) The water pressure can be converted into kinetic energy in the form of high speed jet before entering the runner. This jet then strikes the buckets, mounted on periphery of the runner. Turbines operating in this way are called impulse turbine.

The common types of turbines employed for small hydropower generation are as follows-

i) Pelton turbines

Pelton turbines are impulse turbines. One or more jets of water strikes on the buckets attatched to periphery of the runner. Each jet emerges out of a nozzle with a needle (or spear) valve to control the flow. These are only used for relatively high heads. The axes of the nozzles are in the plane of the runner. The buckets are designed to keep exit velocities to minimum as the some kinetic energy leaving the runner is always lost. The turbine casing is only need to protect the surroundings against water splashing and hence can be very light. A typical Pelton turbine is shown in figure 4.16 (a).

ii) Turgo turbines

The Turgo turbine can operate under a head in the range of 30-300 m. It is an impulse turbine, but its buckets are differently shaped and the jet of water strikes the plane of its runner at an angle of 20º. Water enters the runner through one side of the runner and emerges from the other as shown in the figure. The volume of water a Pelton turbine can admit is relatively smaller because the water leaving each bucket interferes with the adjacent ones, whereas Turgo runner does not present this problem. Thus it results in higher runner speed of the Turgo turbine. This results in improved efficiency and decreased maintenance cost. A typical Turgo turbine is shown in figure 4.16 (b).

iii) Michell-Banki turbines

It is a impulse and cross-flow turbine. It is used for a wide operating range of heads (1-200 m) and discharges (0.02-10 m3/sec). Water enters the turbine, directed by one or more guide-vanes and through the first stage of runner with a small degree of reaction. After the flow occurs in the first stage, the water tries to cross the open centre of the turbine. A compromise direction is achieved as then flow enters the second stage resulting in significant shock losses.

The runner constitutes of two or more parallel disks connected near their rims by a series of curved blades. The efficiency of this turbine lower as compared to other conventional turbines, but remains at the same level for a wide range of flows and heads. A typical Michell-Banki turbine is shown in figure 4.16 (c).

Figure 4.10(a): Pelton turbine

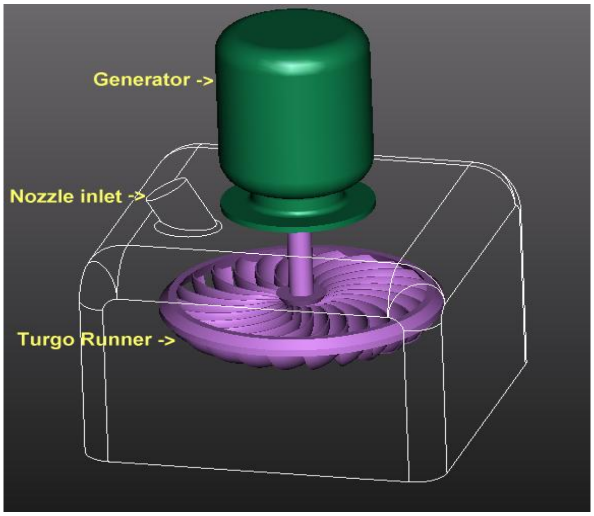


Figure 4.10(b): Turgo turbine

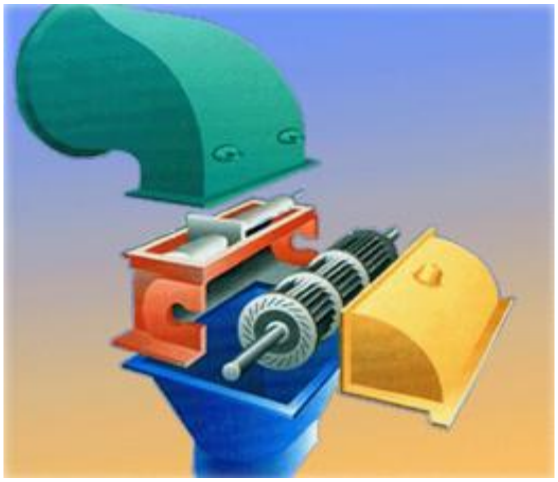


Figure 4.10(c): Michell-Banki Turbine

4.5 Performance

The performance of a SHEP directly depends on the flow available and head available. The figure 4.18 below shows an illustration of these elements along with turbine flow over the course of a single year.

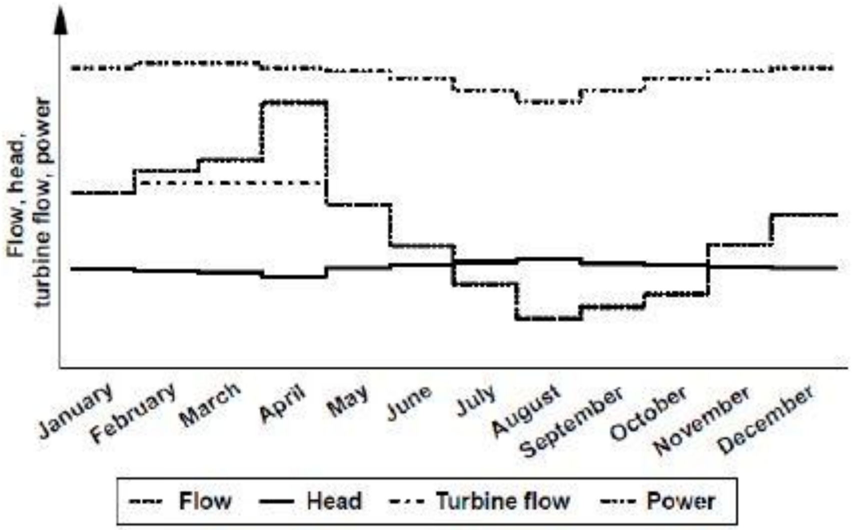


Figure 4.11: Performance graph of SHP

The turbine flow is directly related to the discharge of the river. The turbines can only generate power for the maximum/design flow, and additional discharge goes unutilized. The power generated by hydroelectric power stations is directly proportional to flow through the turbine as found in above eq. (4.4). Available head also affects the power output, but it is usually less significant because it remains nearly constant.

The power production can be adjusted according to changing flows at any given time of the year. Decreasing flows result in lower power generation. Hence a hydroelectric plant must be turned off to prevent the turbines from being damaged. Hence a plant must be designed and positioned accordingly such that these circumstances occur rarely. In contrast, increasing flows above the design capacity results in decreased power generation as the turbine cannot intake the discharge (i.e., increased flows cause the difference between the head and tail water height to become insignificant).

The flow prediction is necessary to operate a hydroelectric power plant. Flow varies with time (daily hours and seasons of the year) and hence it becomes important to study water flow variability before installing SHPs.

CHAPTER 05

RESULT AND DISCUSSION

In the present study, the discharge and elevation data has been used to locate feasible locations and their potentials. The potential power thus generated can save a lot of coal used in thermal power plants and thus restrict the emission of many greenhouse gases. Thus in our study these environmental issues have also been discussed.

5.1 Maps generated based on basin characteristics

1) DEM

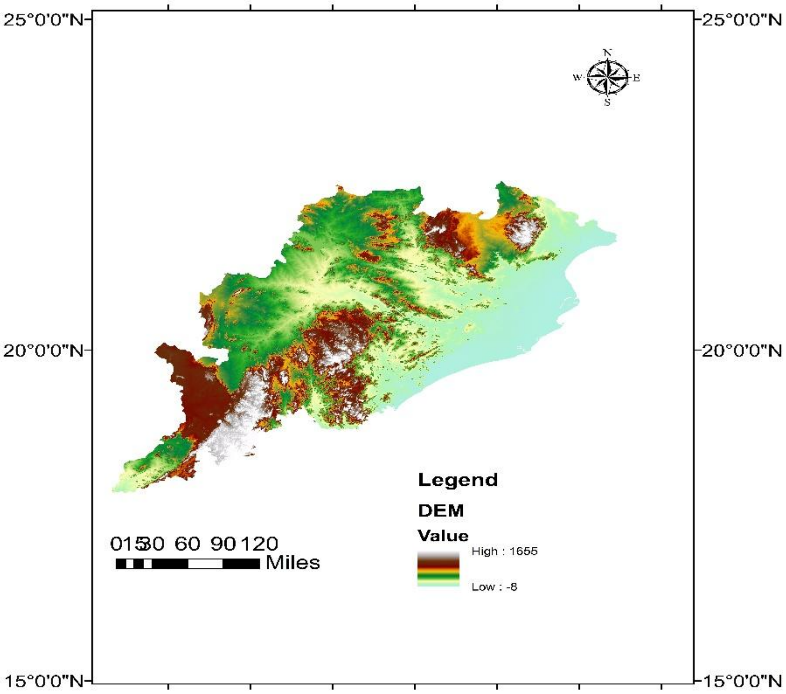
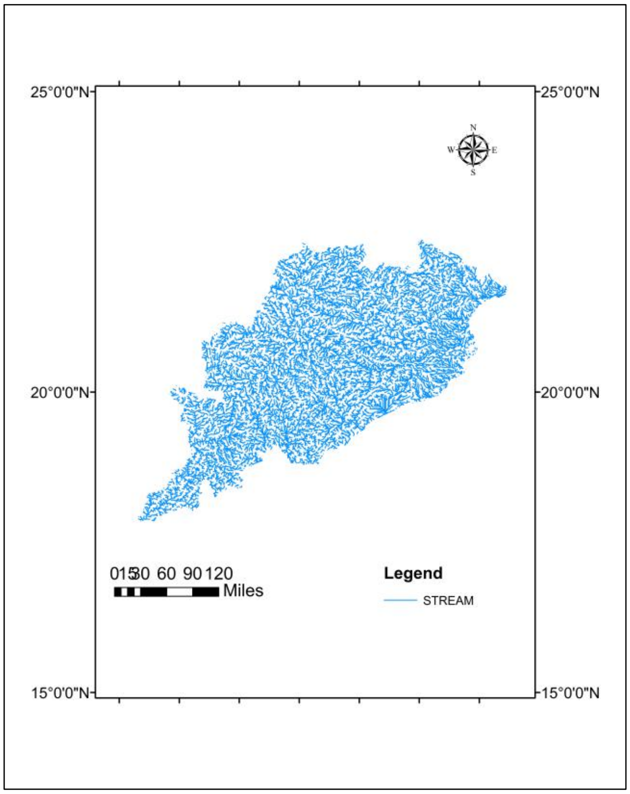


Figure 5.1: DEM of Odisha

2) Basin characteristics of the study area



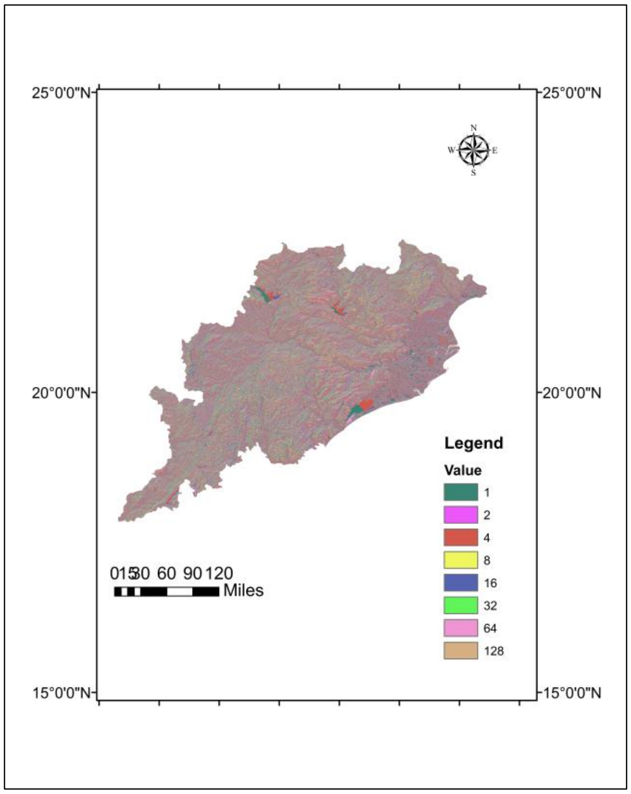
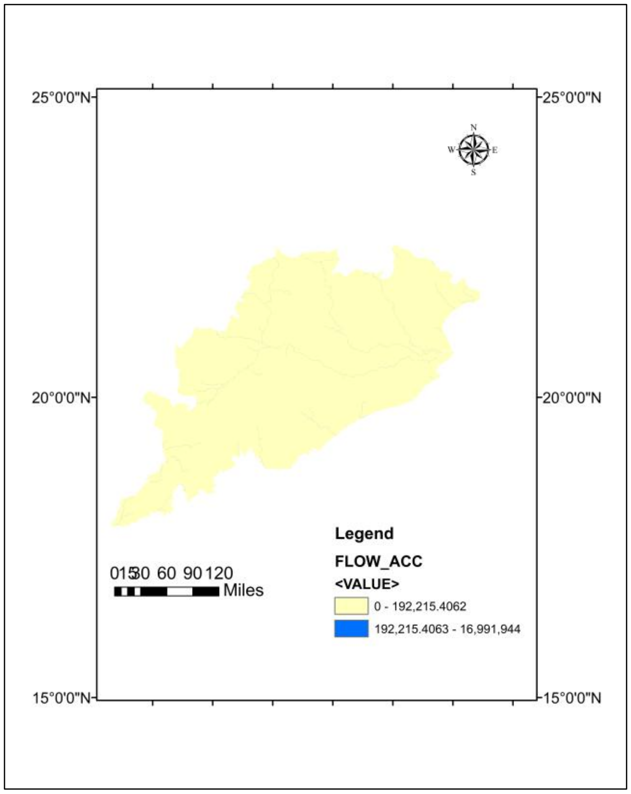


Figure 5.2: Stream map of Odisha **Figure 5.3: Flow direction map of Odisha**



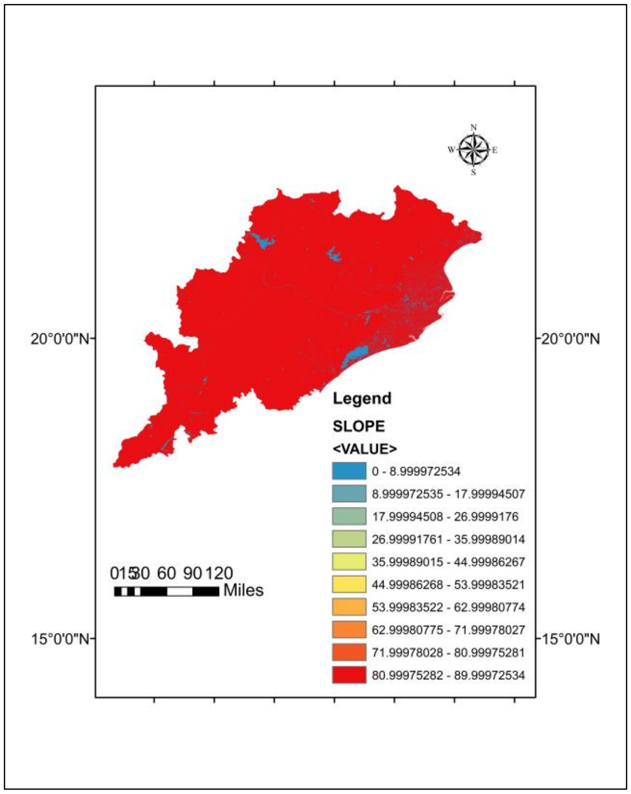


Figure 5.4: Flow accumulation map of Odisha

Figure 5.5: Slope map of Odisha

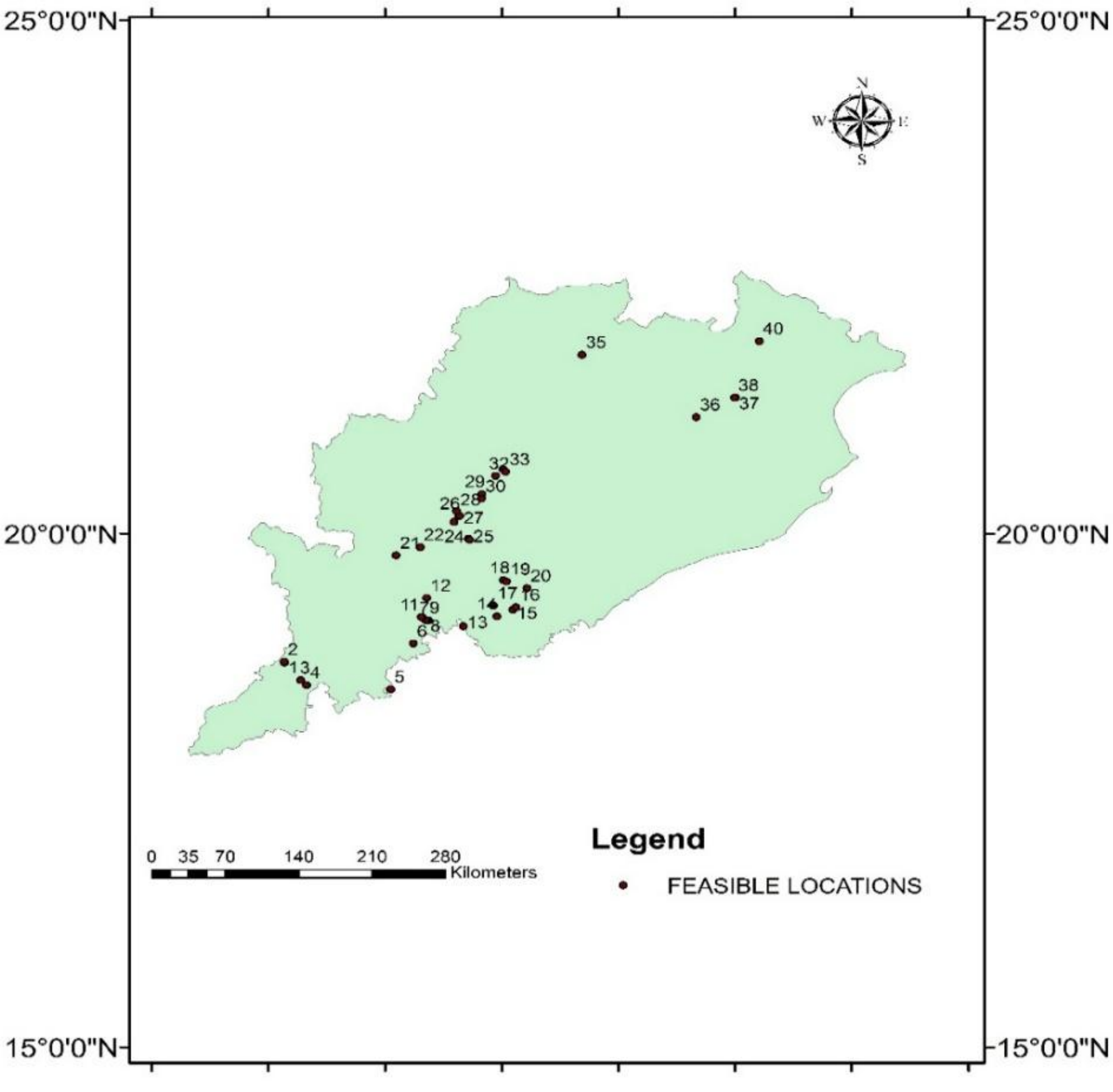
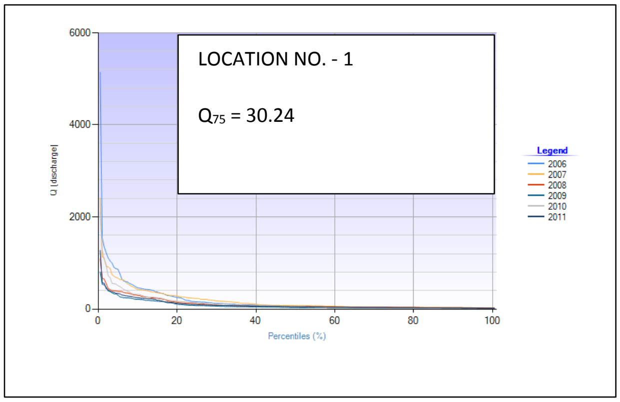
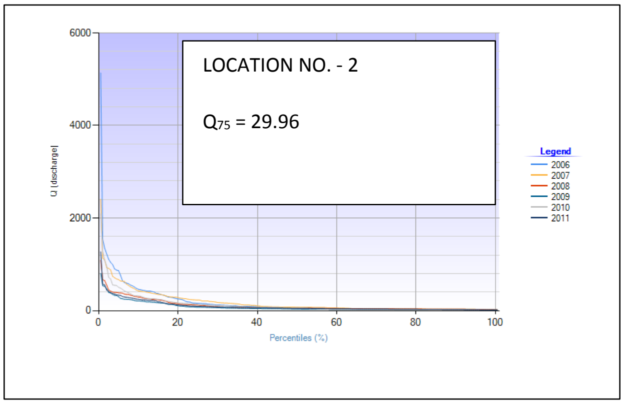


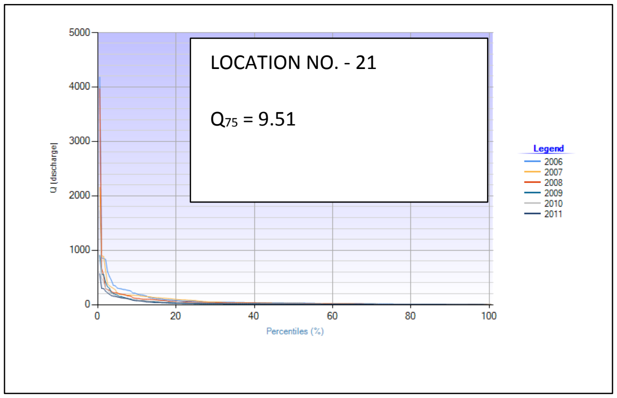
Figure 5.6: Feasible locations for SHP installation

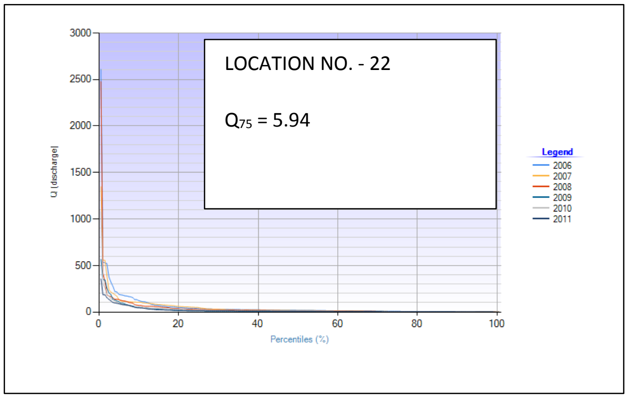
5.2 FDC of the feasible locations

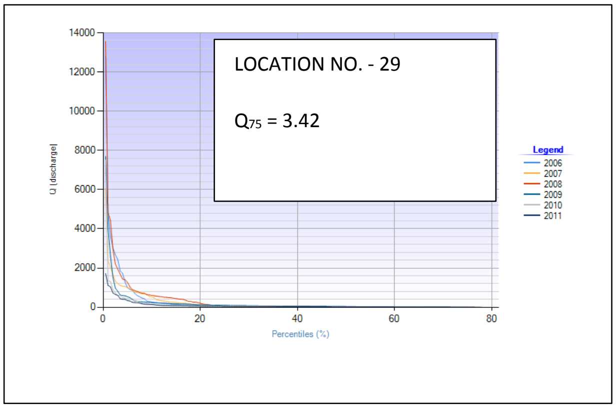
The FDC of some important locations are shown in figure

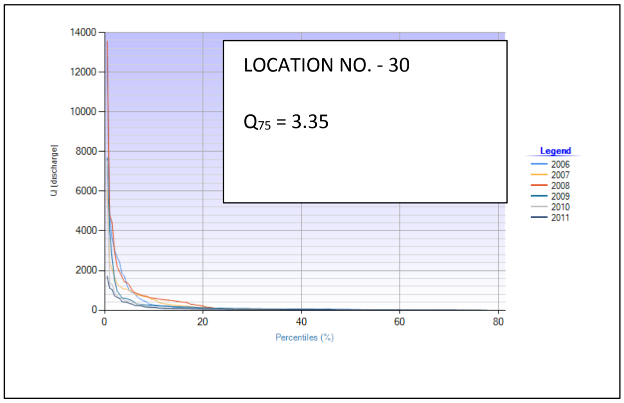












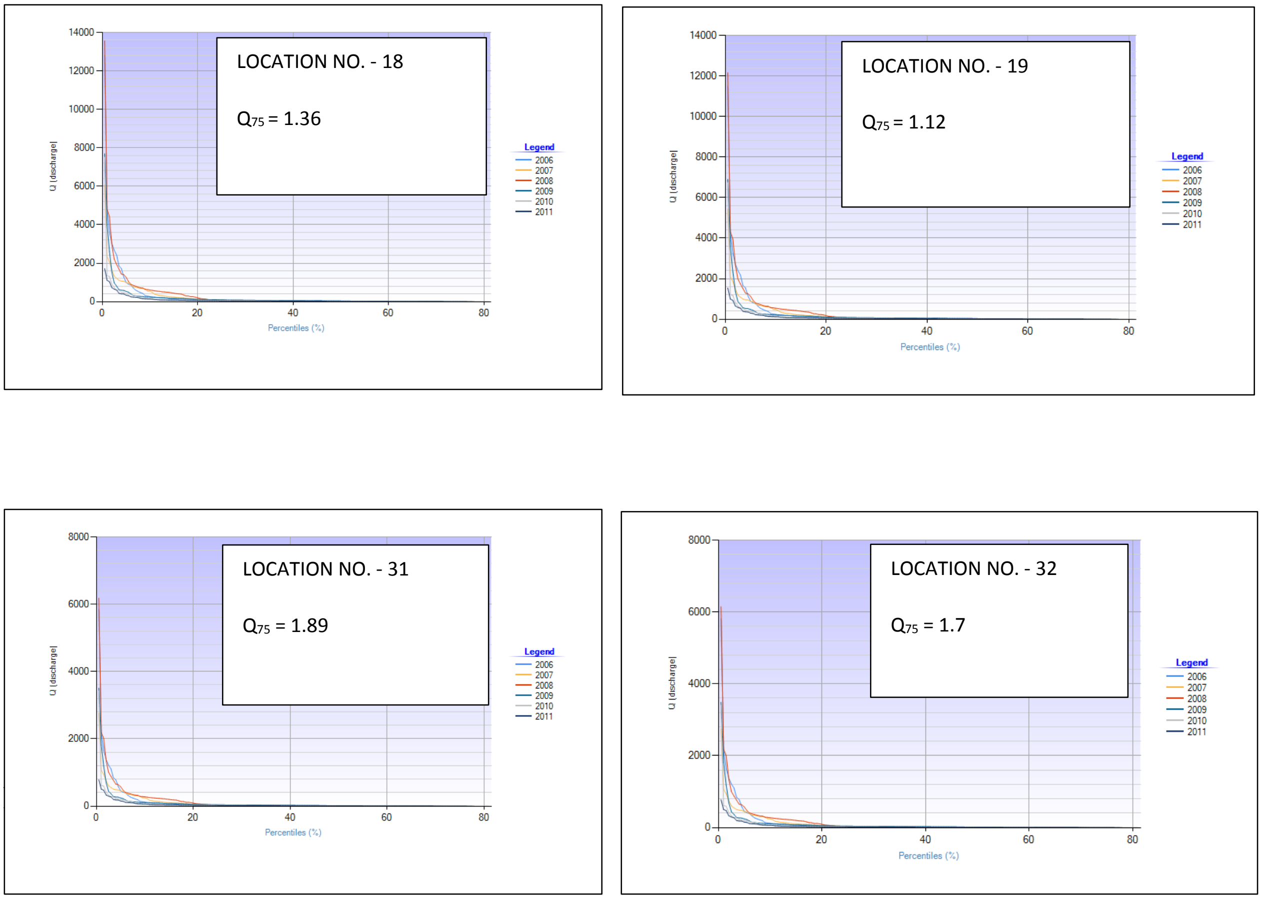


Figure 5.7: FDC of some feasible locations

The FDC of other locations are shown in the appendix.

5.3 Location and potential calculation

The location and potential of SHP has been listed in the following table-

Table 5.1: Feasible locations for SHP installation and their potential

NAME	LATITUDE	LONGITUDE	RIVER	CATCMENT AREA (km2)	HEAD (m)	Q75 (m^3/s)	POTENTIAL POWER (MW)
1	82°8'11.666"E	18°44'44.293"N	KOLAB	2655	35	30.24	8.306323
2	82°8'4.171"E	18°45'11.062"N	KOLAB	2651	45	29.96	10.58067
3	82°16'35.137"E	18°34'25.824"N	SAPTADHARA	131	35	1	0.27468
4	82°19'33.739"E	18°31'33.646"N	SAPTADHARA	52	25	0.4	0.07848
5	83°2'44.544"E	18°29'12.841"N	PEDDA GEDDA	77	110	0.1	0.086328
6	83°14'30.53"E	18°55'51.91"N	JHANJAVATI	528	50	0.67	0.262908
7	83°22'17.037"E	19°9'23.202"N	CHASHISHIHAT	790	30	1	0.23544
8	83°21'18.103"E	83°21'18.103"E	CHASHISHIHAT	787	25	1	0.1962
9	83°20'52.747"E	19°9'33.481"N	CHASHISHIHAT	455	30	0.58	0.136555
10	83°19'7.899"E	19°11'16.274"N	CHASHISHIHAT	297	35	0.38	0.104378
11	83°18'37.746"E	19°11'15.589"N	CHASHISHIHAT	290	40	0.37	0.11615
12	83°21'20.904"E	19°22'28.127"N	NAGAVALI	1154	30	1.47	0.346097
13	83°40'12.823"E	19°5'58.319"N	PEDAGURHA	57	30	0.072	0.016952
14	83°57'25.89"E	19°11'37.535"N	SAN	741	25	1.01	0.198162
15	84°5'43.921"E	19°15'35.329"N	SAN	404	30	0.58	0.136555
16	84°7'13.76"E	19°17'2.788"N	SAN	356	50	0.51	0.200124
17	83°55'44.45"E	19°17'53.328"N	MAHENDRATANAYA	273	20	0.39	0.061214
18	84°0'40.792"E	19°32'56.608"N	HARIBANGA	952	35	1.36	0.373565
19	84°2'20.844"E	19°32'2.471"N	HARIBANGA	782	40	1.12	0.35159
20	84°12'52.12"E	19°28'6.476"N	HARIBANGA	352	35	0.5	0.13734
21	83°5'40.932"E	19°47'18.611"N	SAGADA	258	30	9.51	2.239034
22	83°18'6.179"E	19°52'6.43"N	RET	161	60	5.94	2.797027
23	83°35'22.758"E	20°6'51.818"N	SUNDAUL	268	20	0.83	0.130277
24	83°42'51.941"E	19°57'2.723"N	RAUL	397	45	0.86	0.303718
25	83°43'21.922"E	19°56'32.742"N	RAUL	395	45	0.86	0.303718
26	83°37'48.917"E	20°10'22.579"N	RAUL	416	30	0.9	0.211896
27	83°38'19.969"E	20°10'25.791"N	RAUL	415	45	0.7	0.247212
28	83°36'43.6"E	20°13'20.325"N	RAUL	84	40	0.18	0.056506
29	83°49'48.251"E	20°23'1.746"N	KHARAG	1575	40	3.42	1.073606
30	83°49'26.836"E	20°20'31.84"N	KHARAG	1543	35	3.35	0.920178
31	84°0'32.419"E	20°37'41.052"N	BUGH	871	30	1.89	0.444982
32	83°56'47.988"E	20°33'42.916"N	BUGH	781	40	1.7	0.533664
33	84°2'1.506"E	20°36'11.965"N	BUGH	139	45	0.3	0.105948

34	84°11'2.619"E	20°36'17.336"N	BUGH	1312	35	2.84	0.780091
35	84°41'11.728"E	21°44'34.803"N	RAKURA	116	30	0.32	0.075341
36	85°40'3.229"E	21°7'58.551"N	RAMIALA	53	50	0.16	0.062784
37	86°0'6.433"E	21°19'28.851"N	SANDHEI	500	20	0.6	0.094176
38	85°59'43.884"E	21°19'26.706"N	SANDHEI	495	25	0.6	0.11772
39	86°12'33.127"E	21°52'22.917"N	KAIROBANDAN	292	35	0.35	0.096138
40	86° 12' 25.693"	21° 52' 28.890"	KAIROBANDAN	253	50	0.3	0.11772
		TOTAL					32.91145

Thus the total small hydro potential according to this analysis is 33 MW.

5.4 Classification according to generation capacity

The above potential SHPs has been classified according to the potential available as shown in table 5.2.

Table 5.2: Classification of SHPs

TYPE	LOCATION NUMBER	NUMBER OF STATIONS
MICRO	4, 5, 13, 17, 28, 35, 36, 37, 39	9
MINI	3, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 18, 19, 20, 23, 24, 25, 26, 27, 29, 30, 31, 32, 33, 34, 38,40	29
SMALL	1,2,21,22	4

5.5 Coal saved

From the table 5.1, we conclude that the potential of SHP installation according to this study is 33MW.

Thus energy produced in a whole year= $33 \times 10^6 \times 365 \times 24 \times 3600$ J

$$= 2.9 \times 10^8 \text{ KWh}$$

According to a research done by M.Mittal the average power produced per ton of coal in Indian thermal power plants is 2640 KWh.

Thus the amount of coal saved = $\frac{2.9\times10^8}{2640}$

= 109849 tonnes

Thus at least 109849 tonnes of coal can be saved per year due to the power generated by the potential SHPs.

5.6 Reduction in greenhouse gases emission

Coal is composed primarily of carbon along with variable quantities of other elements, chiefly hydrogen, sulfur, oxygen, and nitrogen. Thus when combustion of coal occurs in thermal power plants, it leads to emission of different types of greenhouse gases such as carbon dioxide, sulphur dioxide and oxides of nitrogen. Due to saving of 109849 tonnes of coal, these greenhouse gas emission can be stopped. The list below shows the average amount of greenhouse gases produced per KWh of power produced in thermal power plants-

Table 5.3: Greenhouse gas emission per KWh production in thermal power plants

Sl.no	Gas	Emission per KWh
1	CO_2	1.1 Kg/KWh
2	SO_2	8 g/ KWh
3	NO_X	2.1 g/ KWh

Thus 109849 tonnes of coal produces 3.2×10^5 tonnes of CO_2, 2320 tonnes of SO_2, 609 tonnes of oxides of nitrogen. Hence if 109849 tonnes of coal is saved then respective amounts of greenhouse gas emission can also be stopped which are a significant account. This can reduce the rate of rampant air pollution.

CHAPTER 06

SUMMARY AND CONCLUSION

The summary and conclusion of the present study are as follows-

i) Feasible points for small hydropower installation in Odisha have been located. The head at these points are found out using the contour maps generated by ArcGIS software. The discharge at these locations are also found out. From these two factors the power potential available at those feasible locations are also estimated.

ii) FDC for these locations have been developed to find out Q_{75}. This Q_{75} is used as the discharge in calculation of power potential.

iii) This surplus power production by the SHPs will lead to lesser load on thermal power plants. Thus there share of power production will decrease. This will lead to lesser coal consumption. From our analysis, we have conclude that around 109849 tonnes of coal can be saved per year if these potential SHPs are installed.

iv) The reduction in coal consumption will ultimately lead to lesser greenhouse gases emission from the thermal power plants. Emission of around 3.2×10^5 tonnes of CO_2, 2320 tonnes of SO_2, 609 tonnes of oxides of nitrogen can be stopped. This will result lesser air pollution and hence a cleaner environment.

v) A lot of rural people who had no access to electricity. Providing them electricity will increase production and will enhance their quality of life. This will lead to increased human development index of the state.

vi) Power outages can be reduced due to the extra power production.

vii) Surplus power can be sold to industries and hence more revenue can be generated.

viii) The application of RS and GIS to delineate drainage, contour, DEM, flow direction, flow accumulation, slope, watershed maps etc were very helpful in determining locations for SHP installations.

ix) The installation, maintenance and operating cost of SHPs are much less compared to its counterparts.

CHAPTER 07

FUTURE SCOPE OF THE WORK

- Environmental impact assessment (EIA) of these SHP installations can be studied.
- Social impact assessment of these projects can be studied on the basis of people displaced (due to reservoirs) and people benefitted.
- More feasible locations can be obtained with more study and more detailed analysis.

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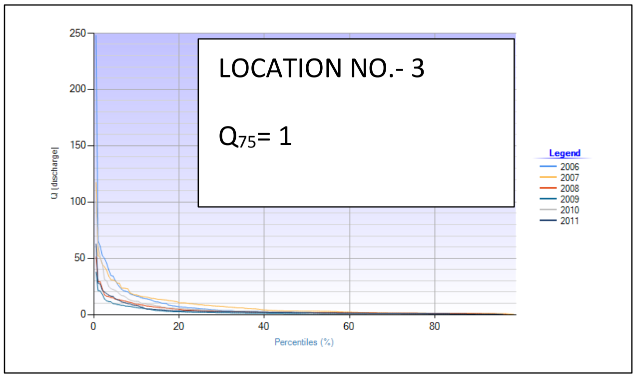
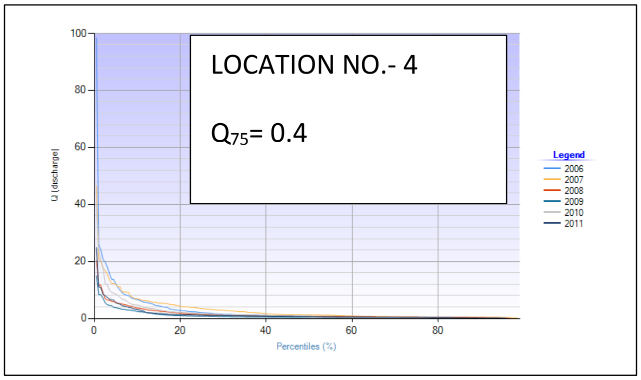
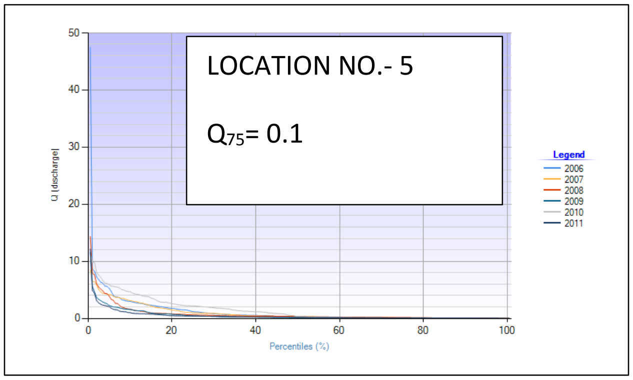
APPENDIX

Table 1: Location of hydro-observation station and their respective catchment area

HO STATION	LONGITUDE	LATITUDE	CA(KM2)
SARADAPUT	82°6'19.021"E	18°36'46.585"N	3581
KOTTA	82°30'6.88"E	18°56'37.089"N	220
ANANDPUR	86°7'22.223"E	21°13'34.726"N	8338
CHAMPUA	85°37'20.347"E	22°7'34.118"N	1570
SUKMA	81°40'8.47"E	18°23'36.966"N	6514
KANTAMAL	83°43'9.154"E	20°39'41.442"N	2121
KESINGA	83°12'10.881"E	20°11'59.027"N	1307
SRIKAKULAM	83°53'25.312"E	18°17'2.481"N	9120
GUDARI	83°42'33.2"E	19°24'25.752"N	3005
GUNUPUR	83°48'15.842"E	19°2'43.711"N	6760
SRIKAKULAM	83°50'32.899"E	18°14'45.515"N	9120
ANDPUR	86°11'1.902"E	21°11'47.429"N	8338
KASHINAGAR	83°55'7.013"E	18°45'35.784"N	7997
KHAIRMAL	83°58'17.179"E	20°50'31.086"N	115514
TIKRAPARA	84°44'32.583"E	20°36'48.745"N	124000
ALTUMA	85°30'47.986"E	20°57'56.521"N	875
JENAPUR	85°56'29.877"E	20°52'13.879"N	36062
PANDIGAON	83°5'11.15"E	20°5'28.59"E	7083



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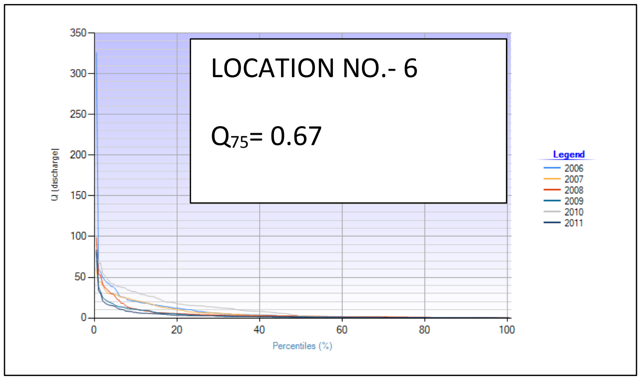
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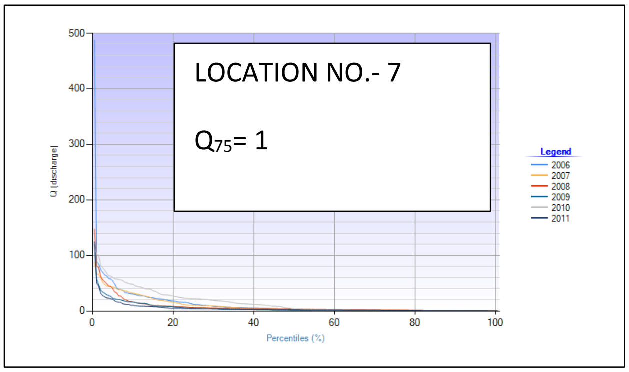
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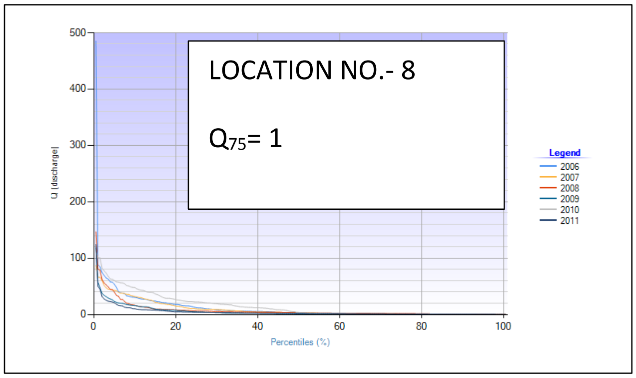
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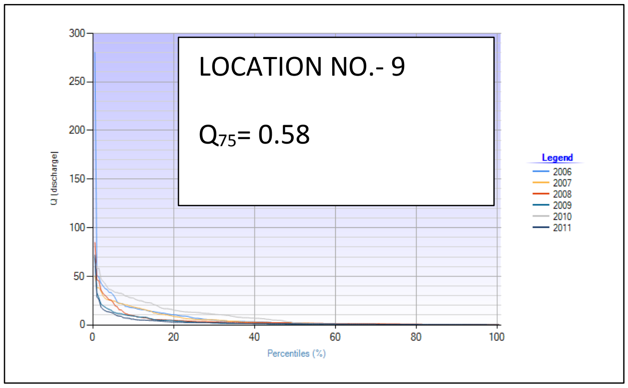
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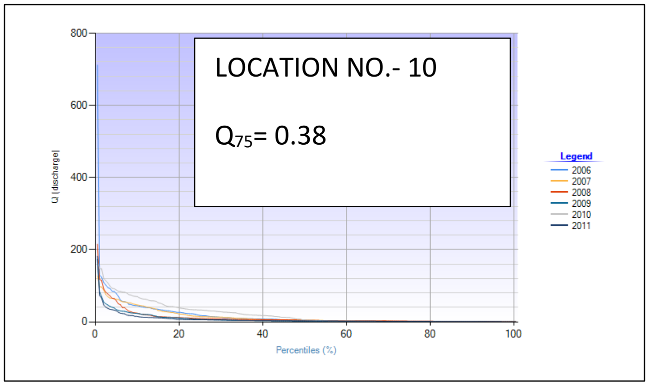
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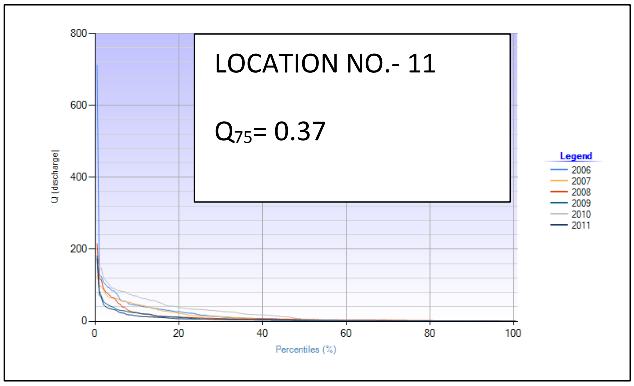
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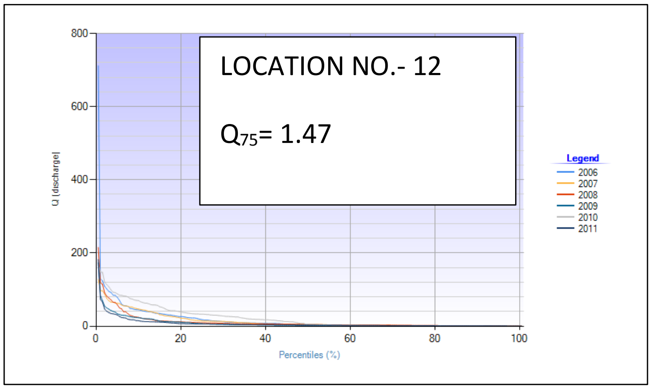
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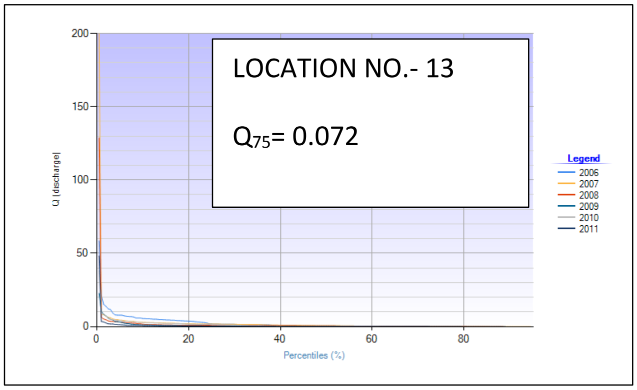
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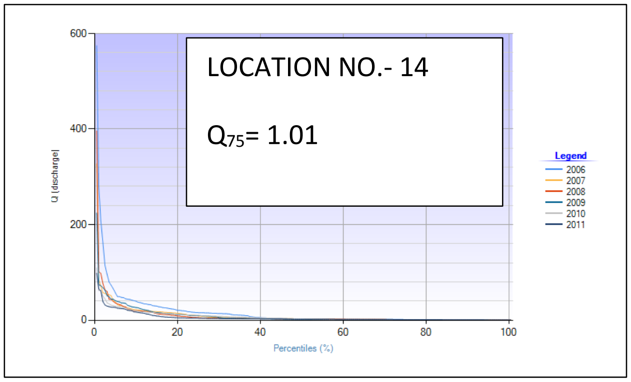
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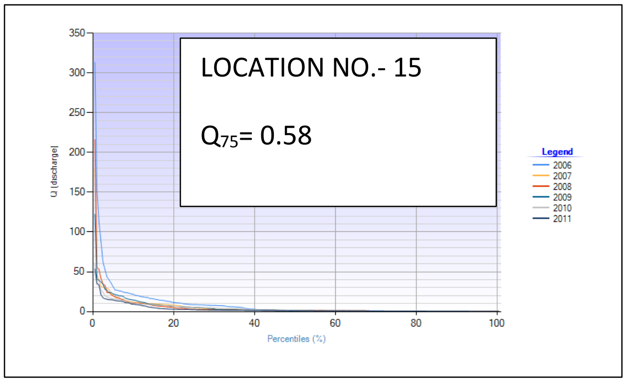
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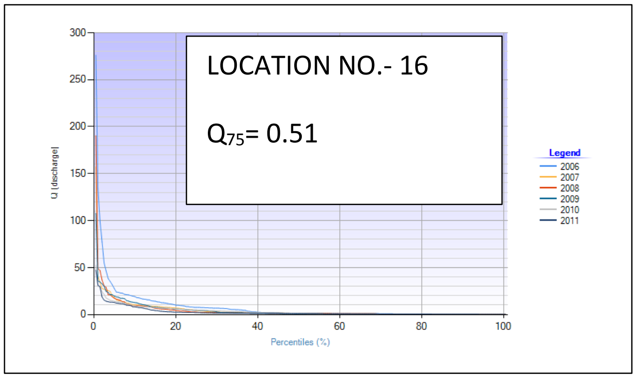
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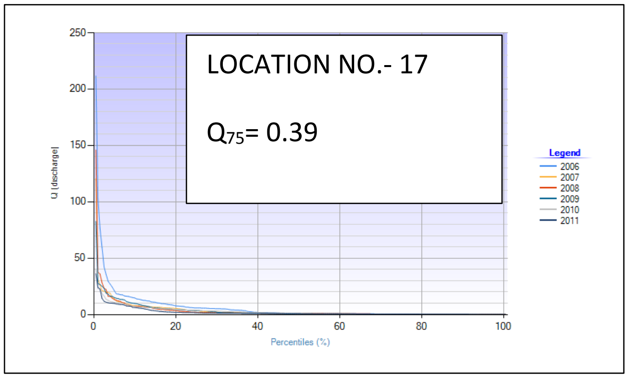

LOCATION NO.- 17

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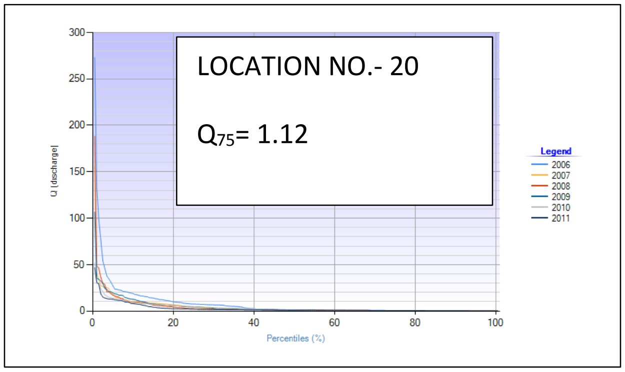

LOCATION NO.- 20

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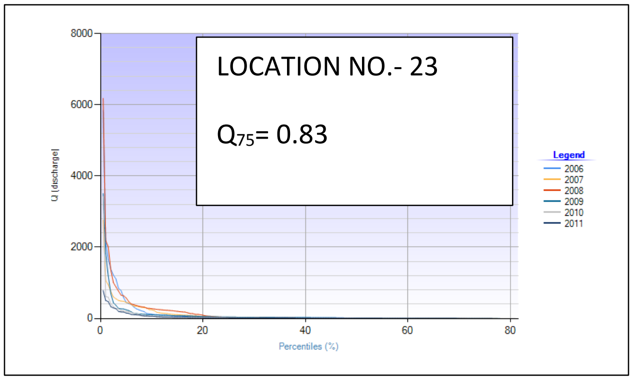

LOCATION NO.- 23

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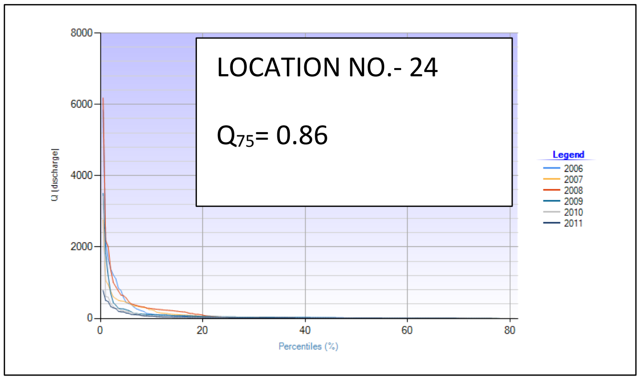
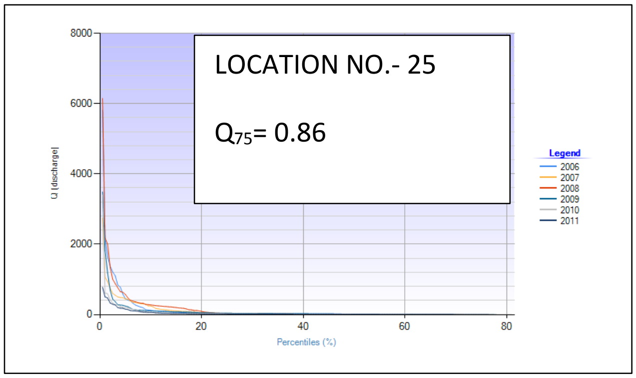


LOCATION NO.- 24

Q_{75}= 0.86



LOCATION NO.- 25

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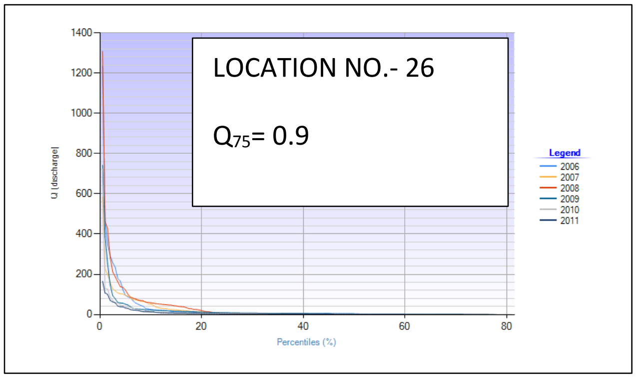

LOCATION NO.- 26

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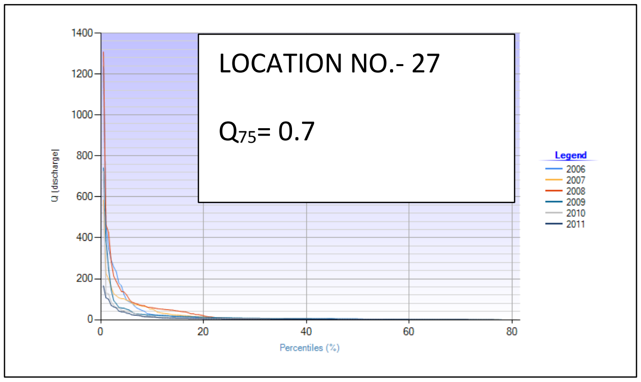
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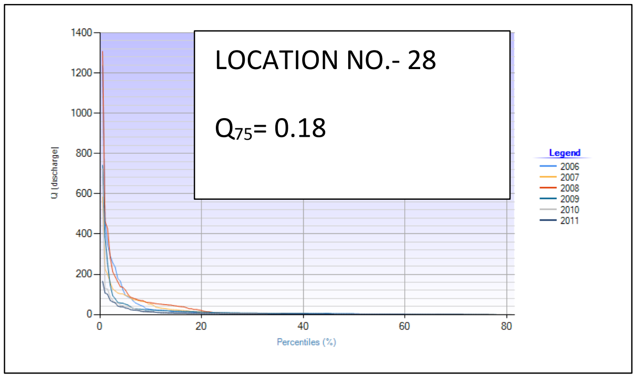
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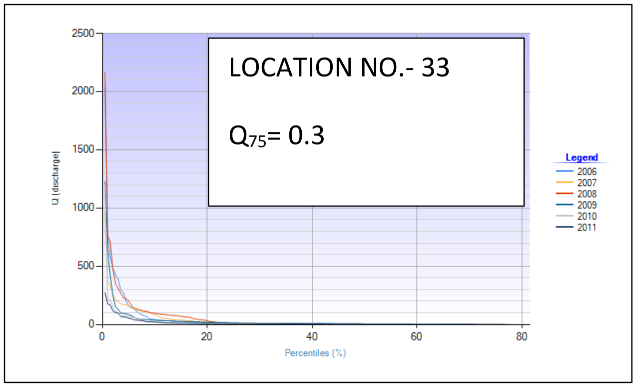
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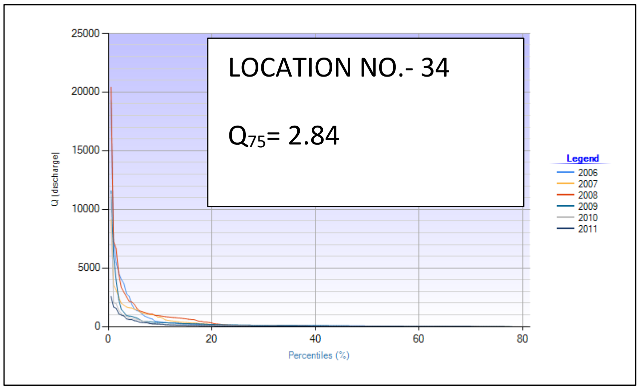
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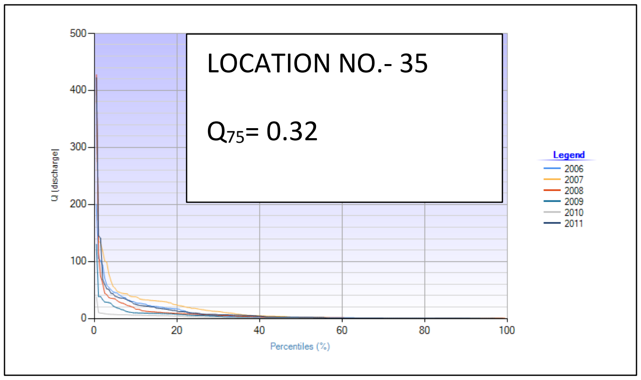
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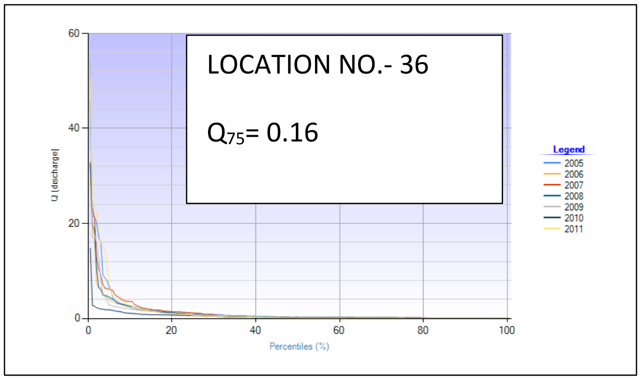
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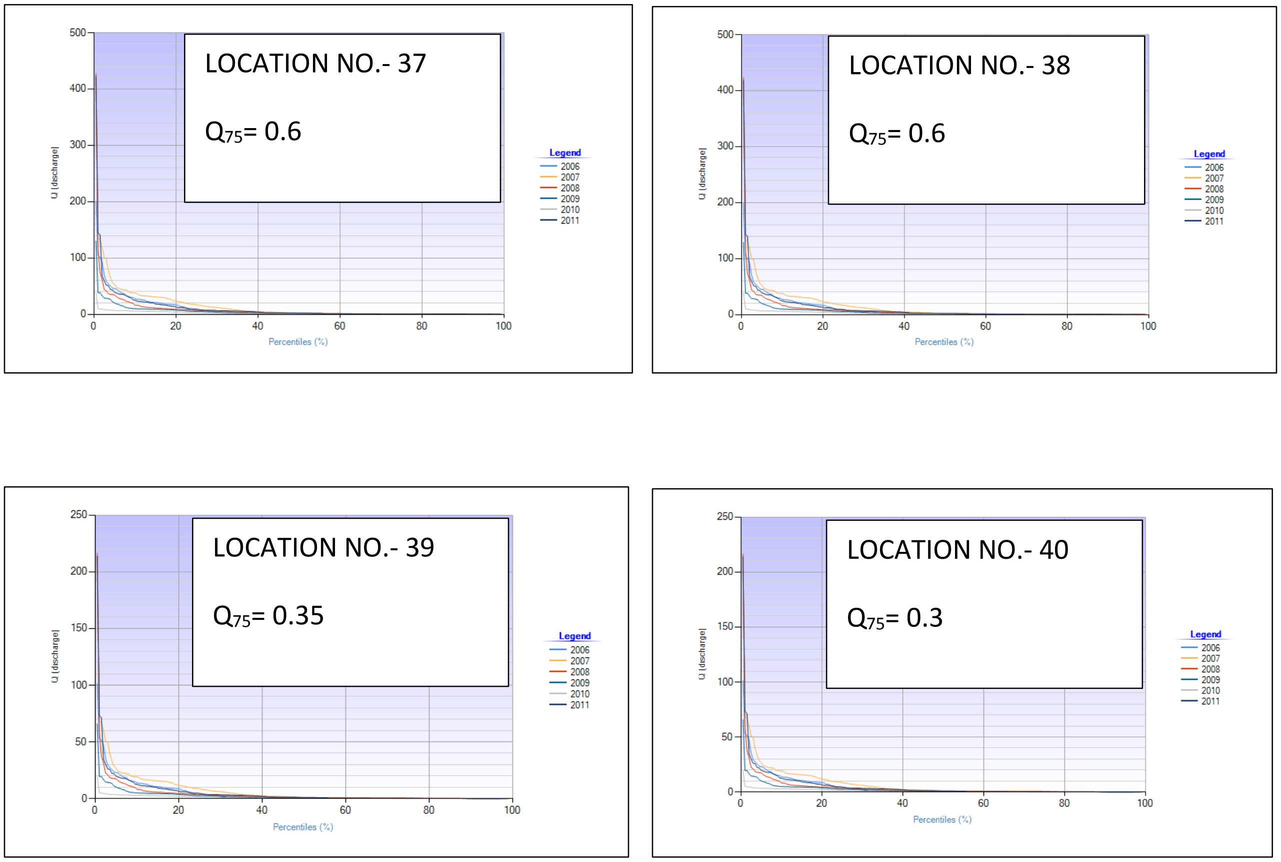

Figure 1: FDC of remaining feasible locations