Comparative Study of Low Head Turbines on Energy Production in Isolated Regions of Ganga River Basin.

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OF

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IN
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Submitted by

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CANDIDATE'S DECLARATION

I Abhishek Singh, Roll No. 2K18/HFE/001 student of M.Tech Hydraulic and Fluid Engineering, hereby declare that the project Dissertation titled "Comparative Study of Low Head Turbine on Energy Production in Isolated Regions of Ganga River Basin" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled “Comparative Study of Low head Turbine on Energy Production in Isolated Regions of Ganga River Basin” which is submitted by Abhishek Singh, Roll No. 2K18/HFE/001, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date:

Prof. S ANBU KUMAR
SUPERVISOR

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Abhishek Singh
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July xx, 2020

Abstract

This research was carried out with the idea to compare and study the low head turbines energy generation capacity in isolated regions of Ganga river basin for the utilization by local residents. With the increase in technological development across multiple zones of society the demand for energy is on a rapid growth. With the introduction of cellular gadgets, electric vehicles and other electricity operated machineries the world is shifting towards a cleaner and greener environment. There still exist a majority of the society which are not urban and live in isolated areas with minimal resources, certain sections have the benefit of Small Scale Hydropower within their surrounding which haven't been tapped into. With the rise in demand and to decrease the load on central grid these decentralized system could exist to meet with the basic needs of the local isolated areas where transportation of electricity is not feasible neither economical. Multiple turbine exists with efficiency of 40 to 70% for heads as low as 0.3 to 10 m. From this study we found that multiple location could be assessed based on the GIS DEM data of the region having possible heads ranging from 5 to 15 meters in the river basin. ANSYS (FLUENT) was used for initial design study for the flow pattern and its behavior with change in Intake angle, variation in vortex flow in turbine chamber. The result of this study indicated that the designed system and turbine type has 70 -80 % efficiency in the Ganga river basin, with average output power capacity of 100KW.

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Chapter 1

Introduction: Small Scale Hydro-Power (SSHP)

1.1 Overview

With the general success of large hydropower as the world's leading source of renewable energy, it is only reasonable that countries consider small hydro, which is run-of-river, development as well. This is particularly relevant for India, a country that hasn’t tapped its abundant hydropower resources for almost a century after introduction of the technology in the country. All of India's major hydropower developments are large, and though they already contribute 13.2% of India's electricity, there remains a growing need for more energy. Large hydro dams are costly to build, and new facilities require extensive timelines for consultation, planning, environmental assessments and construction. In addition, most of the more favorable hydropower sites in India have been developed. These factors have propelled small hydro into the energy scene.

An old technology with many recent innovations, small hydro is appealing for its reduced environmental impacts, potentially cheaper development, and plentiful prospective sites. Public discourse about small hydro often mistakes the reduction of environmental and social impacts for elimination of them. It is important to understand that small hydro inflicts a smaller impact on aquatic ecosystems and local communities, but like all forms of energy cannot completely prevent stresses on plant, animal, and human well-being. Additionally, the negative, cumulative effects of run of river systems operating along the same river network may present further problems, and research in this area is severely lacking. Although not yet cost comparable to large hydro, small hydro is still capable of yielding lower costs per kWh than some other sources, such as diesel-electric. In India, small hydro has found a niche in replacing polluting diesel generators in remote, often First Nations, communities.

This development must be undertaken with care, however, as the risk of affecting river ecosystems directly connects to the stability of traditional lifestyles. The linkage between social and environmental concerns is closely bonded in these places. Long and often confusing permitting processes have slowed the progress of small hydro in India, alongside hesitancy created by unaddressed social and environmental concerns.

Small hydro is likely to gain a stronger presence in coming years if research and development (R&D) becomes more of a priority. Developments must be made in the technology's overall efficiency, as well as in its environmental status, in order for expansion to truly take hold.

There are three primary classifications of SSHP (Small Scale Hydro Power) plants on basis of power generated:

SSHP TYPES/CLASS	POWER (STATION CAPACITY)	HEAD (Meters)
MICRO	UPTO 100 KW	1 – 5
MINI	101 KW – 2 MW	2 – 10
LOW	2 MW - 25MW	10 – 20

Table 1.1: Classification of SSHP Turbine types based on Head.

Hydro-power systems are measure in KW’s and we size them based on the amount of electricity they produce.

Compared with other renewable energy resources like wind power and solar power, the small scale hydropower system can offer a longer lifetime and stable good quality power can be supplied. For this reason, small-scale hydropower systems are applicable to various sites such as dams, rivers, agricultural channels, city water and sewage water plants, and factories.

- Use of maintenance water for discharge from small scale dams:
  This system is used to generate power based on the use of maintenance water discharge from a small scale dam [1]. The generated power is used as a power supply for dam management office.
- Use of river water:

River water is directly used for power generation without any storage facility. Since power is used as a power supply for the dam management office.

- Use of agricultural water:

  Power generation is dependent on agricultural water used for the irrigation of rice and vegetable fields. The generated power is fed to agricultural water irrigation facilities in order to reduce the maintenance cost.

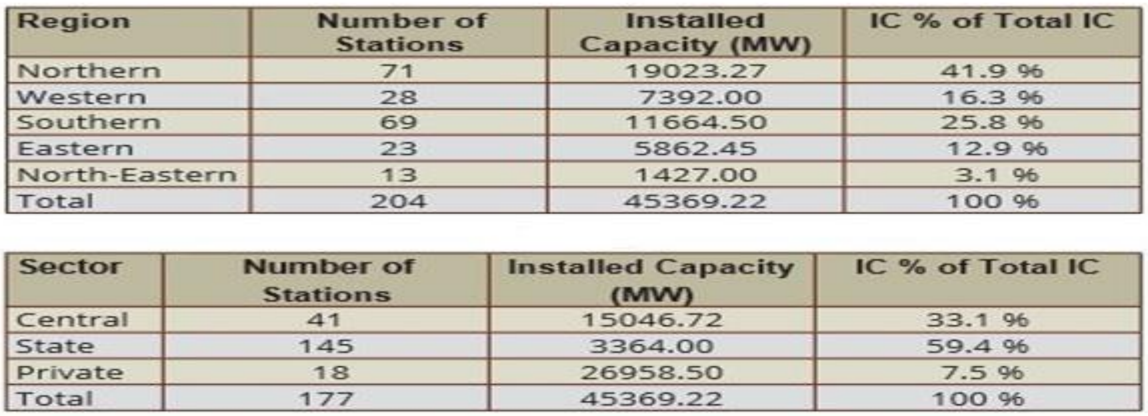
- Use of Industrial Water:

  Power is generated with the use of the residual pressure at the industrial water intake tank [1].

1.2 Present Scenario

Water is one among the nature's best renewable gifts in India, which may be harnessed for reasonable power generation. Hydro power potential of India is estimated at 84,000 MW (at 60% load factor) and supreme possible installed capacity of 145,320 MW in stations with installed capacity over 25 MW. While water may be a State subject, electricity may be a subject in Concurrent List. Development of hydro power in India is governed by Indian Electricity (Supply) Act, 1948 and its amendment Indian Electricity Act, 2003. [2]

Region-wise distribution of hydro power potential counted, potential developed, under development and balance to be developed is given in Table 1. North-East Region has the largest potential of (58356 MW i.e. 40 per cent) followed by North Region (52263 MW i.e. 36 per cent), South Region (15890 MW i.e. 11 per cent), East Region (10680 MW i.e. 7.4 per cent) and West Region (8131 MW: 5.6 per cent). In addition to details mentioned above, 1,840 MW in Western region, 2,005.6 MW in Southern region and 940 MW in Eastern region (total 4,785.60 MW) has also been added in pumped storage schemes. Thus, taking the total installed capacity of hydro power stations works out to be 45,369.22 MW as on 31 August 2018. [2]



Region	Number of Stations	Installed Capacity (MW)	IC % of Total IC
Northern	71	19023.27	41.9 %
Western	28	7392.00	16.3 %
Southern	69	11664.50	25.8 %
Eastern	23	5862.45	12.9 %
North-Eastern	13	1427.00	3.1 %
Total	204	45369.22	100 %

Sector	Number of Stations	Installed Capacity (MW)	IC % of Total IC
Central	41	15046.72	33.1 %
State	145	3364.00	59.4 %
Private	18	26958.50	7.5 %
Total	177	45369.22	100 %

TABLE 1.2: Representation of hydro-power station output and their percentage production in total hydropower capacity of Indian sub-continent at current potential. [2]

Hydropower is one of the largest renewable energy source, and it produces around 16 percentage total of the world’s electricity and over four-fifths of the world’s renewable electricity. Currently, quite 25 countries within the world depend upon hydropower for 90 percentage total of their electricity supply (99.3 % in Norway), and 12 countries are 100% reliant on hydro. Hydro produces the majority of electricity in 65 countries and plays some role in additional than 150 countries. Canada, China and also the United States are the countries which have the most important hydropower generation capacity [4,5,6] (IPCC, 2011; REN21, 2011; and IHA, 2011).

Hydro-power, the most adaptable and recognized nature driven wellspring of power generation available and is equipped for reacting to request variances in minutes, conveying base-load power and when a reservoir is present, storing electricity over weeks, months, seasons or maybe years [3,4] (Brown, 2011 and IPCC, 2011).

One key advantage of hydropower is its unparalleled “load following” capability (i.e. it can meet load fluctuations minute-by-minute). Although other plants, notably conventional thermal power plants, can answer load fluctuations, their response times aren't as fast and sometimes aren't as flexible over their full output band. Adding to grid flexible nature and security systems (spinning resources), hydro-power dams with large reservoir storage be accustomed store energy over time to satisfy system peaks or demand decoupled from inflows. Storage are often over days, weeks, months, seasons or maybe years counting on the dimensions of the reservoir.(re technologies analysis and hydropower)

Ministry of New and Renewable Energy has been invested with the response and idea of developing Small Hydro Power (SHP) projects up to 25MW station capacities. The estimated potential of power generation in the country from such plants is about 20,000 MW. Most of the potential is within the Himalayan States as river-based projects and in other states on irrigation canals. The SHPP's Programme is now essentially private investors driven relying on funding's from individuals. Projects are normally economically viable and local & private sector is showing lot of interest in investing in SHP projects. The viability of those projects improves with increase within the project capacity. The ministry’s aim is that at least 50% of the potential in the country is harnessed in the next 10 years. (https://mnre.gov.in/small-hydro)

Small Hydro Power (SHP) Programme is one among the thrust areas of power generation from renewable within the Ministry of new and renewable Energy. It’s been recognized that micro hydropower projects can play a critical role in improving the general energy scenario of the country and especially for the remote and inaccessible areas. The ministry is encouraging development of small hydro projects both within the public in addition as private sector. Equal and unparalleled attention are being paid to grid-interactive, decentralized and small scale projects which will benefit the local population directly. (https://mnre.gov.in/small-hydro)

1.3 Thesis Objective & Scope

This work aims to study the performance of small scale Hydro-power system in Ganga river Basin for decentralized energy production to power isolated rural household’s .The study includes use of GIS (BHUVAN) CARTOSAT 30M data from ISRO BHUVAN web portal to identify locations for setup and also profiling of terrain. CFD Fluent analysis of proposed system for proper & possible designing based on available raw data. The implementation of proposed system with publically available policy and technology is presented, and simulation results are discussed. The scope of this work is limited to decentralized network of Small Scale Hydro-Power System with separate grid network for rural sector of Bihar Region.

1.4 Thesis Outline

The rest of the thesis is outlined in this section. In Second chapter, different strategies and hydro-power schemes for different capacity is being discussed. Also previously installed systems and their generation capacity in order to meet with the demand will be discussed. Third chapter discusses the application of GIS for laying digital elevation model (DEM) of geotagged residential location as well as the river flow across its surroundings. ISRO’s BHUVAN CARTOSAT 3 data will be used for whole process. Fourth chapter will give us an overview of the Ganga river basin characteristics and the flow parameters such as to set initial and boundary data for the design of the SSHP system. The simulation setup and results are discussed in chapter 5. Finally thesis terminates with the conclusion and scope for the future work in chapter 6.

Chapter 2

Capacity Assignment Strategies & Hydropower Schemes

2.1 Overview

The ability to setup a SSHP over a region has multiple challenges and assignments to see. Continuous flow of source, necessary demand of energy within the region, local/state policies for adopting the design and materials for whole setup of the system are a few of the things that one has to keep in mind while designing the system to meet up with the demand of the people. Also, on the contrary the effect it will have over the surrounding environment and aquatic habitat plays a vital significance in the whole design to setup methods of the system. Multiple hydropower schemes and capacity assignments are provided by the government in order to make the impact of SSHP's to minimum over the environment and obtain maximum efficiency out of it.

2.2 The Hydropower Schemes

Hydro-power is taken into account together of the foremost desirable source of electricity thanks to its environmental friendly nature and extensive potential available throughout the planet. Within the scope of hydro-electric power, small scale power plants have gained much attention in recent years. Small Hydro power Plants, being a mature technology may be optimally employed for sustainable power generation in rural communities in world wide. Hydropower plants convert potential energy of water at a height to mechanical energy which is used to turn a turbine at a lower level for generation of electricity.

In rural areas, small run-of-river hydro turbine is suitable for electrification because it is green, inexpensive, not fuel dependent, and is simpler to implement than other green energy technologies. A small hydropower scheme requires both water flow and a drop by height called a head to supply useful power.

Water in nature is taken into account a source of power when it's ready to perform useful work, particularly turn water wheels and generate electricity at a rate such, the development of power can be accomplished in a most efficient and economical way [7,8] (Adejumobi, I.A, (2011).

Schemes are generally classified consistent with the Head:
- High head: 100-m and above
- Medium head: 30 - 100 m
- Low head: 2 - 30 m

These ranges aren't rigid but are merely means of categorizing sites.

Schemes also can be defined as:
- Run-of-river schemes
- Schemes with the powerhouse located at the bottom of a dam
- Schemes integrated on a canal or during a water system pipe

2.2.1 Run of river schemes

Run-of-river schemes are where the turbine generates electricity as and when the water is out there and provided by the river. When the river dries up and therefore the flow falls below some predetermined amount or the minimum technical flow for the turbine, generation ceases.

Medium and high head schemes use weirs to divert water to the intake, it's then conveyed to the turbines via a pressure pipe or penstock. Penstocks are expensive and consequently this design is usually uneconomic. An alternative is to convey the water by a low-slope canal, running alongside the river to the pressure intake or forebay then through short penstock to the turbines. If the topography and morphology of the terrain doesn't permit the straightforward layout of a canal a low pressure pipe, are often a cheap option. At the outlet side of the turbines, water is discharged into the river through a tailrace.

Low head schemes are mainly idealized in river valley areas with available scope for setup. Two technological options are often selected. Either the water is diverted to an influence intake with a brief penstock, as within the high head schemes, or the head is made by a small dam, given sector gates and an integrated intake, powerhouse and passage.

2.2.2 Schemes with the powerhouse located at the base of a dam

Small hydropower scheme doesn't afford a large storage reservoir to function, when it is most convenient, the cost of a relative larger dam and its hydraulic appurtenances and nature would be too high to make it economically viable. But if the reservoir has already been built for some other purposes, such as flood control, irrigation, water abstraction for a big city, recreation area, etc., - it might be possible to generate electricity using the discharge compatible and utilizable with its fundamental application or the ecological flow for the storage reservoir [12]. The main issue still prevails is how to link headwater and tail water by a waterway and how to fit the turbine at a certain location in this waterway. If the dam already has a bottom outlet, for a possible solution.

Provided the dam is not that high, a siphon intake could be installed. Integral siphon intakes provide and supports an elegant solution in schemes, generally, with heads up to 10 meters and for electrical power units up to about 1000 kW, although there are certain examples and exceptions of siphon intakes with an installed power up to 11 MW in Sweden and heads up to 30.5 meters in the United States. The turbine setup can be located either on the top of the dam or on the downstream side of the same. These units can be delivered pre-packaged from the works, and installed without any major modifications and necessities to the dam for their proper functioning and working.

2.2.3 Scheme integrated with an irrigational canal

Two variable schemes exist and can be designed to exploit multiple canals:

- The canal can be extended or enlarged to accommodate the intake, power station, tailrace and the lateral bypass, with an underwater powerhouse fitted with a 90° angle Kaplan drive turbine. To keep the water supply for irrigation for safekeeping, the scheme should exist with a lateral bypass, in case scenario of shutting of the turbine. These kind of schemes are existing and also designed at the same time as the canal, as an additional work. Whilst doing it when the canal is in full operation can be a very expensive and high budget option.

- If the canal already exists, it is a suitable option. The canal should be accordingly enlarged to include the intake and the spillway. To decrease the breadth of the sectional stock of the intake to a minimum, an extended spillway must be installed in the system. From the intake section, a penstock running parallel in the canal brings the water volume under pressure to the turbine chamber. The water passes through the turbine chamber and is returned into the river through a short tailrace.

- Planning for a Small Scale Hydro-Power System Scheme:-

The complete undertaking or plan comes as the aftereffect of a mind boggling and iterative procedure, where thought is given to the ecological effect and distinctive technological choices. These are then costed and an economic evaluation carried out.

In spite of the fact that it is difficult to give a point by point control on the best way to assess a plan, it is conceivable to portray the essential strides to be followed, before choosing if one ought to continue to an itemized achievability study or not. A list of the studies that should be undertaken:

- Topography and geomorphology of the site.
- Evaluation of the water asset and its producing potential
- Site selection and basic layout
- Hydraulic turbines and generators and their control
- Environmental impact assessment and mitigation measures
- Economic evaluation of the project and financing potential
- Institutional framework and administrative procedures to attain the necessary consents

The water streaming along regular and man-made trenches, led by low and high-pressure pipes, overflowing weir peaks and moving the turbines includes the use of fundamental engineering principles in fluid mechanics. These principles are reviewed together with shortcuts arising from the experience accumulated from centuries of hydraulic systems construction.

In order to decide whether a scheme will be viable it is necessary to start by evaluating the existing water resource at the site. The scheme's energy potential is proportional to the flux and head product. The gross head may typically be considered constant except for very small heads but the flow varies over the year. A flow-duration curve is most useful for choosing the most suitable hydraulic equipment and estimating the sites potential with estimates of the annual energy production. There is little value to a single measure of instantaneous flow in a stream.

Measuring the gross head requires a topographical survey. The results obtained, by using a surveyor's level and staff is accurate enough, but the recent advances in electronic surveying equipment make the topographical surveying work much simpler and faster. It is easier to produce a flow period curve at a gauge than to produce a curve at an ungauged location. This includes an understanding of hydrology in greater detail. Techniques such as ortho-photography, RES, GIS, geomorphology, geotectonic, etc. - used nowadays for site evaluation.

Turbines themselves are not studied in depth, but attention is concentrated on turbine designs, especially for low head schemes, and the turbine selection process, with particular emphasis on speed parameters. Since small hydro schemes are usually operated unattended, the control systems, based on personal computers, are also considered a part of study.

2.3 Definition & Current Examples of SSHP’s

2.3.1 Definition of SSHP

SSHP are hydropower plants which serves industry and local communities on a small scale. In our country the development of SSHP projects up to a capacity of 25MW has been vested to ministry of new and renewable energies. SSHP has multiple advantages which are discussed below:

- Energy Efficient Source

SSHP's requires very minimal amount of discharge and the power production can be transferred to nearby communities.

- Reliable Energy Source

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

- No Reservoir Required

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

- Cost Effective Energy Solution

  Construction of SSHP requires very less investment computed to its counterpart. The maintenance requirement is also very less as compared to other processes.

- Integration with Local Power Grid

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

- Environment Friendly

  SSHP contributes to no greenhouse gas emission. Also on the contrary it altercates the natural path of the river to a very minimal extent.

- Increase Oxygen Content in Lower Course

  Turbines of SSHP's aerate the water by spinning oxygen into the water which increases the DO level downstream of the river. This is very good for the aquatic life D/S of the turbine setup.

2.3.2 Current Example of SSHP's

1. AGNOOR

LOCATION	BIHAR
CONFIGURATION	2 X 50 KW
TUBINE TYPE	S TURBINE

OPERATION YEAR	2006
BUILT LOCATION	PATNA BRANCH CANAL
CONSTRUCTION COST	797 Lacs

2. DHELABAGH

LOCATION	BIHAR
CONFIGURATION	2 X 500 KW
TUBINE TYPE	SEMI KAPLAN TURBINE
OPERATION YEAR	2006
BUILT LOCATION	ROHTAS
CONSTRUCTION COST	670 Lacs

3. EASTERN GANDHAK CANAL

LOCATION	BIHAR
CONFIGURATION	3 X 5 MW
TUBINE TYPE	BULB
OPERATION YEAR	1995-1997
BUILT LOCATION	VALMIKINAGAR
CONSTRUCTION COST	4790 Lacs

4. SONE EASTERN CANAL

LOCATION	BIHAR
CONFIGURATION	2 X 1.65 MW
TUBINE TYPE	BULB
OPERATION YEAR	1996
BUILT LOCATION	BARUN
CONSTRUCTION COST	970 Lacs

5. SONE WESTERN LINK CANAL

LOCATION	BIHAR
CONFIGURATION	4 X 1.65 MW
TUBINE TYPE	BULB
OPERATION YEAR	1993
BUILT LOCATION	DEHRI
CONSTRUCTION COST	4500 Lacs

2.3.3 Advantages of Small Scale Hydro-Power

- Minimal environmental impact: zero emission of CO2.

- High energy efficiency (about 80-85%).
- Continuous source of energy that allows the reduction of supply from sources subjected to significant fluctuation in prices, such as fuel.
- Reliable, mature technology and competitive costs.
- Approval and licensing processes that are generally simpler than those for large scale facilities.

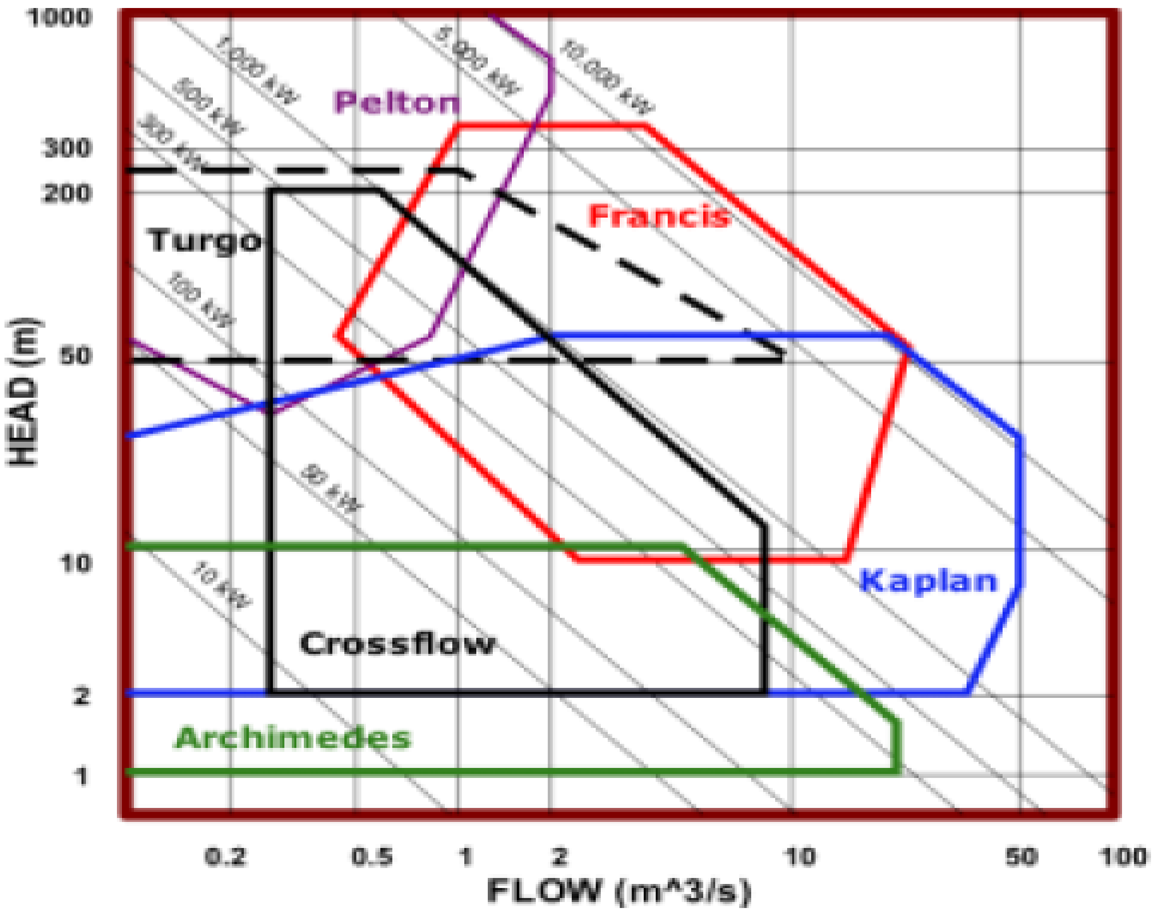


FIGURE 2.3.3.1: A General Inter-relation of Head versus the flow discharge across multiple variant of Turbines [source: http://greenbugenergy.com/get-educated-knowledge/types-of-turbines]

2.4 Current and Future Demand of Energy across Country & State

With a population of 1.4 billion and one of the world's fastest-growing major economies, India will be vital for the future of the global energy markets. The Government of India has gained great ground as of late in expanding Indian citizen's access to power and clean cooking. It has also successfully implemented a range of energy market reforms and carried out a huge amount of renewable electricity deployment, notably in Hydro & Solar energy.

Looking ahead, the government has laid out an ambitious vision to bring secure, affordable and sustainable energy to all its citizens. This in-depth review aims to assist the government in meeting its energy policy objectives by setting out a range of recommendations in each area, with a focus on energy system transformation, energy security and energy affordability. The review also highlights a number of important lessons from the rapid development of India's energy sector that could help inform the plans of other countries around the world.

By December 2019, India had sent a sum of 84 GW of matrix associated inexhaustible power limit. By correlation, India's all out creating limit arrived at 366 GW in 2019. India is gaining ground towards its objective of 175 GW of renewables by 2022. In September 2019, the prime minister of India, announced that India's electricity mix would eventually include 450 GW of renewable energy capacity. Progress towards these targets will require a focus on unlocking the flexibility needed for effective system integration. This can possibly be accomplished by improving the plan of renewables barters, with clear directions and standards to reflect quality, area and framework esteem, alongside measures to encourage matrix development and request side reaction across India. Absolute power age in India during 2015 was 1300 TWh from the two utilities and non-utilities. In 2013, the electricity consumption from all sectors was 824 TWh, and with an average growth rate of 9%, and it was estimated to be approximately 980 TWh in 2015. The electrical network suffers from transmission losses of approximately 25%. In 2015, per capita power utilization was 746 kWh. Since per capita electricity consumption has a positive relation with GDP per capita, it can be used as a standard for judging the stage of economic development. Most countries with a GDP per capita of more than US$ 10,000 have an electricity consumption of more than 4500 kWh per capita. There are few exceptions to this case, depending on the structure of the economy in that country. It can be expected that with the growth of the Indian economy, the GDP per capita will improve, and hence, there will be a need for more electricity in the future. (electricity generation in India)

Electricity production in India is mostly achieved through coal thermal power plants (Figure 2.4.1). In spite of the fact that there have been endeavors to broaden the choices, especially on account of sustainable power sources, coal remains the predominant wellspring of power in the nation. Since 2000, the portion of power creation from coal has been gradually expanding; it was 68% toward the beginning of the starting years and has expanded to 73% in 2013. The percentile shares of all other energy sources, except renewables, have decreased during that time.

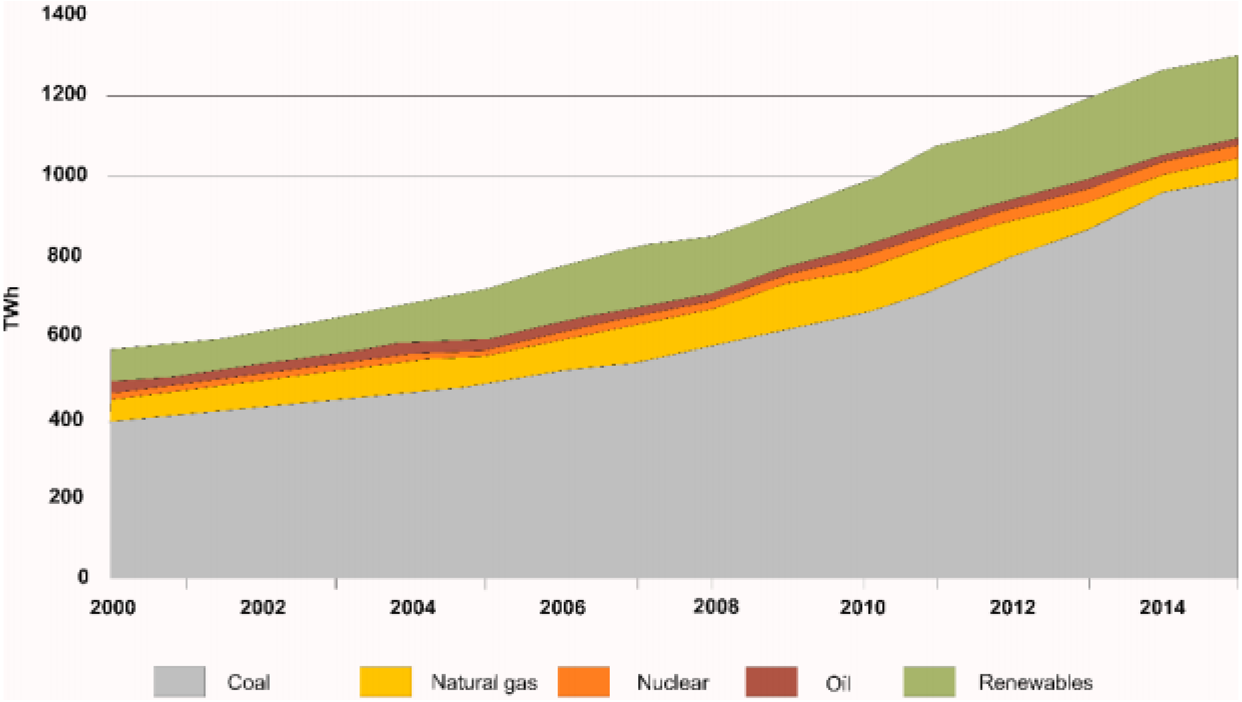


FIGURE 2.4.1: Electricity Production in India from Different Sources

As mentioned, the bulk of the production comes from coal power plants that produced 840 TWh in 2015 (Figure 2.4.2), which is 63% of the total production, followed by non-utilities (185 TWh) and hydropower (125 TWh, excluding small hydro). Nuclear, natural gas, lignite and oil also contributed 38 TWh, 44 TWh, 34 TWh and 500 GWh, respectively, to electricity generation. Inexhaustible sources were assessed to add to 70 TWh of power in 2015. Currently, most of the renewable electricity generation is from wind energy and small hydropower plants. India is likewise enthusiastic about building up its inexhaustible sources.

In India, coal satisfies 70% of the total demand that is mostly used in the power sector, and with India having the fifth biggest coal holds on the planet, it has demonstrated to be the most practical type of vitality and power in India. Considering an increase in coal production of 5% each year, the coal reserves are expected to last for another 40–50 years. The World Institute of Sustainable Energy arranged an examination report for coal power in India and anticipated that the complete coal power plant limit before the finish of 2032 would be 400 TW if coal-based force plants are supported or 220 TW if sustainable power source and gas are supported.

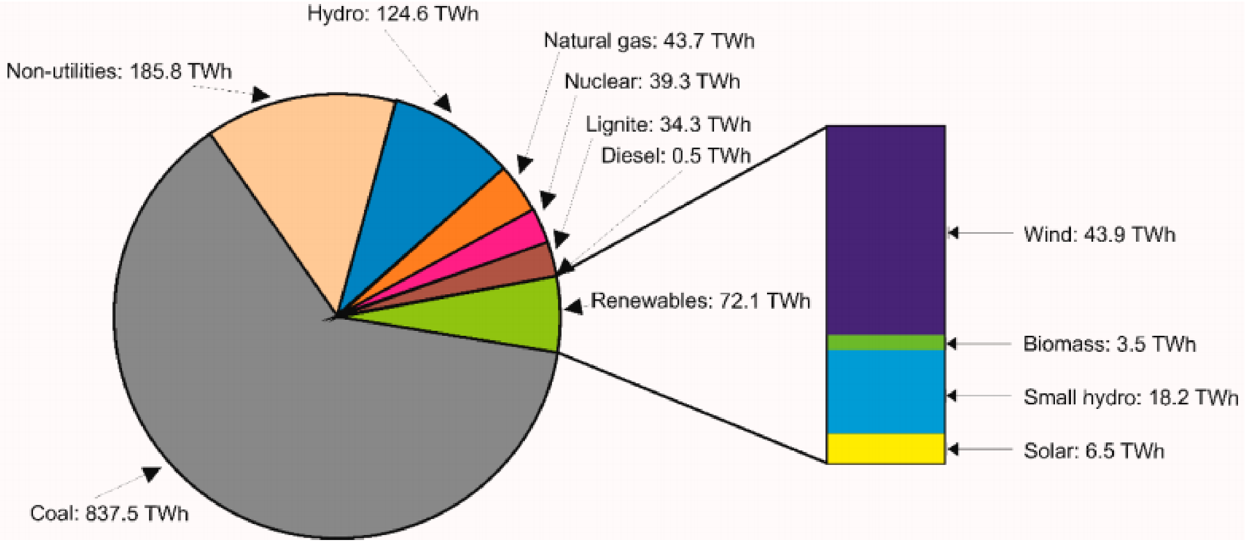


FIGURE 2.4.2: Electricity Mix of India (As per 2015 data)

India is also focusing greatly on renewable energy. India was projected to be able to generate up to 84,000 MW of hydroelectric power at 60 per cent load factors. The government also plans to accelerate a hydro development plan, where it aims to build 50,000 MW of new capacity by 2026 (roughly the end of the 14th Five-Year Plan)

In 2011, 55% of rural households were electrified compared to 93% of households in the urban sector. Therefore, is makes no sense to compare India with elasticities of electricity demand of developed countries such as U.S., G7 countries or Australia. These data indicate that there is still a large portion of the population without access to electricity, especially in rural areas. With India adopting rural electrification programs such as the “Deendayal Upadhyaya Gram Jyoti Yojana”, which aims to achieve a 100% electrification rate for rural areas, the electricity consumption from the local division would increment exclusively because of the way that new family unit are being zapped. Nonetheless, the utilization of power from this segment relies upon the salary level of the occupants. Higher salary occupants would have more comforts, for example, TVs, PCs, and fridges, which would bring about greater power utilization.

As predicted, more exposure to modern conveniences such as televisions became accessible to the urban population. In a report by the Global Buildings Performance Network, the annual electricity consumption per household will increase to 2750 kWh by 2050. It was also stated that with the help of better data, policy roadmaps and a residential building energy code, consumption can be reduced by more than half.

The high growth of industry showed a large number of energy requirements from the industrial sector. All industries were expected to develop at a slightly higher pace than the historical levels, while the intensity of electricity per ton of output remained fairly constant. Figures 2.4.3 represent the demand for electricity from the different sectors to 2030 in this scenario. Industrial interest for power is relied upon to develop about multiple times contrasted with 2015. Every other segment additionally experience development of about multiple times contrasted with 2015. In the domestic sector, the growth is attributed to the rise in population and income levels of the residents. Business areas develop due to growing business floor space and the intensity of power use per square meter. This part shows higher development than the horticulture segment, and these two segments likewise expend a similar measure of power by 2030.

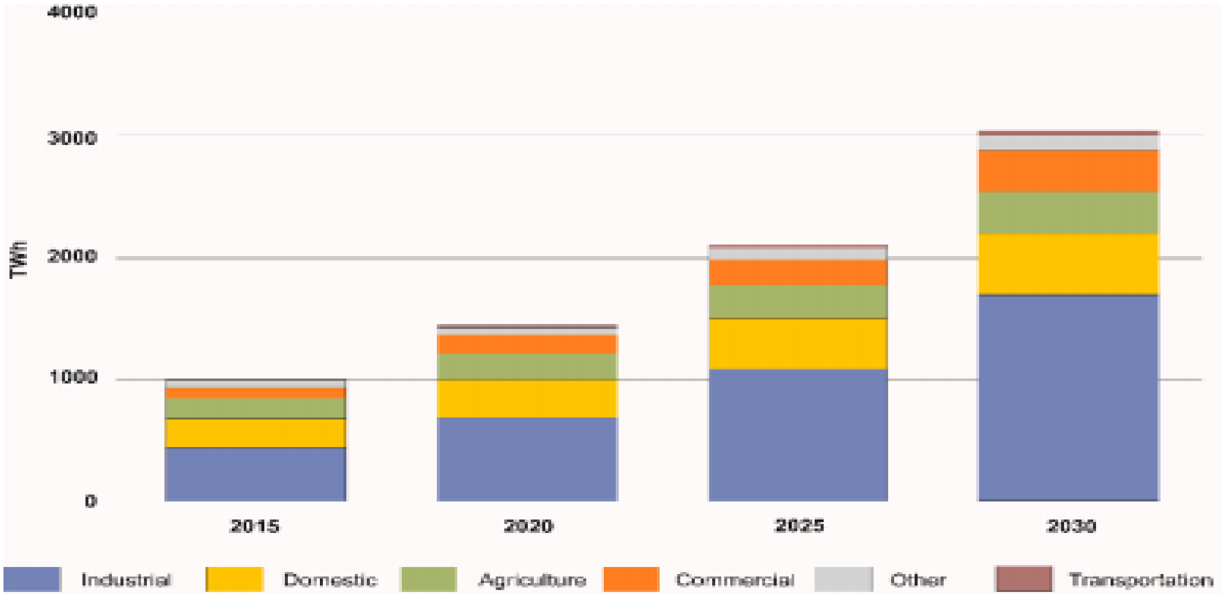


FIGURE 2.4.3: Electricity consumption from different sector

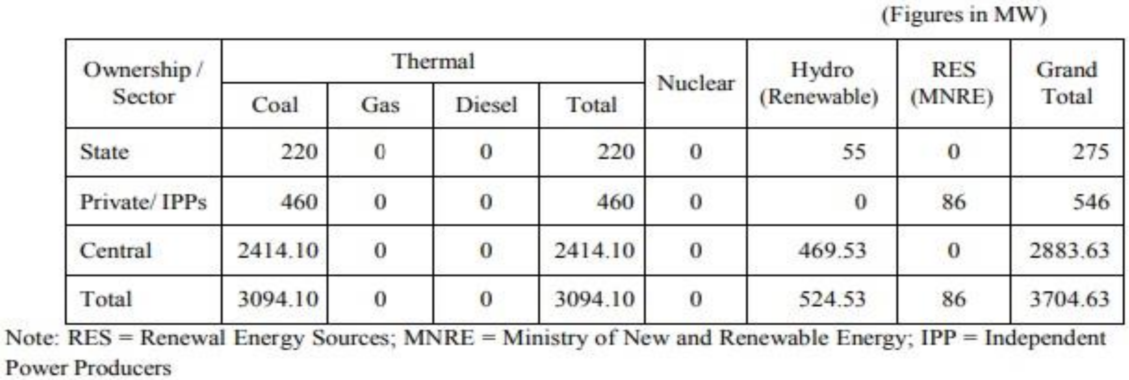
The **Table 2.4.1** below enlists the condition prevalent in Bihar and the requirements that they pose on the power supply:

SITUATION	**REQUIREMENT**
Exceptionally high rate of growth in the recent years and future	Reliable energy supply to support it
Majority share of the populace is underneath destitution line	Low cost/ affordable power
Dissipated yet huge number of little scope business exercises	Reliable & flexible power supply systems
Low investment flow	Innovative techniques to lure investors
Low infrastructure development	Increased support from private entities for infrastructure development
High population density and spread	Zoom in better penetration and reach for power distribution
High transmission losses	Local micro grids, local management of resources.

Table 2.4.1: Conditions Vs Requirement in Bihar. [Source: Bihar energy situation; energypedia.info]

Keeping all these requirements in mind, one possible solution for Bihar seems to be the decentralized electricity generation. This will demonstrate especially useful for remote zones where grid connection availability is not possible.

The total available power generation capacity as for the state as of March 2015 was 3704.63 MW. Out of this, 83.5 percent is from coal based thermal power, 14.12 percent from hydro power, and the balance 2.3 percent from renewable energy sources. In terms of ownership, central sector has the largest share of 77.9 percent, followed by the private sector (14.7 percent), and state sector (7.4 percent). The details of existing generating capacity in Bihar are shown in **Table 2.4.2**:



(Figures in MW)

Ownership / Sector	Thermal				Nuclear	Hydro (Renewable)	RES (MNRE)	Grand Total
	Coal	Gas	Diesel	Total				
State	220	0	0	220	0	55	0	275
Private/ IPPs	460	0	0	460	0	0	86	546
Central	2414.10	0	0	2414.10	0	469.53	0	2883.63
Total	3094.10	0	0	3094.10	0	524.53	86	3704.63

Note: RES = Renewal Energy Sources; MNRE = Ministry of New and Renewable Energy; IPP = Independent Power Producers

SOURCE: http://dcmsme.gov.in/dips/state_wise_profile_16-

Table 2.4.2: Data representing ownership of various energy production industries across Bihar region.

The per capita power consumption of Bihar is 228.8 kWh which is 76% lower than the all-India average of 901.3 kWh. The low power consumption per capita clearly suggests that a significant portion of Bihar's population has no access to modern energy, despite reporting that more than 98 percent of villages are electrified. [Load generation balance report, central electricity authority]

Chapter 3

Strategic Location of SSHP Based on GIS Data

3.1 Digital Elevation Model

The same Digital Elevation Model (DEM), based on the Hydro Sheds SRTM DEM (Lehner et al., 2006), as incorporated in the SPHY model, is applied and resampled to the model resolution, projection and extent. Based on the DEM, a local drain direction map is derived, which indicates the drainage direction of each grid cell. With this procedure, the stream network of the model is defined, which facilitates water routing from upstream to downstream. The full extent of the DEM is shown in Figure 3.1.1.

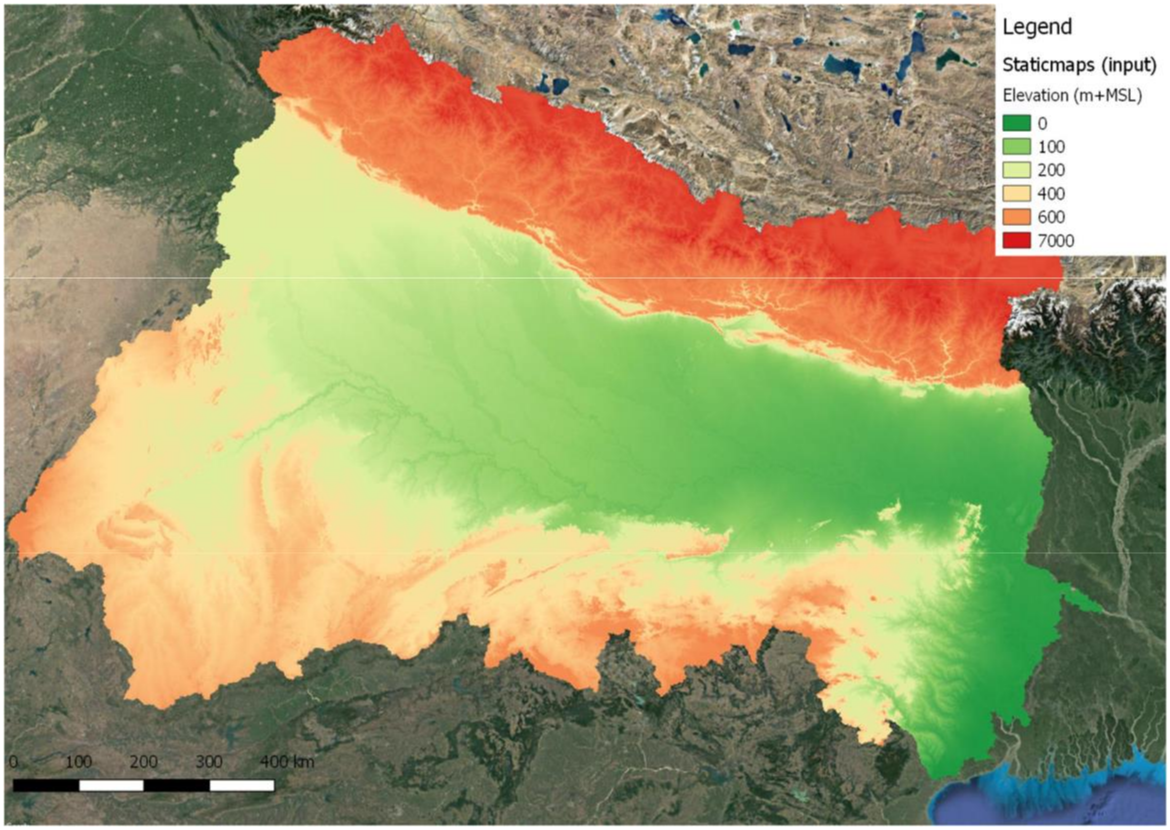


Figure 3.1.1: SRTM Digital Elevation Model (DEM) for the project area.

- River Layer

To make sure that the derived drainage direction follows the actual rivers accurately, a shapefile of the river, based on Open Street Map, is used to force the drainage direction derivation algorithm. This is especially needed for the shallow parts of the basin, in which the digital elevation model is less accurate. The shape file, shown in Figure 3.1.2, is used to burn the river network into the DEM before determining the drainage direction map, thus overriding the drainage pattern derived from the DEM itself.

- Land-use/Land-cover Data

The land-use or land-cover map is an important input map to the model. Many parameters in the model do depend on the land-use. For example, the rooting depth varies greatly for different types of vegetation, e.g. grass versus trees. Also, the Manning coefficient, which determines roughness, differs considerably between dense vegetation and urban areas.

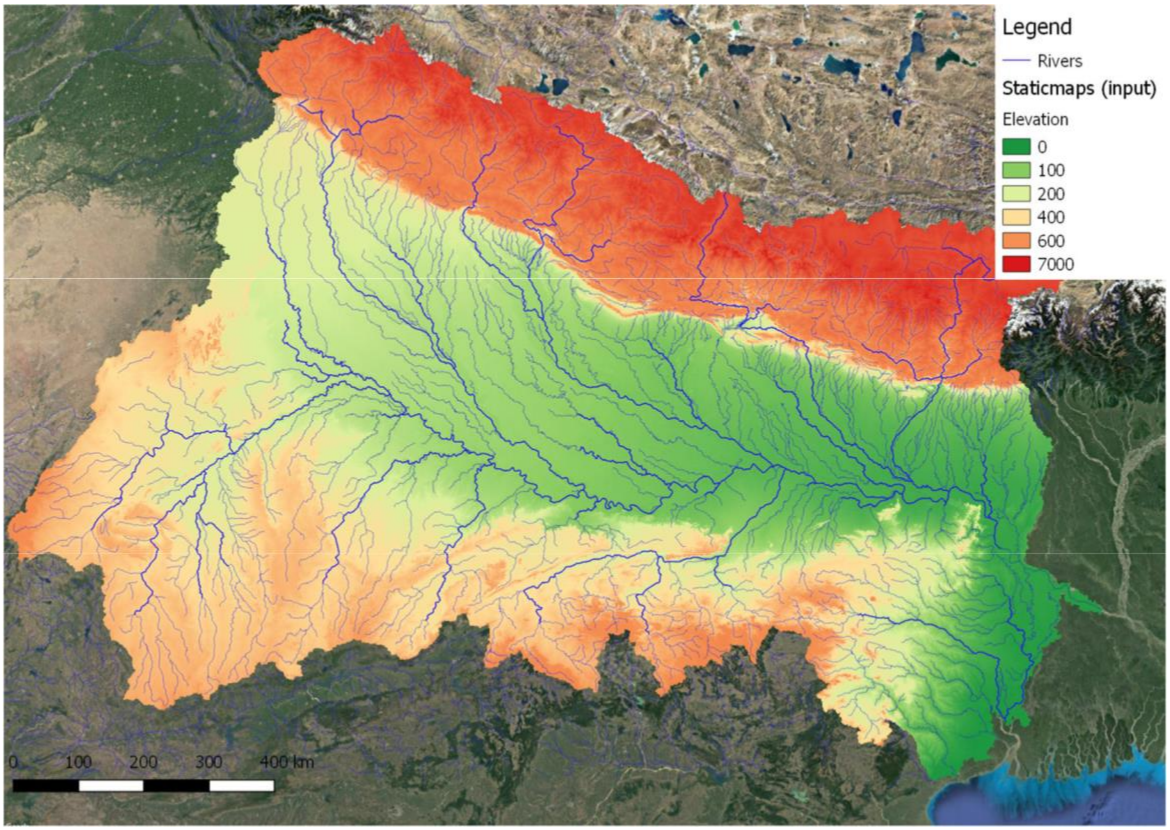


Figure 3.1.2: River layer from Open Street Map, used as input layer for the derivation of the model.

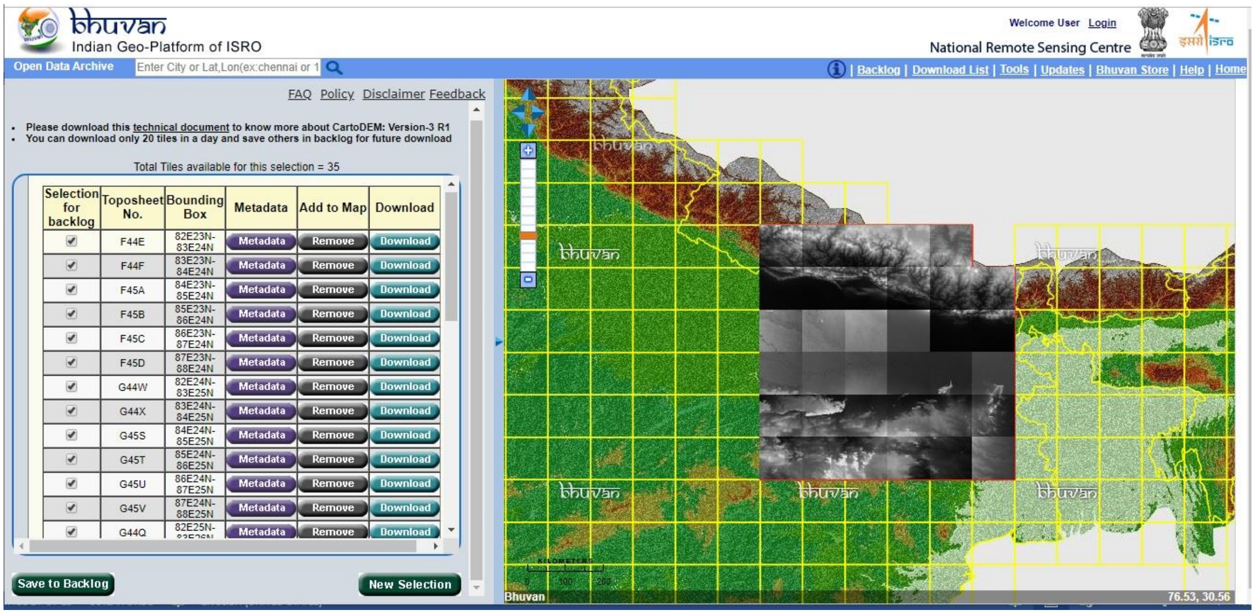
3.2 ISRO BHUVAN (CARTOSAT-3) Digital Terrain Modelling Platform

The study parameter for this project was undertaken for the state of Bihar. As the state has multiple River basins having perennial flow across the state, the application for geo-terrain modelling for variation in elevation reading as a linear representation of the terrain will help us understand the possible location for installation of SSHP's. An administrative and state boundary representation of the state is depicted below in the picture.

Pictorial representation for the state of Bihar showing administrative boundary, national highways and river basins across the state.

Bhuvan, is an Indian electronic utility which permits clients to investigate map based substance arranged by Indian Space Research Organization. The substance which the utility serves is for the most part confined to Indian limits and is offered in 4 territorial dialects. The substance incorporates topical guides identified with debacles, agribusiness, water assets, land spread and furthermore prepared satellite information of ISRO. Bhuvan is known for its relationship with different areas of Government of India to empower the utilization of Geospatial innovation. Bhuvan has since its beginning empowered Indian government to have open geospatial information as Information layers for perception and open utilization. Many DEM are available with the Indian Space Research Organization collaborative program with Indian Remote Sensing Institute on CARTOSAT 30M satellite imagery. Further ARCGIS is also available to prepare a

DEM based on ASTER 30M data or SRTM 30M/90M data of the particular region to delineate and prepare contour graphs. Following are a few graphical representation of Digital Elevation Model prepared based on cloud platform BHUVAN.



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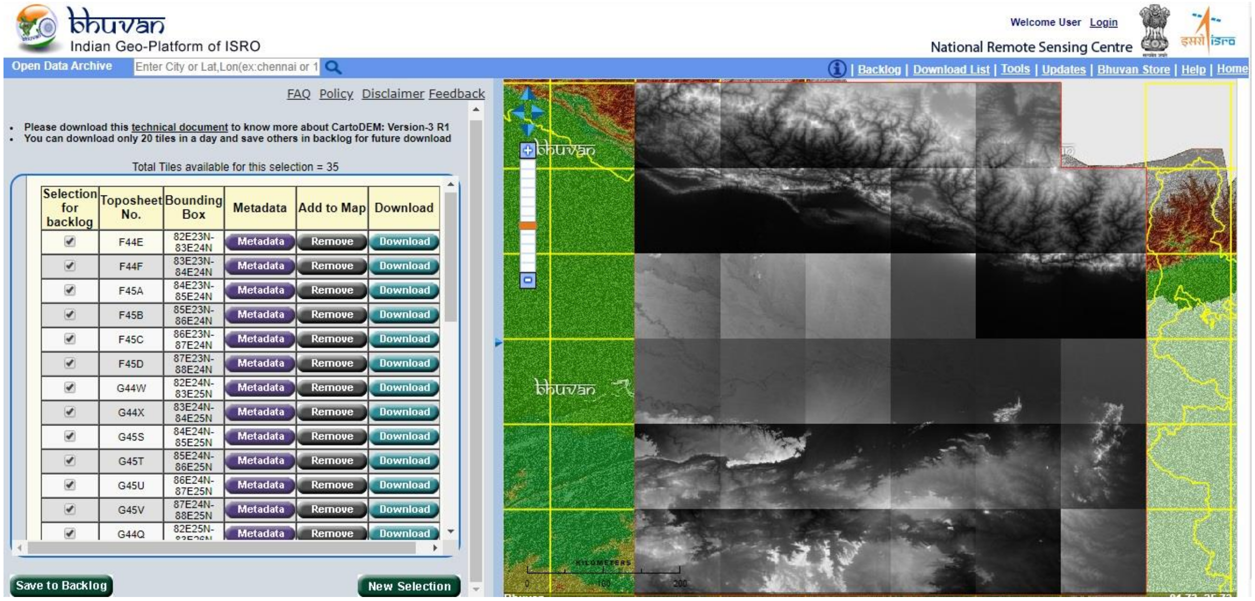
☑	F44F	83E23N- 84E24N	Metadata	Remove	Download
☑	F45A	84E23N- 85E24N	Metadata	Remove	Download
☑	F45B	85E23N- 86E24N	Metadata	Remove	Download
☑	F45C	86E23N- 87E24N	Metadata	Remove	Download
☑	F45D	87E23N- 88E24N	Metadata	Remove	Download
☑	G44W	82E24N- 83E25N	Metadata	Remove	Download
☑	G44X	83E24N- 84E25N	Metadata	Remove	Download
☑	G45S	84E24N- 85E25N	Metadata	Remove	Download
☑	G45T	85E24N- 86E25N	Metadata	Remove	Download
☑	G45U	86E24N- 87E25N	Metadata	Remove	Download
☑	G45V	87E24N- 88E25N	Metadata	Remove	Download
☑	G44Q	82E25N-	Metadata	Remove	Download

FIGURE 3.2.1: Digital Elevation Model in raster form for Bihar at large scale.



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☑	F45D	87E23N- 88E24N	Metadata	Remove	Download
☑	G44W	82E24N- 83E25N	Metadata	Remove	Download
☑	G44X	83E24N- 84E25N	Metadata	Remove	Download
☑	G45S	84E24N- 85E25N	Metadata	Remove	Download
☑	G45T	85E24N- 86E25N	Metadata	Remove	Download
☑	G45U	86E24N- 87E25N	Metadata	Remove	Download
☑	G45V	87E24N- 88E25N	Metadata	Remove	Download
☑	G44Q	82E25N-	Metadata	Remove	Download

FIGURE 3.2.2: DEM in raster format for River basin at closer range of 30m.

Digital elevation profile of Ganges River flowing across major cities i.e. starting @ BUXAR and ending @ BHAGALPUR was taken into study to check for general declination across the 266km linear stretch across the state. The rate of change was drastic giving sufficient head to work on the SSHP's design and application.

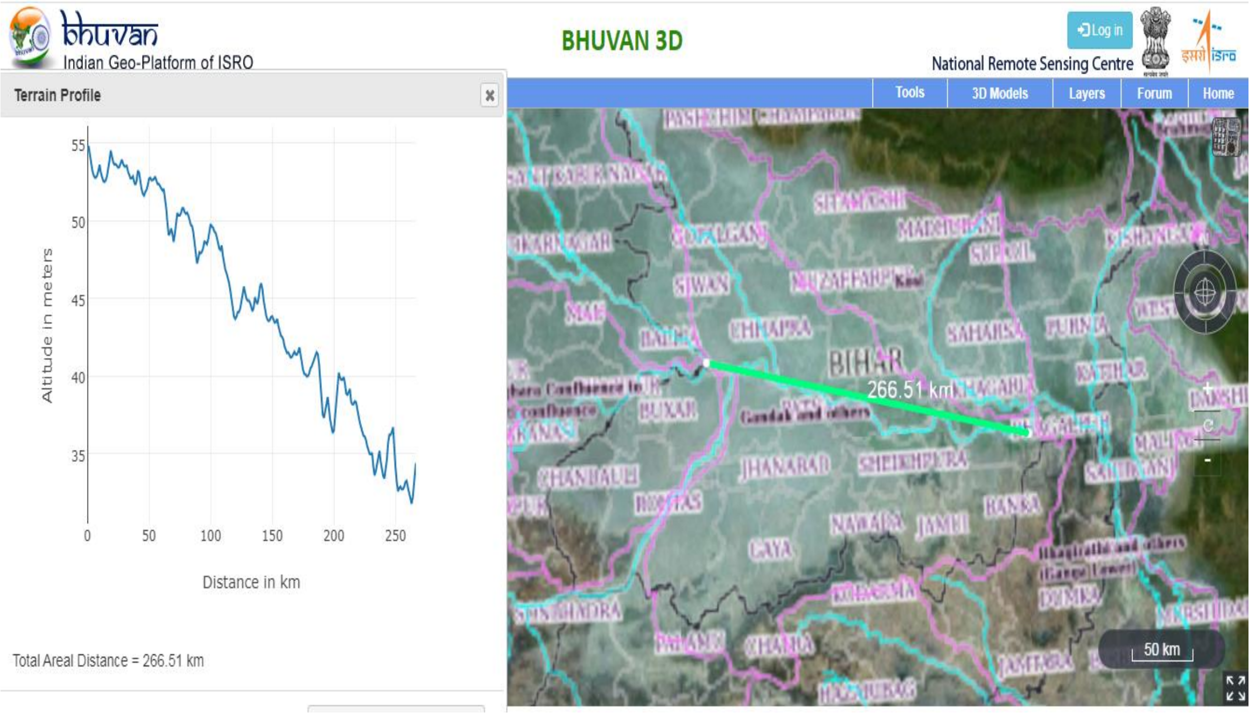


FIGURE 3.2.3: Linear DEM of Ganges River across the state of Bihar, with variation of terrain profile across the basin.

Using the BHUVAN platform for the linear terrain modelling multiple locations were studies for possibility to install SSHP's in order to create an energy generation source for the local population. The idea was to create a separate Grid for electricity in the isolated region where transmission of electricity from point of generation was not feasible and also to promote the sustainable development goal in the locality by creating opportunity for locals.

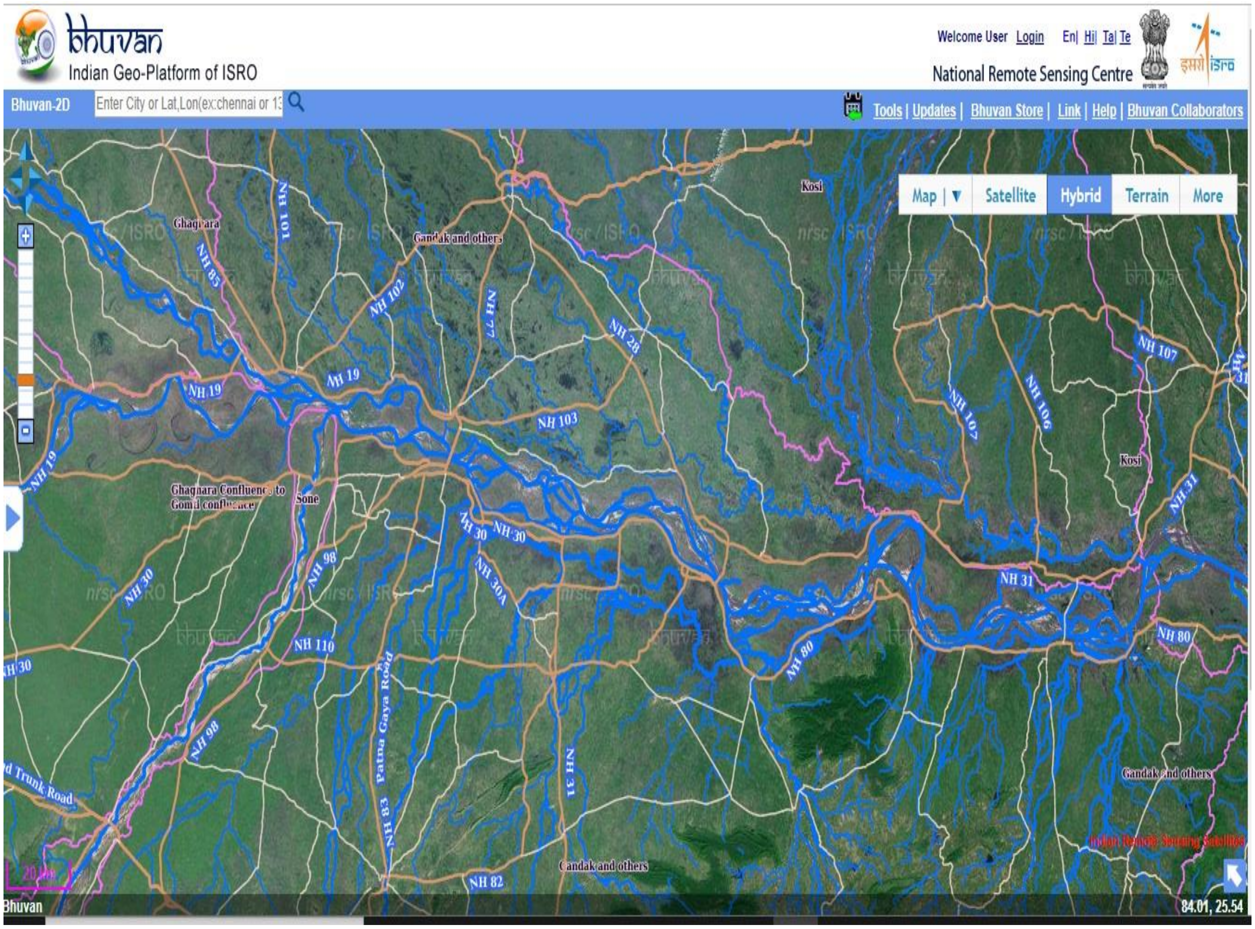


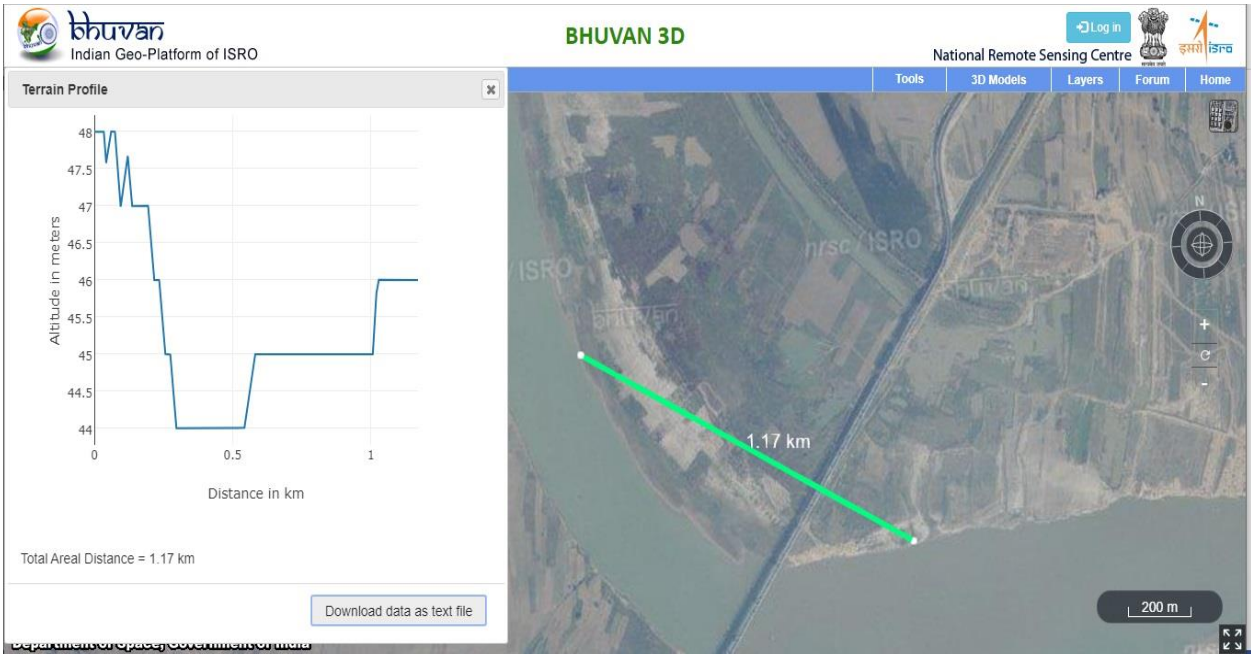
FIGURE 3.2.4: Water network profile across the state of Bihar.

3.3 Geo-Tagging Potential Residential Zones

Multiple location analysis based on their Linear DEM and global positioning are stated below-

- LOCATION 1:

NAME	DIGHA BRIDGE
LAT & LONG	25.680092,85.114832
MAXIMUM ELEVATION	48m from MSL
MINIMUM ELEVATION	44m from MSL
LENGTH OF CANAL	1.17 Km

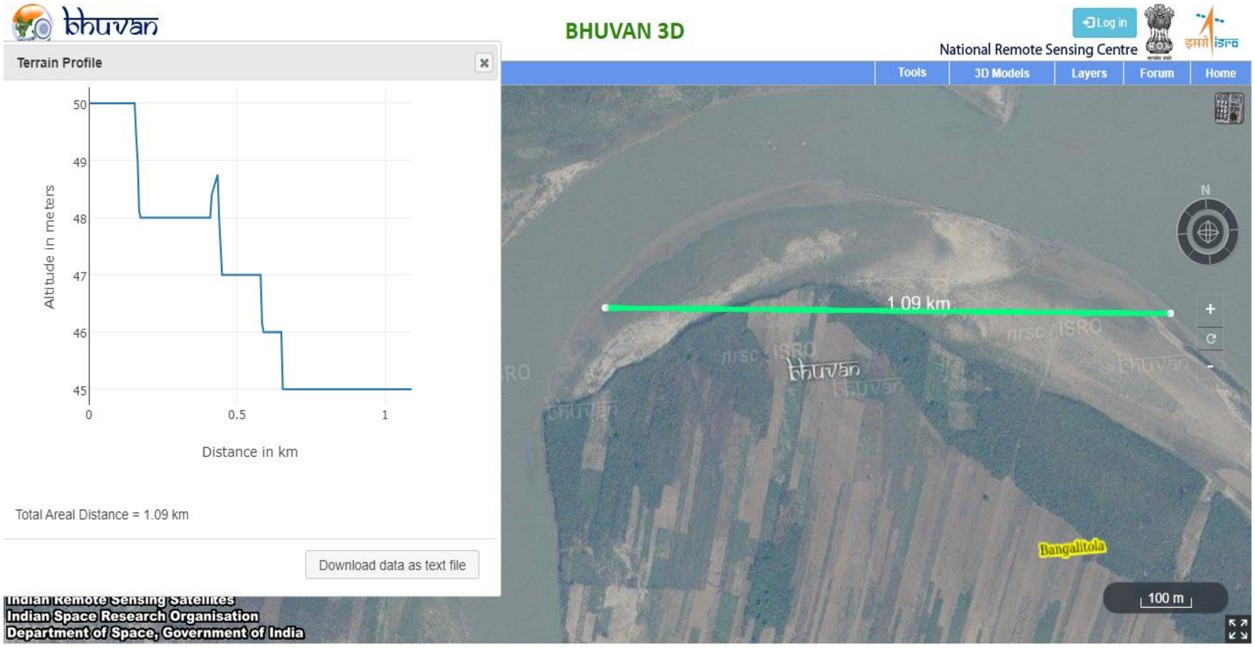


Total Areal Distance = 1.17 km

FIGURE 3.3.1: Linear terrain profile across the Digha Bridge, Patna Rural.

- LOCATION 2:

NAME	BANGALITOLA
LAT & LONG	25.526222,85.850145
MAXIMUM ELEVATION	50m from MSL
MINIMUM ELEVATION	45m from MSL
LENGTH OF CANAL	1.09 Km

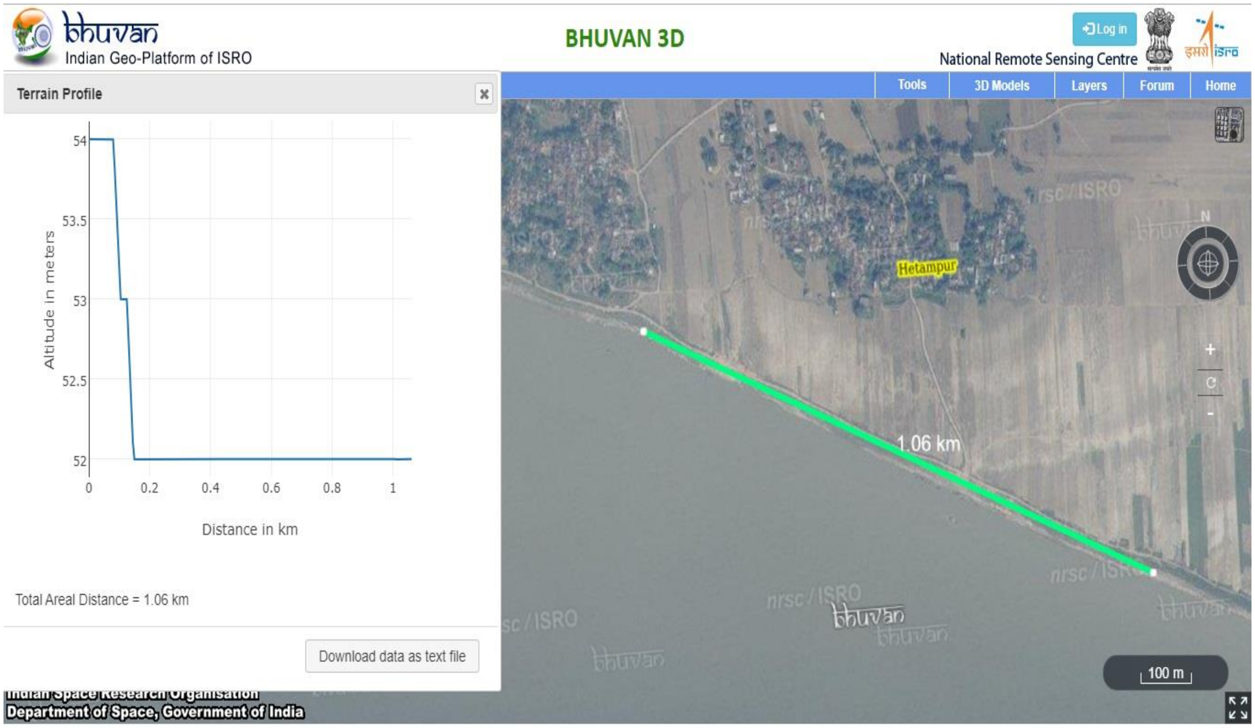


Total Areal Distance = 1.09 km

FIGURE 3.3.2: Linear Terrain profile across Bangalitola, Patna Rural.

- LOCATION 3:

NAME	HETANPUR
LAT & LONG	25.678600,85.020990
MAXIMUM ELEVATION	54m from MSL
MINIMUM ELEVATION	52m from MSL
LENGTH OF CANAL	1.06 Km

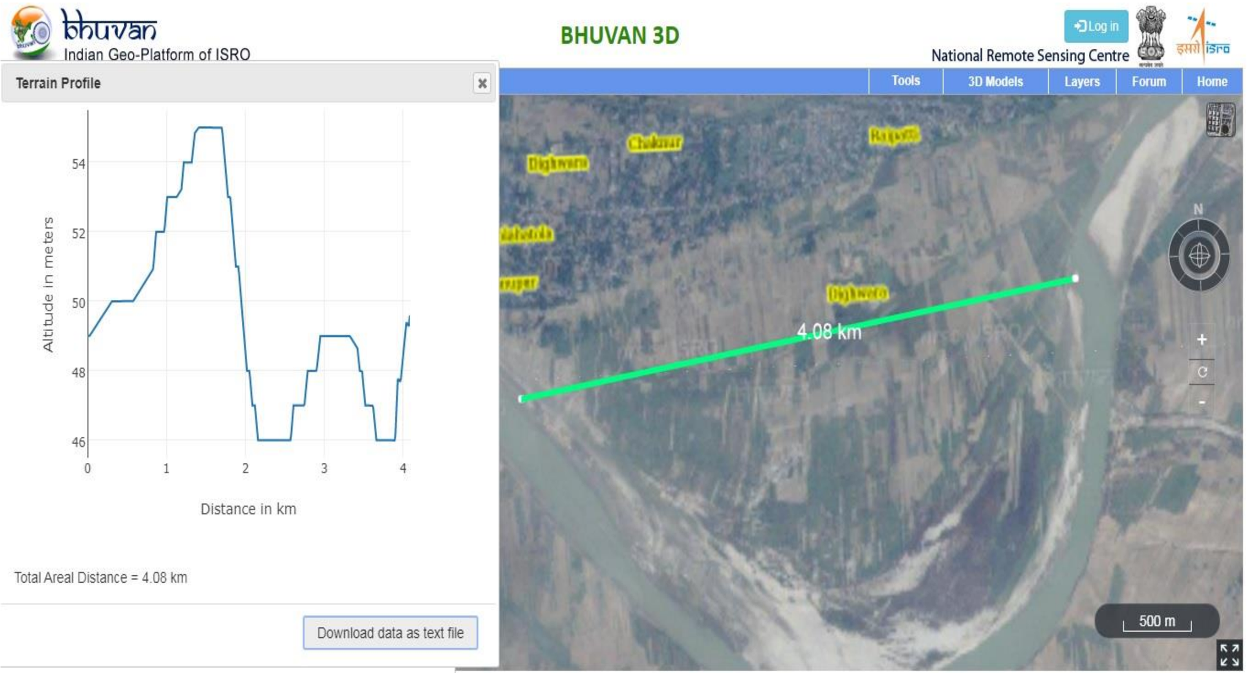


Total Areal Distance = 1.06 km

FIGURE 3.3.3: Linear terrain profile across Hetanpur river bank.

- LOCATION 4:

NAME	BATRAULI
LAT & LONG	25.733931, 84.995605
MAXIMUM ELEVATION	55 m from MSL
MINIMUM ELEVATION	46 m from MSL
LENGTH OF CANAL	4.08 Km

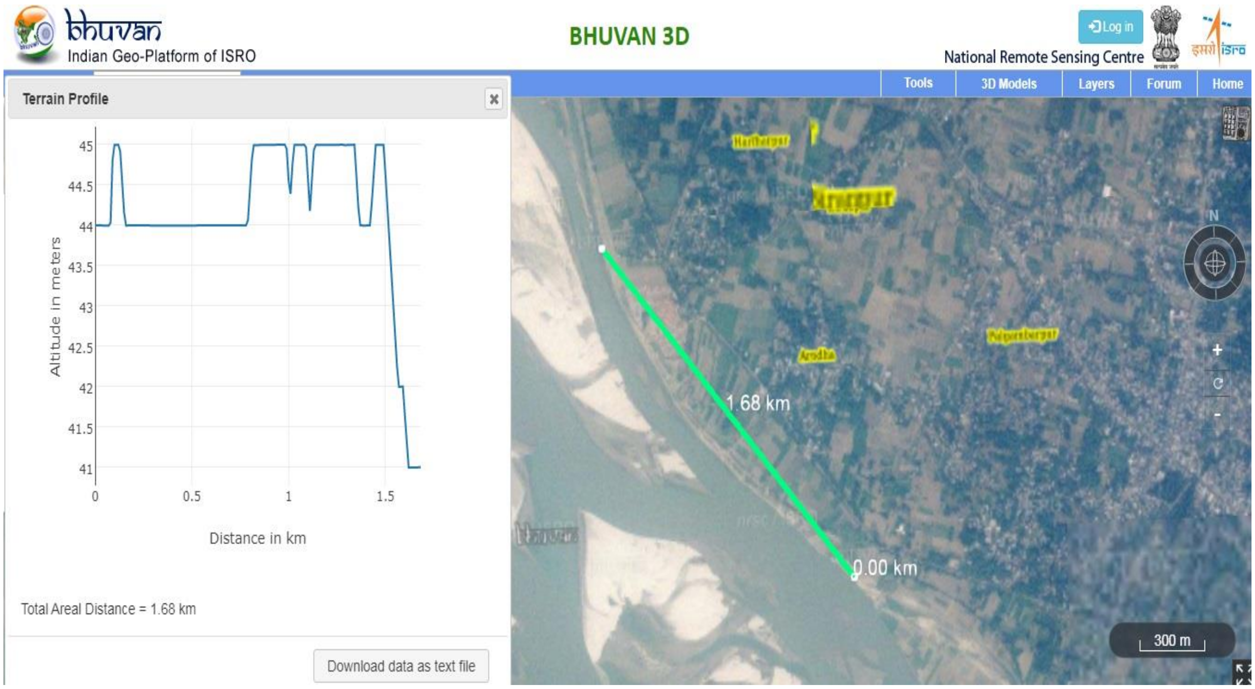


Total Areal Distance = 4.08 km

FIGURE 3.3.4: Linear Terrain Profile across Batrauli, Chapra.

- LOCATION 5:

NAME	BINALPUR
LAT & LONG	25.493254, 85.918040
MAXIMUM ELEVATION	45 m from MSL
MINIMUM ELEVATION	41 m from MSL
LENGTH OF CANAL	1.68 Km

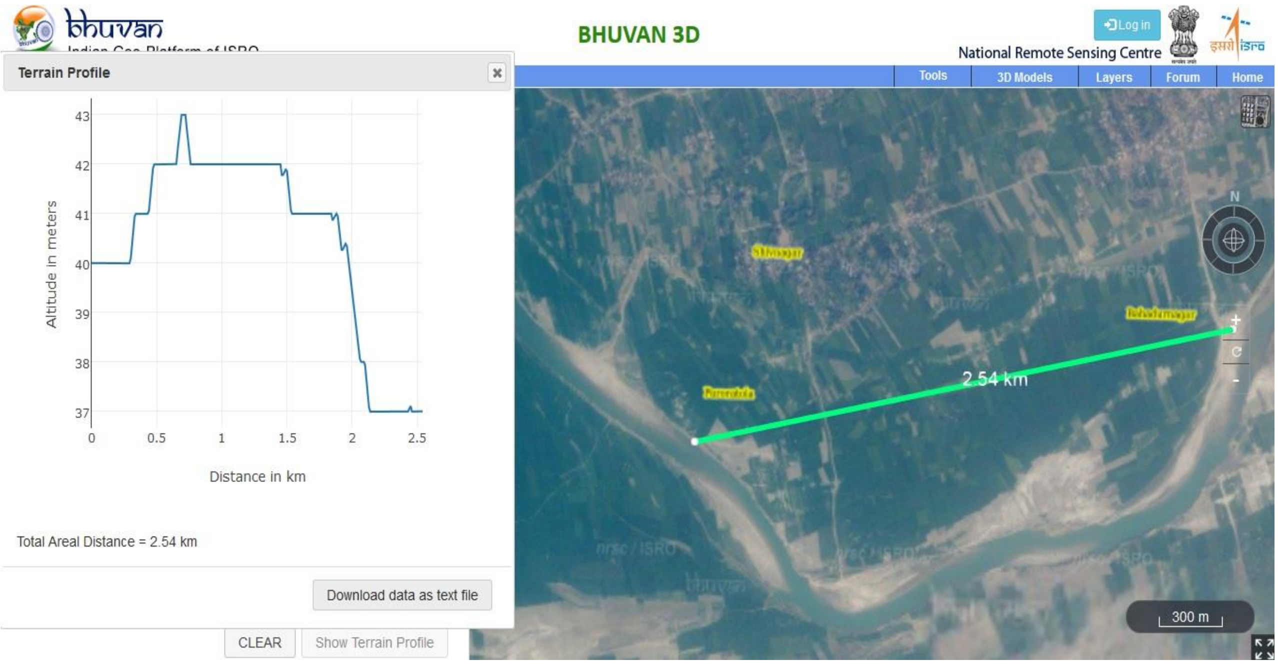


Total Areal Distance = 1.68 km

FIGURE 3.3.5: Linear Terrain Profile across Binalpur Ghat, Begusarai.

- LOCATION 6:

NAME	KUTLUPUR DIYARA
LAT & LONG	25.341831, 86.351592
MAXIMUM ELEVATION	43 m from MSL
MINIMUM ELEVATION	37 m from MSL
LENGTH OF CANAL	2.54 Km



Total Areal Distance = 2.54 km

FIGURE 3.3.6: Linear Terrain Profile across Kutlupur, Khagaria.

Multiple location can be studied and analyzed for their small scale hydropower potential depending upon the GIS date to create a linear terrain profile. Just like above few examples multiple locations near the Ganga river basin close to isolated community or in regions of isolation with population less than 100 persons can be utilized to create a source of energy which will be decentralized and will be proving sufficiently to the basic need to the community.

Chapter 4

Ganga River Basin Characteristics & Flow Parameters

The Ganga Basin is the world's most populated river basin, home to half of India's population, including two-thirds of the poor people of the country. The basin provides over one-third of the available surface water in India and contributes to more than half the national water use of which 90 percent is diverted to irrigation.

The Ganga river basin is huge with a surface area within India of 860,000 km2 (FAO Aquastat, assessed December 19, 2017) and a population of 485 million people (derived from 2011 census data, Office of the Registrar General & Census Commissioner, India, 2011). Population is concentrated in the plains of the Ganga basin. Most of this area supports irrigated agriculture. The plain has a very limited slope from some 250 m above sea level in the east to approximately 25 m near Farakka at the border with Bangladesh. North of the plain the Ganga and its tributaries flow from the Himalaya with elevations over 6000 m above sea level. The Himalaya Mountains are covered by snow and glaciers, which has a significant influence on the flow pattern of the rivers. The mountains and hills to the south are much lower with an average elevation around 1000 m. There is a decreasing gradient in water availability in the plain from west to east. The flow of the Ganga and Yamuna rivers from the Himalaya supplies a large portion of the water supply. Further to the east in the basin, precipitation increases as does the flow in the Ganga River fed by its tributaries.

To quantify the agreement between the simulated and observed discharge a series of correlation coefficients are calculated. These coefficients are used for quantification of model performance for the SPHY, Wflow and RIBASIM models. A well-known example is the **Nash-Sutcliffe Efficiency Coefficient (NSE),** (Nash and Sutcliffe, 1970).

$$\text{NSE}= 1- \frac{\sum_{t=1}^{T}(Q_o^t-Q_s^t)}{\sum_{t=1}^{T}(Q_o^t-Q_o^-)}$$

Where Q_o^- is the mean of the observed discharge and Qs is simulated discharge. Q_o^t is observed discharge at time t. The closer the value of NSE is to 1, the better the model performance.

4.1 Monthly Discharge Variation

The Ganges River follows a 900 km (560 mi) arching course passing through the cities of Kannauj, Farukhabad, and Kanpur. It is joined by the Ramganga along the way, which contributes an average annual flow of approximately 500 m3 / s (18,000 cu ft / s). The Ganges joins the river Yamuna at the Triveni Sangam at Allahabad, a holy confluence in Hinduism. The Yamuna is larger than the Ganges at their confluence, contributing about 2,950 m3 / s (104,000 cu ft / s), or about 58.5 per cent of the combined flow.

Presently streaming east, the waterway meets the Tamsa River (additionally called Tons), which streams north from the Kaimur Range and contributes a normal progression of around 190 m3/s (6,700 cu ft/s). After the Tamsa the Gomti River joins, streaming south from the Himalayas. The Gomti contributes a normal yearly progression of around 234 m3/s (8,300 cu ft/s). At that point the Ghaghara River (Karnali River), likewise streaming south from the Himalayas of Nepal, joins. The Ghaghara (Karnali), with its normal yearly progression of around 2,990 m3/s (106,000 cu ft/s), is the biggest tributary of the Ganges. After the Ghaghara (Karnali) intersection the Ganges is joined from the south by the Son River, contributing around 1,000 m3/s (35,000 cu ft/s). The Gandaki River, at that point the Kosi River, join from the north spilling out of Nepal, contributing around 1,654 m3/s (58,400 cu ft/s) and 2,166 m3/s (76,500 cu ft/s), separately. The Kosi is the third biggest tributary of the Ganges, after the Ghaghara (Karnali) and Yamuna. The Kosi converges into the Ganges close Kursela in Bihar.

AVERAGE DISCHARGE	16,648 m^3/s [5,87,900 cu ft/s]
MINIMUM DISCHARGE	2000 m^3/s [71000 cu ft/s]
MAXIMUM DISCHARGE	70,000 m^3/s [25,00,000 cu ft/s]

TABLE 4.1.1: Discharge data for Ganga River @ Farakka Barrage

Since most of the river flows are influenced by water use and the operation of water infrastructure. The calibration period is 1995–2009 and the validation period is 1985–1994. Calibration and validation focused on the Ganga River and its main tributaries. Figure 4.2.1 shows the results of the calibration and validation for the Ganga River near Varanasi. The results show that simulated and measured flows are quite similar, with some model overestimation of the peak monsoon discharge. However, for a water resources study the very good fit of low flows is more important.

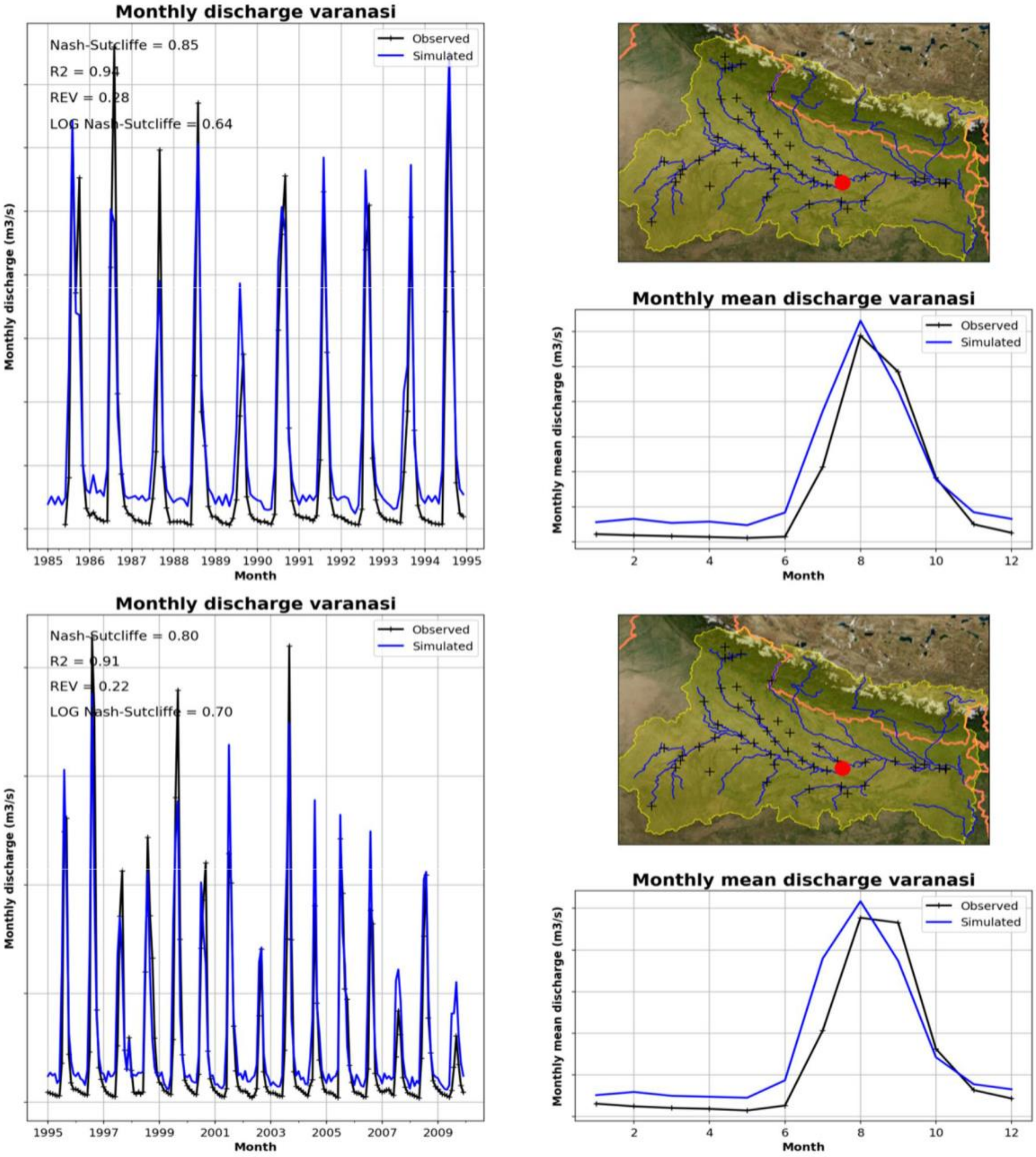


Figure 4.2.1: Validation (1985–1994, top) and calibration (1995–2009, bottom) results for the Ganga river at Varanasi with the monthly discharges (left), mean monthly discharges (right bottom) and location of the station (red dot on map right top)

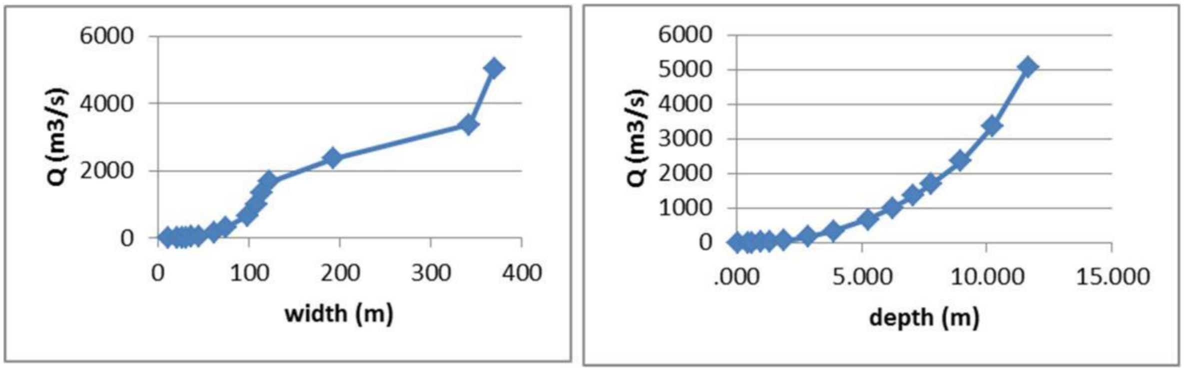


Figure 4.2.2: Example of the relations between discharge and river width (left) and depth (right) for the Ganga River as per reports given to World Bank & Government of India, 2018.

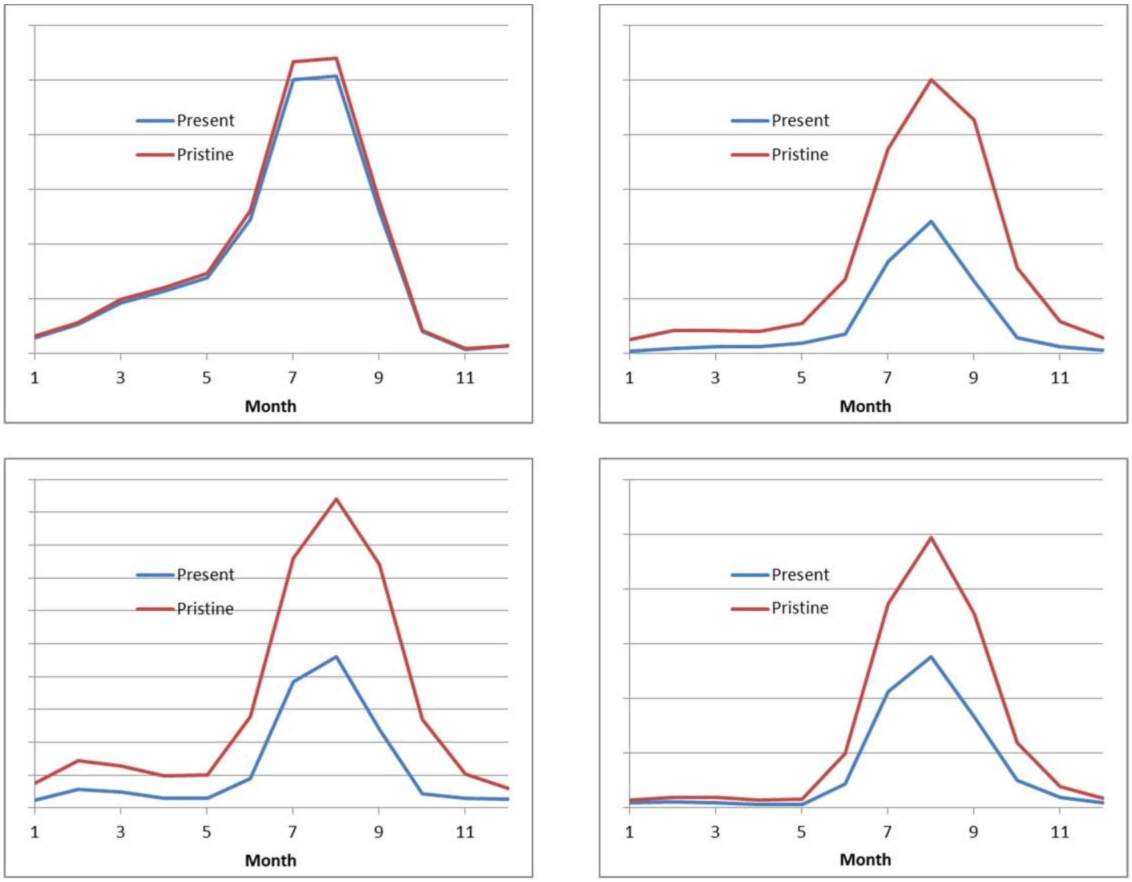


Figure 4.2.3 : Comparison of average monthly simulated discharges for the period 2000–2014 for the Present and the Pristine scenario for a catchment in the Himalaya (top left), the Ganga near Kanpur (top right) and near Varanasi (bottom right) and the Yamuna below Delhi (bottom left).

4.3 Policies for Hydropower Establishment across Ganges River:

Hydropower is an important energy strategy that reshapes the ecological functions and services of a river system. Huge dams were fabricated soon after Indian Independence as a major aspect of national turn of events and noteworthy protections from these enormous dams created in the accompanying three decades. The current wave of dam investment is motivated by the twenty-first century interest in industrial growth and urban expansion, and by expanded water consumption. In 2002, the Government of India announced a *50,000 MW initiative* to narrow the gap between supply and the growing demand for power. This hydropower push has concentrated on the Indian Himalayas where the precarious drops of tributaries to the Indus, Ganga and Brahmaputra streams can possibly produce bigger yields of intensity. The sites of current development are located across the northern region of India, in the states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Uttar Pradesh, Sikkim, Arunachal Pradesh and Assam [9] (alley 2013; hydro policy).

In light of the suggestions of the Committee on Hydro Power which presented its report in March, 1997, the Hydro Power Development Policy was planned. On 26.8.1998, the Government has concurred endorsement to the strategy on Hydro Power Development.

The object of the Policy is to forestall a decrease in hydro share and to attempt measures for the misuse of huge hydro-electric potential in the nation particularly in the North and North Eastern Regions. Hydro stations currently represent just 25% of the absolute introduced limit as against the perfect hydro warm blend of 40:60. The all out hydro potential evaluated by Central Electricity Authority (CEA) at 60% burden factor is 84,044 MW. As on 31.7.1998, 15% of this potential has been utilized. With the completion of the hydel projects under construction, the hydro potential utilized would increase to 22%.

The objectives of the policy are:

i. Ensuring targeted capacity addition during 9th Plan;
ii. Taking advantage of huge hydroelectric capacity at a faster pace
iii. Promoting small and mini hydel projects;
iv. Strengthen the role of PSUs / SEBs in the construction of new hydel projects;
v. Increasing private investment.

The goals will be accomplished with the following policy instruments:

i. Providing adequate funds in the Central/State Government budget and organizing supplementary funding through Power Finance Corporation.
ii. Entrusting Central Hydel Public Sector Corporations with wise creation of the Basin.
iii. Funding support for Survey and Investigations.
iv. Establishing a Power Development Fund by toll of cess on power expended and utilizing two-third of the returns to advance force improvement by the State Governments. The staying 33% will be used by the Central Government for advancing hydel ventures in the Central Sector and for interest in transmission lines for clearing of intensity from between State mega hydel ventures.
v. Providing a differential valuing for cresting capacity to encourage more noteworthy interest in hydel ventures which have the ability to flexibly topping force in a financially savvy way.
vi. Providing an systemic framework for managing geological hazards.
vii. Utilizing the joint venture frame work for promoting hydel projects.
viii. Simplification of procedures relating to transfer of clearances from State Government to Central Public Sector Undertakings and State Government to private sector.
ix. Improving the techno-economic clearance ceiling limits by CEA in respect of projects supported along the MOU path.
x. Transfer of work identifying with the advancement of little hydel extends up to 25 MW limit from Ministry of Power to Ministry of Non-Conventional Energy Sources and giving a reasonable impetus bundle. [policy on hydropower Govt. of India_ Ministry of power]

Along the northwestern tributaries of the Ganga River in the State of Uttarakhand, the Tehri dam and several run of the river dams were completed in the first decade of the twenty-first century to provide energy and water supply to the northwestern states of Uttar Pradesh, Delhi and Rajasthan. The development has been fierce and controversial with energy and industrial interests in water pushing out allocations and uses for farmers and residents, and citizens have mounted various campaign and movements against specific projects. The practices in the Ganga basin are similar to those playing out along all the other river systems sharing the Himalayas. For example, along the Beas and Sutlej rivers that flow into the Indus river system, several hydropower projects have been constructed and many are underway. These ventures are also the focus of local and national demonstrations. In Sikkim a cascade of dams is proposed along the Teesta River to augment the existing two. In the northeastern state of Arunachal Pradesh, the government has drawn up a blitz of projects along the Brahmaputra's major tributaries, along the Siang, Subansiri, Lohit and Dibang rivers (see Fig. 4.3.1). [9]

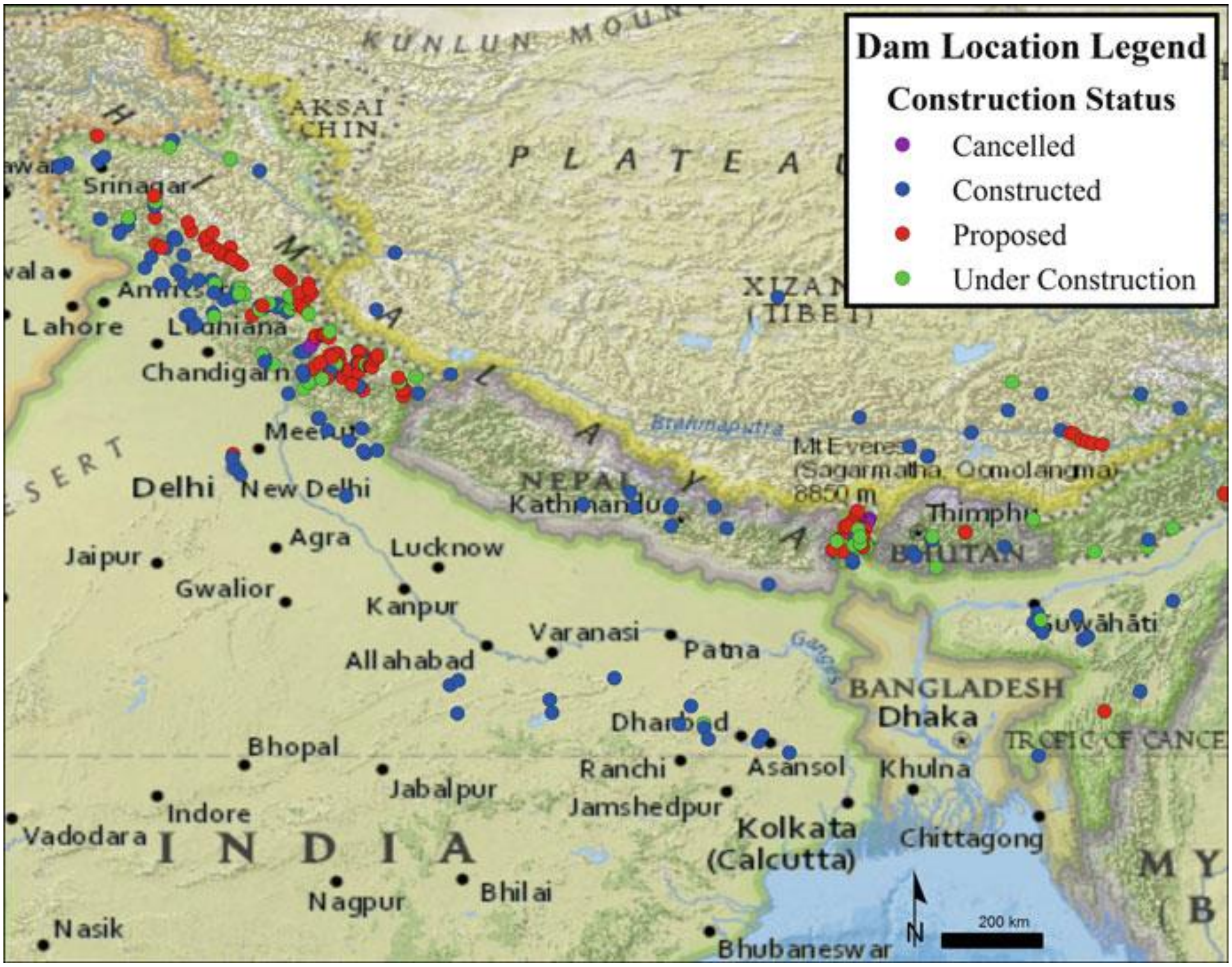


FIGURE 4.3.1: Dam sites (constructed, under construction, and proposed) within the Ganges and Brahmaputra basins (Source: National Geographic base map in ArcGIS. Map created by: Ryan Hile (permission granted) [file name: South Asia dams])

The current push for hydropower across the Himalayas is supported by assessments that only a small portion of the power potential has been tapped in the region. Financial specialists have been tricked by new motivating forces for open access and the opportunity to sell power on a trader premise, the chance of moving hydrological dangers to people in general, and late exchanging

Clean Development Mechanism (CDM) carbon credits. Be that as it may, as opposed to desires, hydropower doesn't generally bring about an expansion in vitality for individuals living in these waterway bowl urban communities and towns; generally local citizens get the end of the trickle down effects of an increase in power supply. The main part of vitality created is offered to top of the line clients, for example, ventures and urban offices. Notwithstanding their vitality utilization, the top of the line clients likewise pull back huge measures of water for modern and urban procedures and return a lot of wastewater to the stream framework.

The Watermills (WM) and Micro Hydel Projects (MHP) can possibly meet the power necessity of remote territories in decentralized way. To energize and quicken the improvement of water factories and Micro Hydel Projects in the remote and sloping territories, it is proposed to give Central Financial Assistance (CFA) during 2014-15 and the remaining period of the 12th Five year plan as per the details given below.

Local Watermills and Micro Hydel Venture Financial Assistance:

The sum of CFA as per the following details will be given:

a) **Watermills:**

S. No.	Category of Watermill	Amount of CFA
1.	Mechanical output only	INR 50,000/- per watermill
2.	a. Electrical output (up to 5kW) or b. Both mechanical and electrical output(up to 5 Kw)	INR 1,00,000/- per watermill

b) **Micro Hydel Projects with power up to 100 kW:**

S. No.	Areas	Amount of CFA
1	All States	INR 1,25,000/- per kW

Note: A minimum contribution of 10% of the project cost should be met by the beneficiaries/project owner.

The State Government departments / State Nodal Agencies, Local Bodies, Co-operatives, NGOs & Individual Entrepreneurs intending to avail CFA are required to submit the application as per enclosed format along with the following documents:

(i) Two versions of the project report, covering different aspects of project execution, timeline of completion, O&M and cost estimates.

(ii) State Government approval for the implementation of the project (including statuary clearances as applicable, if any)

(iii) Financial contributions to meet project expense of the balance.

(iv) Evidence of availability of the Land needed for a project.

[Source: annexure-E SSHP policy; Govt. of India; Ministry of New & Renewable Energy]

Chapter 5

Simulation & Results

5.1 Simulation setup

Simulation was done is order to get an understanding of the designing parameter of the supporting channel based on the study of Intake angle, flow variation, behavior of flow with change of discharge/ head. A rough construct of the general system of SSHP is given in the below mentioned figure. The figure is not to scale but just for mere understanding of the conceptual idea for design.

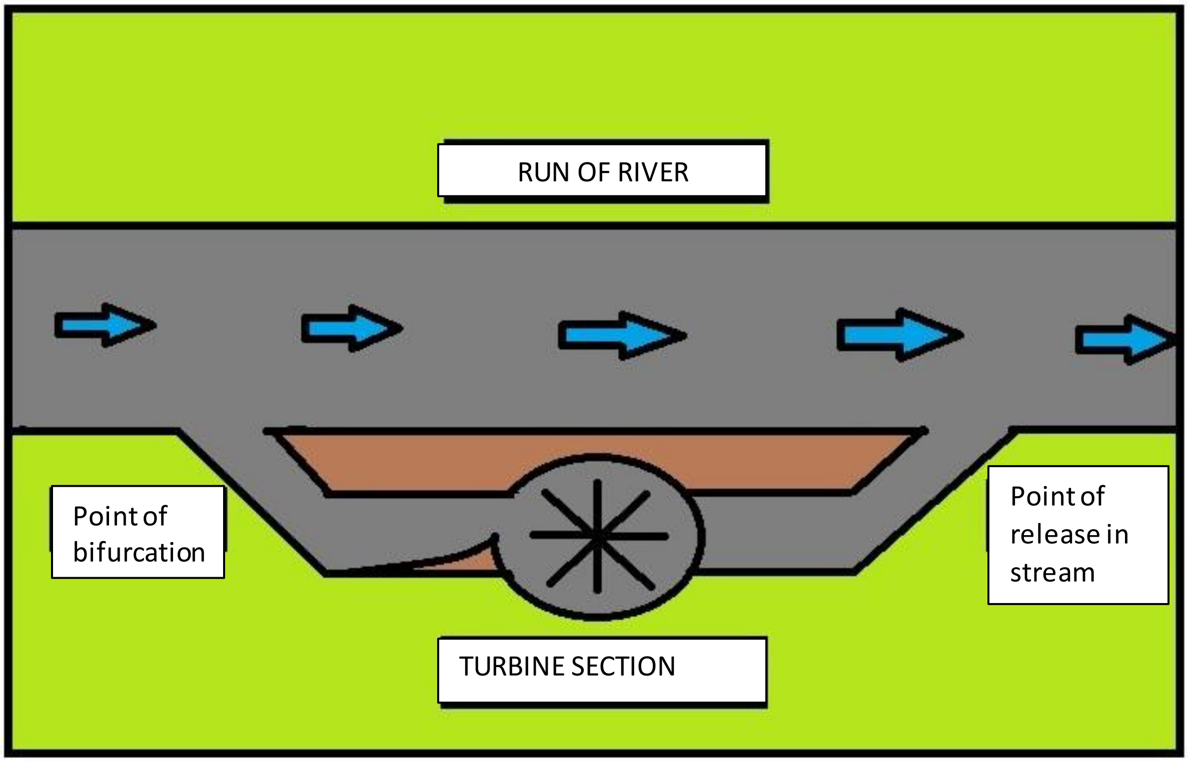
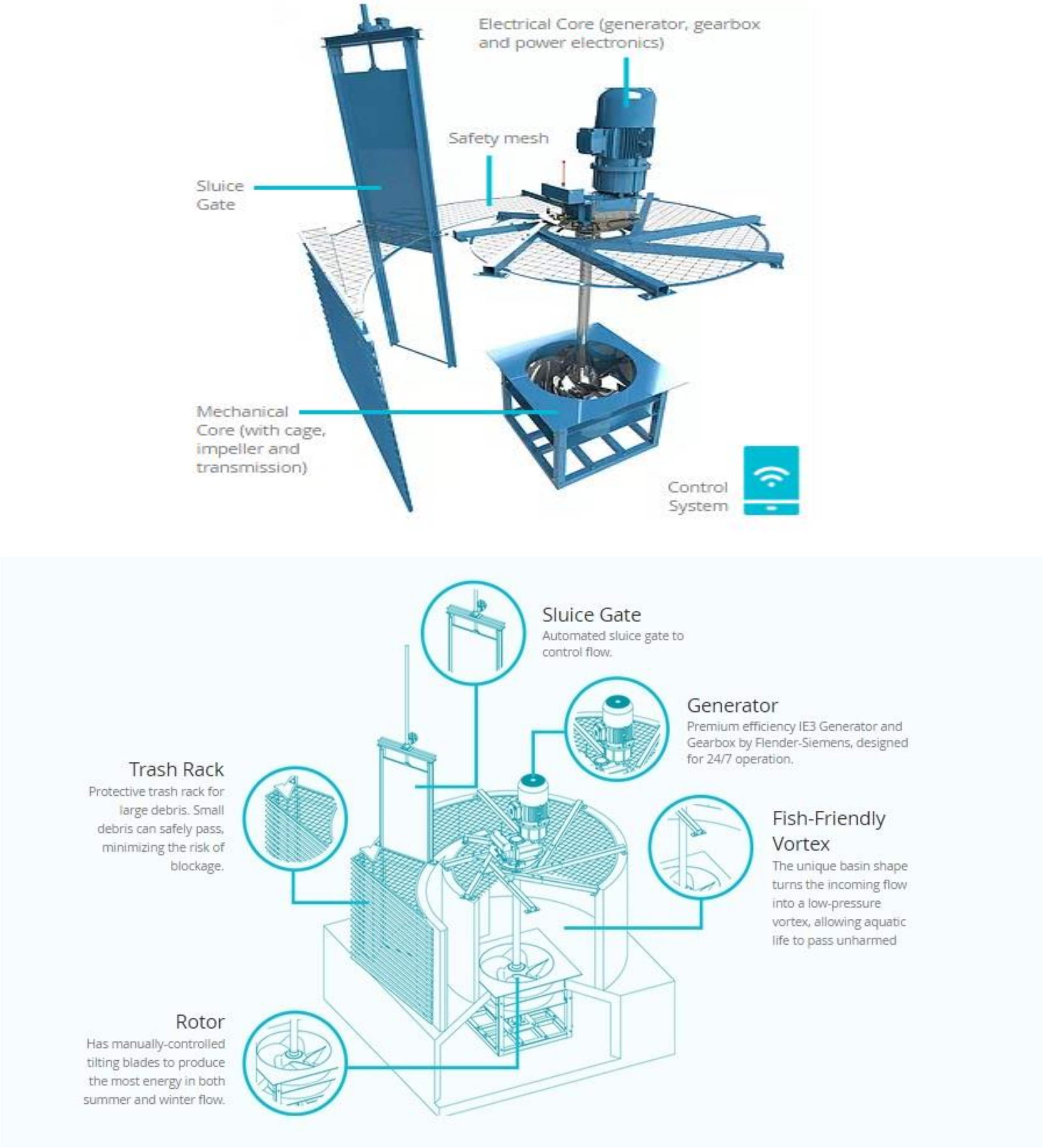


Figure 5.1.1: Top View of the Setup in Rough Animated description. [NOT TO SCALE]

As per the past research work done in the field related to the same topic but yet distinctive to what has been done in this project, multiple design and models have been prepared one such model is depicted below to give an idea of the vortex turbine which has been studied by multiple researchers in the field for their optimal efficiency and productivity.



[SOURCE: https://turbulenthydropower.org/ design/lowheadturbine.xlps]

Figure 5.1.2: 3D detailed representation of the system with energy production unit attached to the top.

As per the previous researches done by multiple personnel pertaining to the field of water resources engineering and mechanical engineering a generalized idea for maximum efficiency for multiple model of turbines based on percentage flow rate is mentioned below in a diagrammatical representation:

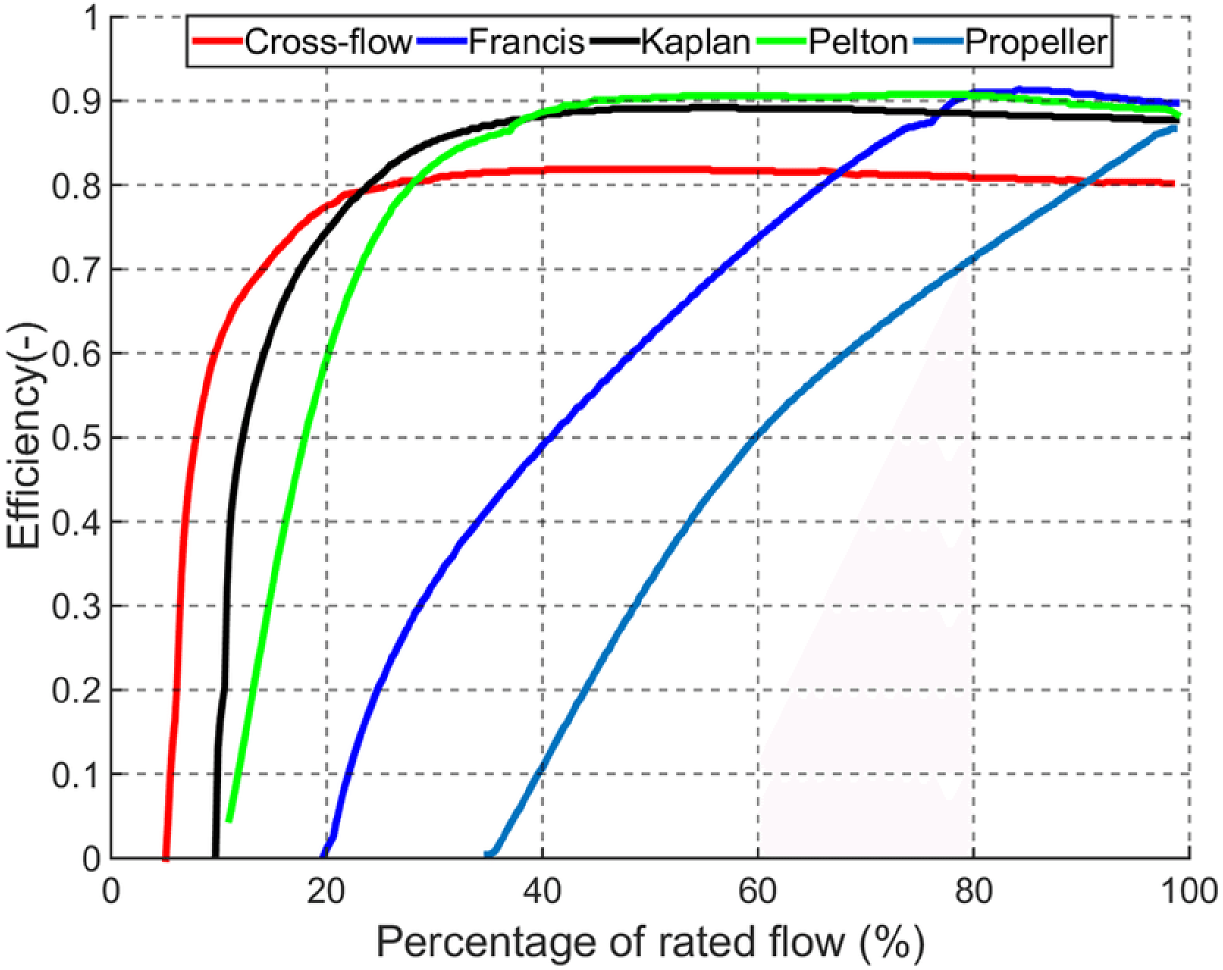


Figure 5.1.3: Efficiency curve of various turbine designs per percentage of rated flow. [10,11]

5.1.1 ANSYS (CFD-FLUENT)

ANSYS (Fluent) simulation gives a better picture of the flow patterns moving across a hydraulic structure whether it’s a turbine or a channel or weir. A part of study in this case is over the feasibility of the whole concept of small scale hydropower and its comparison under different low head turbines by means of COMPUTATIONAL FLUID DYMANICS simulation over various variables and parameters.

DETAILS OF THE PROTOTYPE FOR ANSYS SIMULATION:

- ⇒ Average discharge variation for the study of model will be varied between 1m^3/s to 5m^3/s.
- ⇒ The width of the main stream section is kept = 600 mm
- ⇒ The width of bifurcating canal from the main stream is kept = 200 mm
- ⇒ Radius of turbine vortex flow zone = 150 mm
- ⇒ Maximum radius of turbine blade is = 145 mm
- ⇒ Total length of the design is limited to = 2000 mm
- ⇒ Length of bifurcating flume in horizontal direction = 1000 mm
- ⇒ Average range of head to be studied is kept between 0.3 to 1 meters w.r.t bottom of the channel.
- ⇒ The flow across the designed channel was kept laminar and the velocity of flow at the inlet section was kept at 1m/s and was varied accordingly to obtain needed discharge.

The process for analysis of the complete setup is done in 3 parts:

- The zone of bifurcation,
- The zone of vortex flow and;
- The zone of release.

The ANSYS simulation steps involved were the same for every zone only the design parameters were different standard atmospheric pressure to be considered was 1 atm. The flow considered was uniform & steady in nature across every zone to replicate the stream flow of Ganga River in natural state in the regions of Bihar.

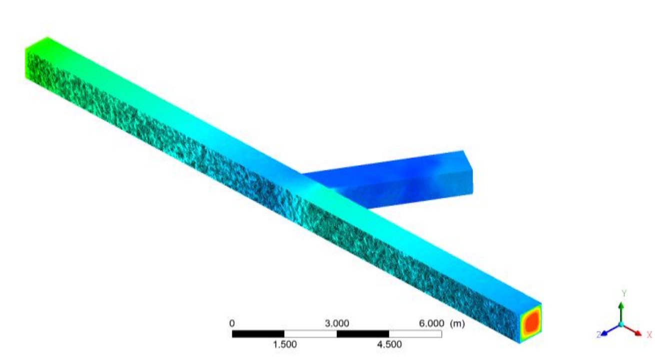
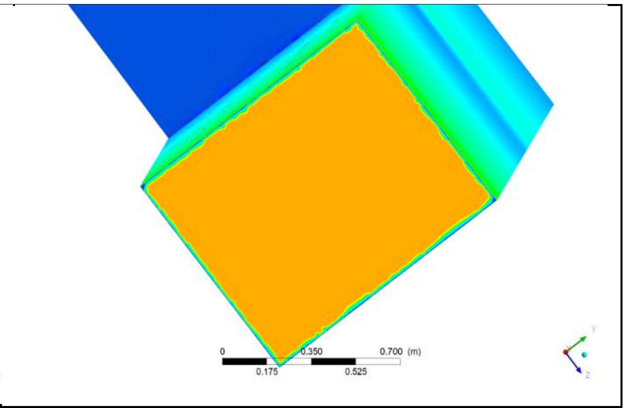
- The steps for ANSYS(FLUENT) simulation involved were as follows:
  - Step 1: Define Domain (shape/geometry of the flow setup as projected above in technical specifications).
  - Step 2: Start ANSYS Workbench 19.2, under analysis system (toolbox tab) choose fluid flow (FLUENT).
  - Step 3: Right click on geometry – properties- set analysis type – 2D (this simulation run is done for 2D type similar for 3D type).

- Step 4: Once ready right click on geometry and choose design modeler for construction of geometry.
- Step 5: Create geometry with a plane of angle 60 degree with the global YZ plane.
- Step 6: Once geometry is created go to meshing portion of the software, complete the meshing keeping the edges properties to be hard and meshing size to be kept at 0.08 meters for fast computation and analysis.
- Step 7: Once the meshing is done go to the result and calculations section, compute iterations and finalize solution.
- Step 8: Construct the contour for pressure distribution, velocity vector profile and other variation parameters across the channel section.

The analysis of the different section resulted in the various profiles of pressure distribution, velocity vector flow, variation across the wall domain of the structure.

Below is the detailed analysis of the various parameters of different sections of the proposed system:-

- **Canal Intake angle @ 60º** is taken for study in initial CFD analysis. The result depicting to the same is represented below showing different parameters which will be compared in the end with different angles of Intake and whether there is any effect to the flow or not.

	
PRESSURE CONTOUR	**INLET PRESSURE CONTOUR**

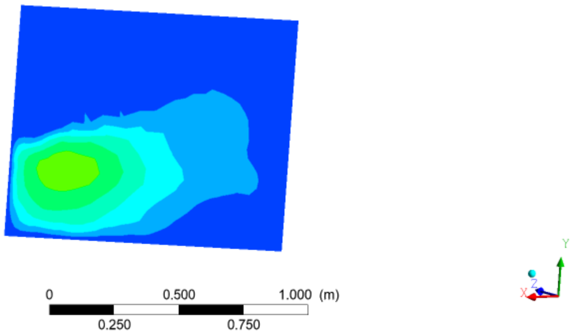
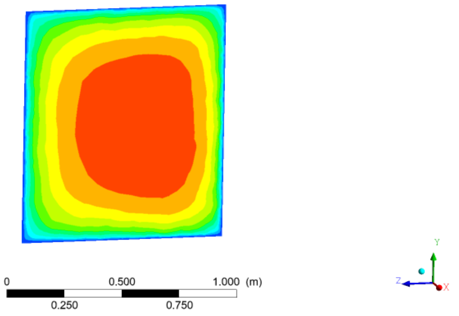
	
OUTLET 1 PRESSSURE CONTOUR	**OUTLET 2 PRESSURE CONTOUR**

Figure 5.1.1.1: Pressure contour for bifurcating canal @ 60^{O}, inlet, outlet 1 and outlet 2.

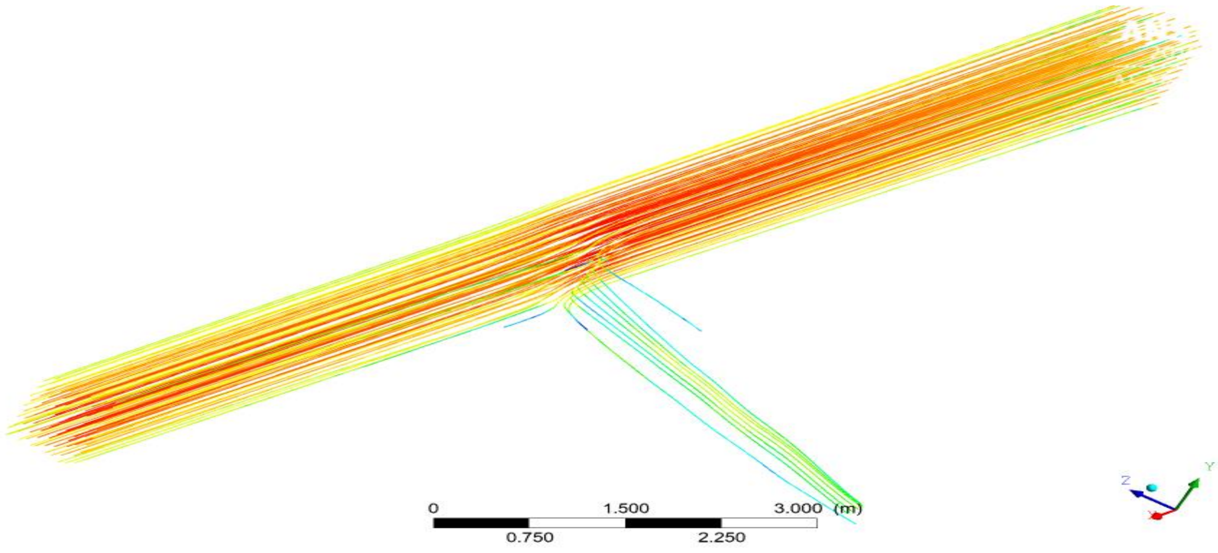


Figure 5.1.1.2: Velocity streamline profile across a bifurcating canal.

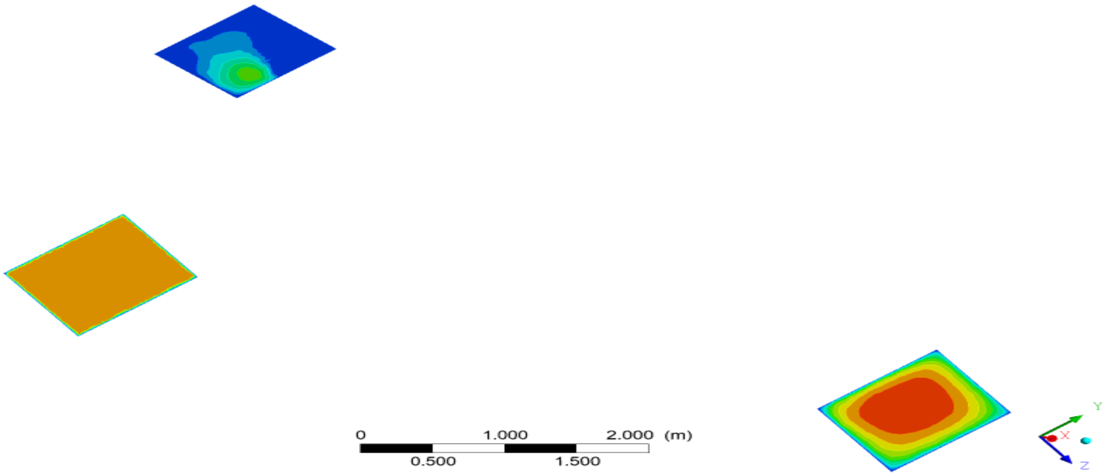


Figure 5.1.1.3: Simultaneous inlet, outlet 1 and outlet 2 velocity contour view

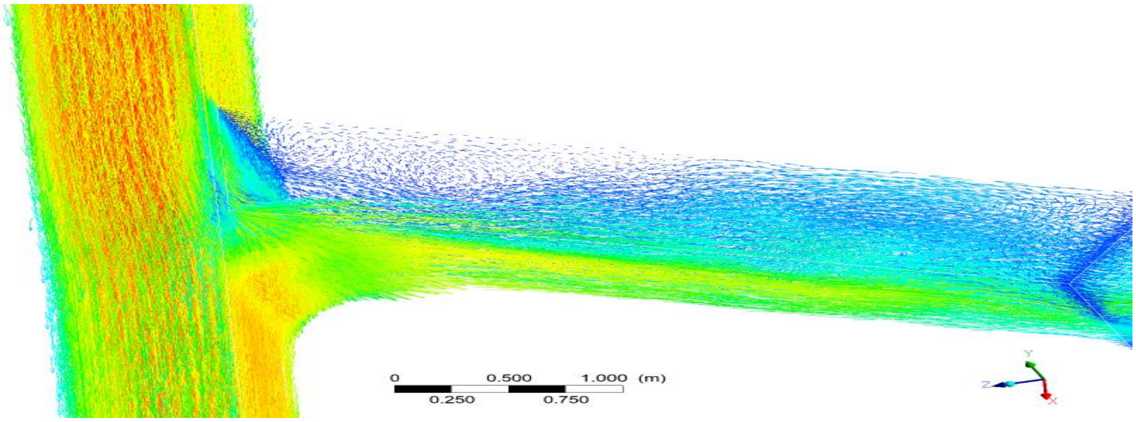


Figure 5.1.1.4: Velocity vector profile at bifurcation vertex

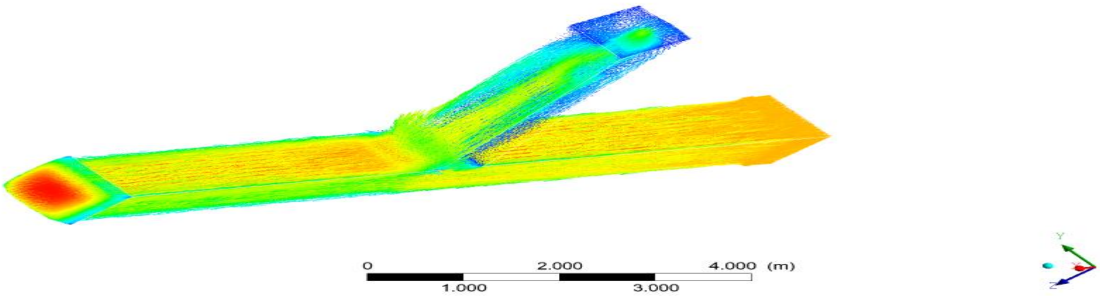
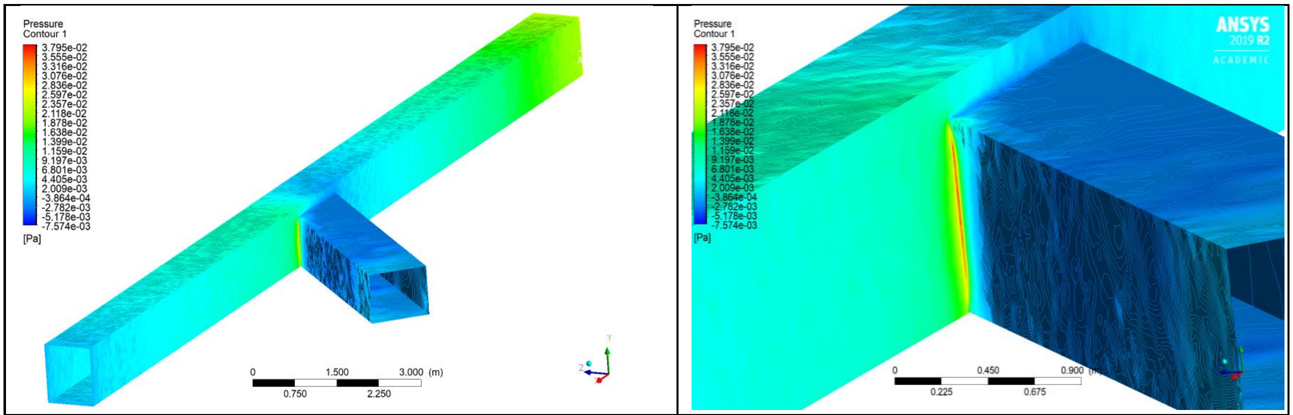


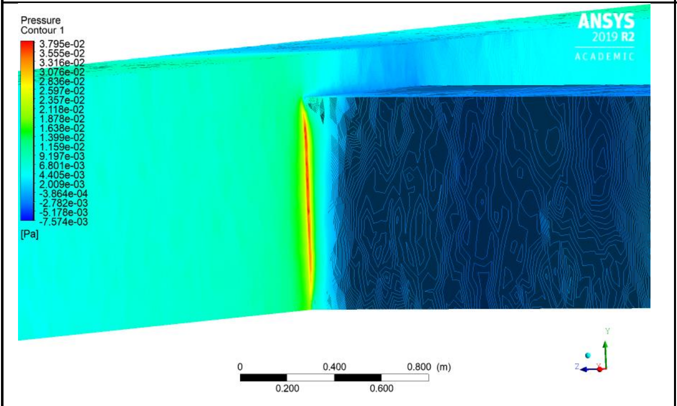
Figure 5.1.1.5: Velocity vector profile of complete canal system

- **Canal Intake angle @ 45**



PRESSURE CONTOUR

VERTEX PRESSURE CONTOUR



VERTEX (2) PRESSSURE CONTOUR

Figure 5.1.1.6: Pressure contour for bifurcating canal @ 45°, inlet, outlet 1 and outlet 2.

The above CFD simulation result depicted that the vertex of intake canal w.r.t main canal had sufficient increment in pressure shown by a red and yellow texture across its length. Having range of pressure 2.375 x $10^{(-2)}$ to 3.795 x $10^{(-2)}$.

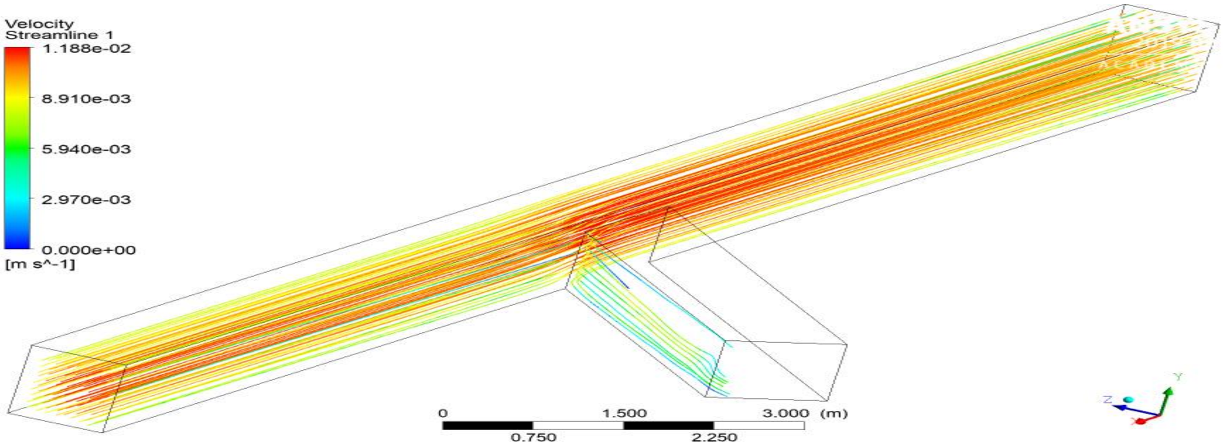


Figure 5.1.1.7: Velocity streamline profile across a bifurcating canal

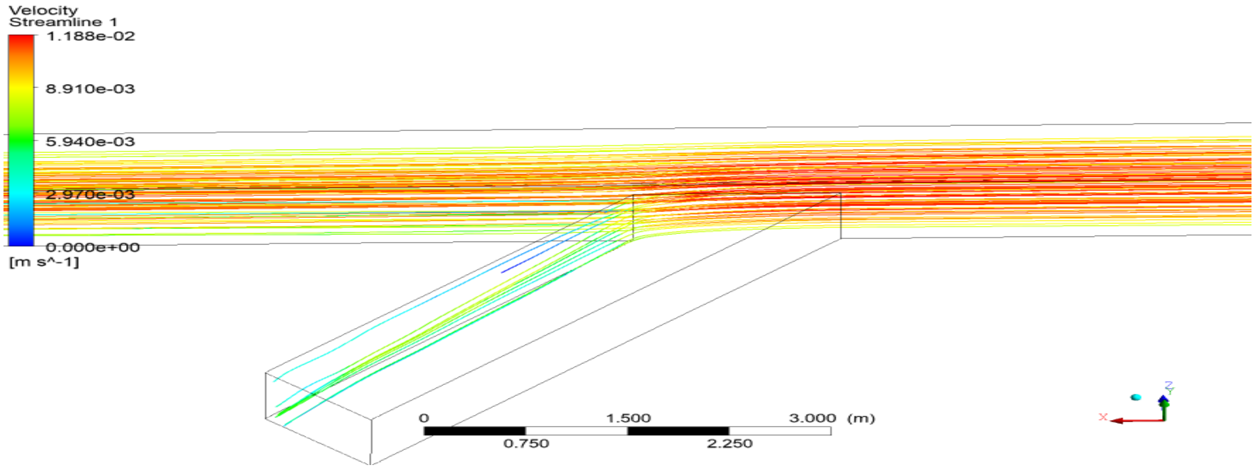


Figure 5.1.1.8: Velocity streamline profile across the vertex in bifurcating canal @ 45°

Velocity streamline profile also showed that majority of the flow in the simulation didn't differed from its main line of flow and the ones which did change path lost significant velocity to produce the required energy needs, hence the need for proper sloping condition is needed to make the bifurcating flow much more dominant in the intake canal.

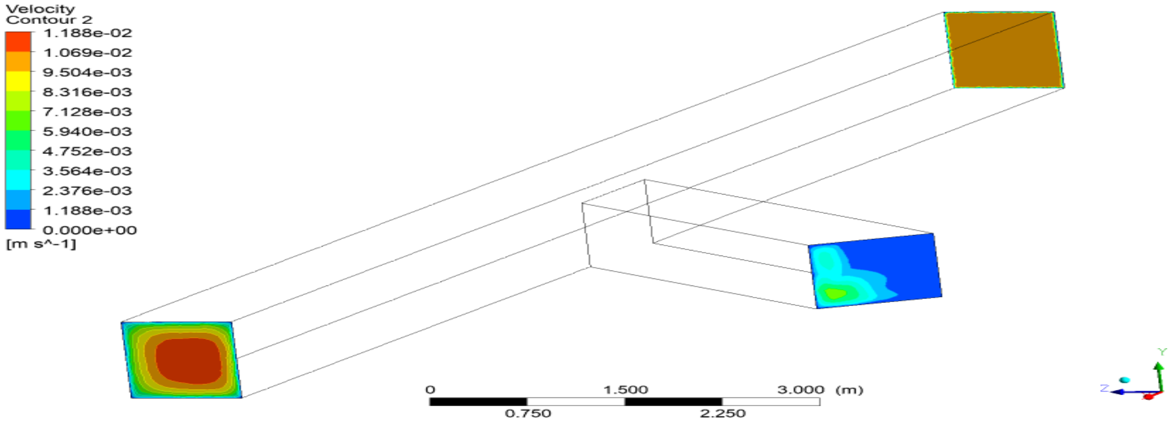
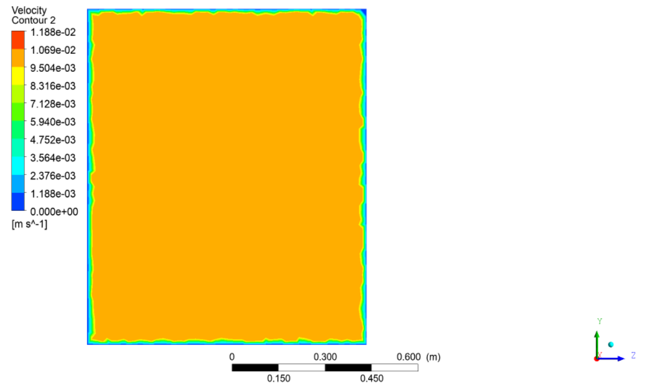
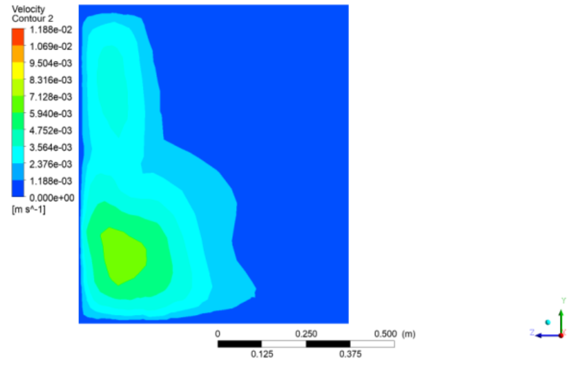


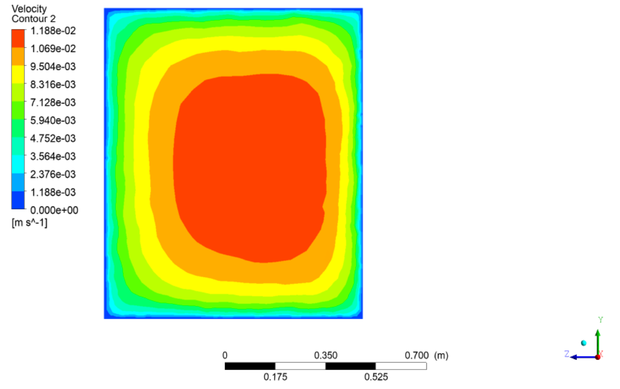
Figure 5.1.1.9: velocity contour view of inlet, outlet 1 and outlet 2



INLET VELOCITY PROFILE



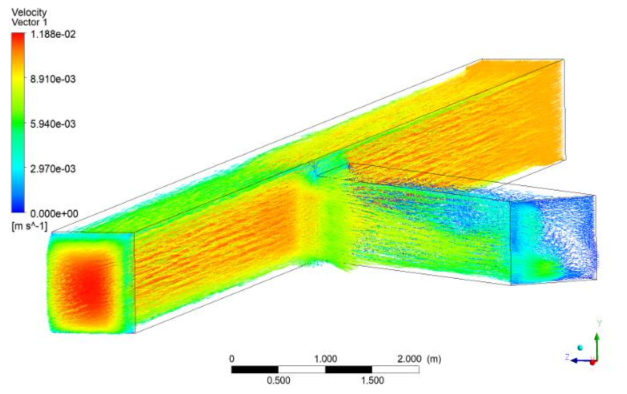
OUTLET 1 VELOCITY PROFILE



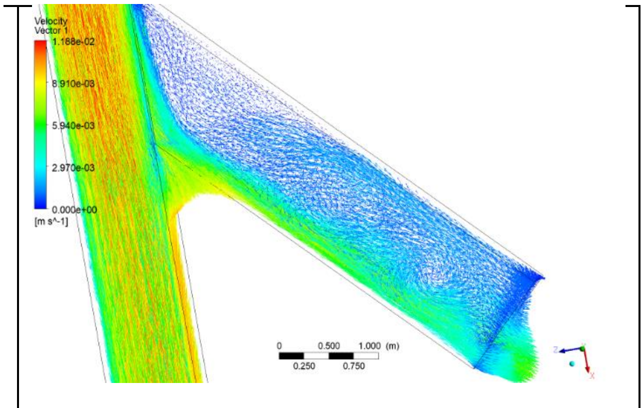
OUTLET 2 VELOCITY PROFILE

Figure 5.1.1.10: Velocity profile of various faces of the channel system.

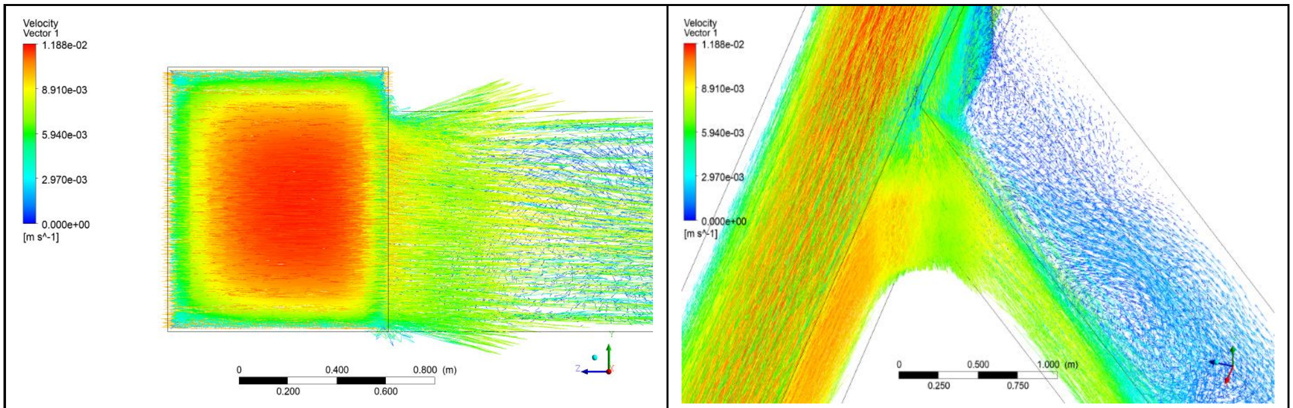
(Figure 5.1.1.10) shows the flow velocity contour concentration at bottom left face having inflow design for turbine blade at that particular location for maximum output, the outlet 2 flow velocity profile has major concentration of contour line nearby the center.



VELOCITY VECTOR



OUTLET 1 VELOCITY VECTOR

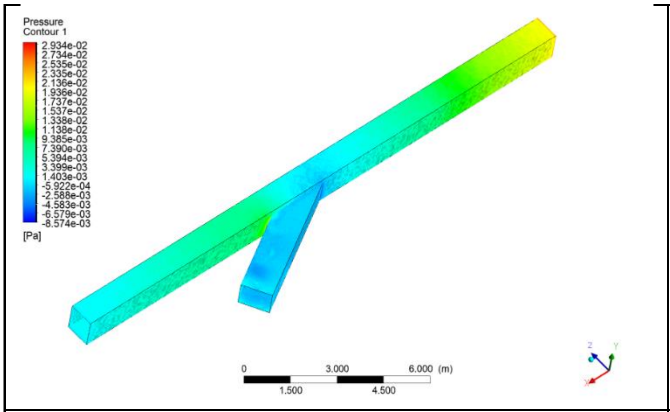


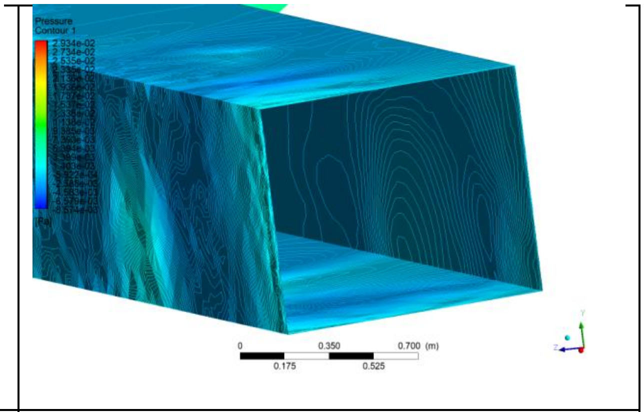
OUTLET 2 VELOCITY VECTOR	**VERTEX VELOCITY VECTOR**

Figure 5.1.1.11: Velocity vector profile for different faces of the channel.

Velocity vector profile shows that at the initial junction of inflow to turbine section the water tends to move towards right side of the intake canal wall. This lead to providing S shaped obstacle on the left face of the intake channel to guide the minor low to the right face and giving the full efficiency of the flow to the vanes of the turbine blade. The CFD simulation described the regions for improving design parameters of the canal such that maximum benefit could be obtained out of it.

- **Canal Intake angle @ 30º**





PRESSURE CONTOUR	**OUTLET 1 PRESSURE CONTOUR**

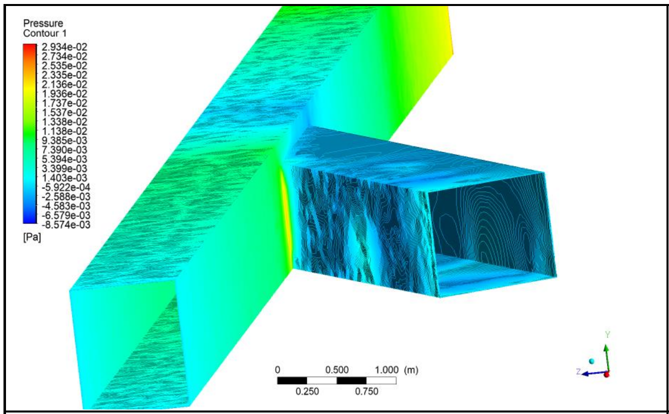
	
VERTEX PRESSSURE CONTOUR	

Figure 5.1.1.12: Pressure contour for bifurcating canal @ 30°, outlet 1 and vertex.

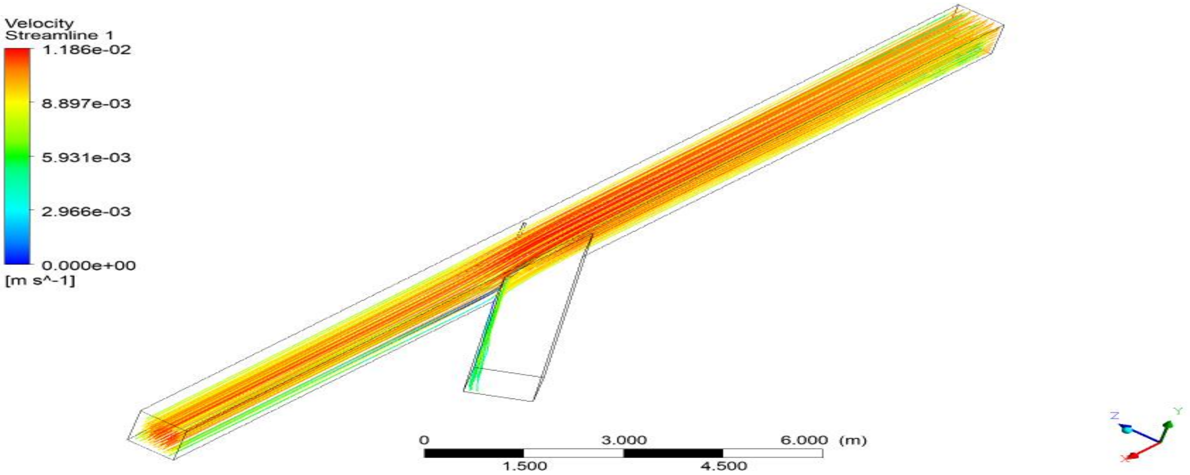


Figure 5.1.1.13(a): Velocity streamline profile across a bifurcating canal @ 30°

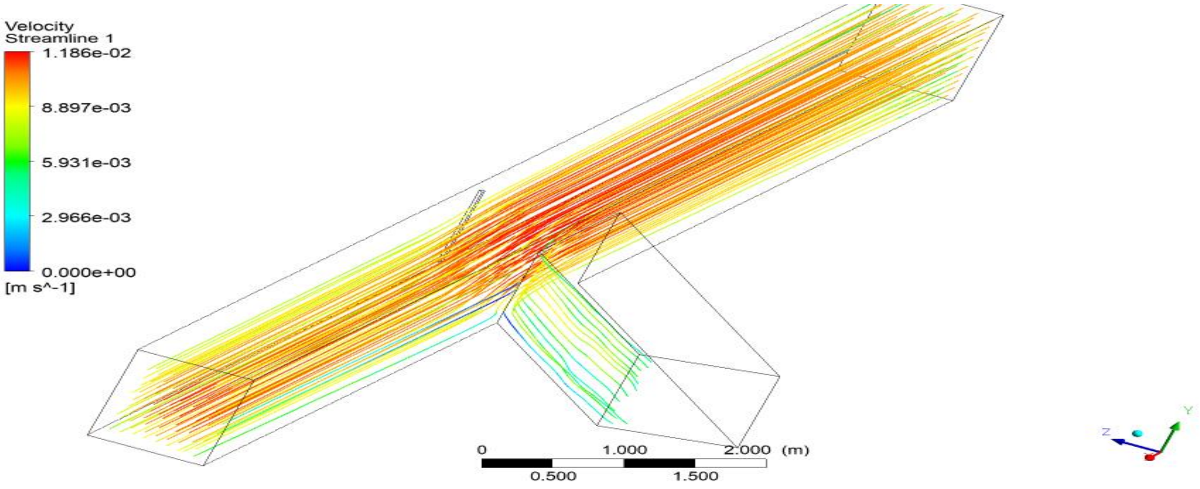
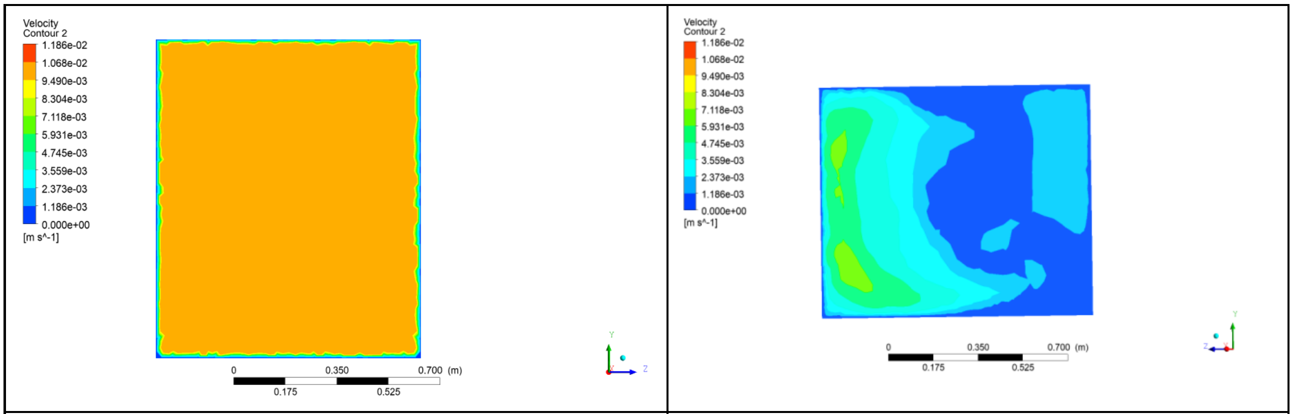
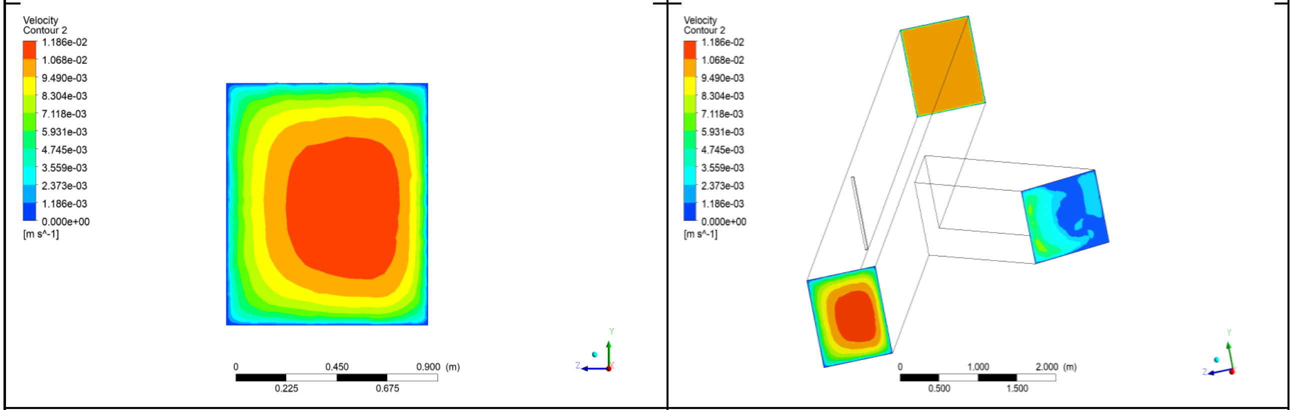


Figure 5.1.1.13(b): Velocity streamline profile across the vertex in bifurcating canal @ 30°



INLET VELOCITY PROFILE

OUTLET 1 VELOCITY PROFILE

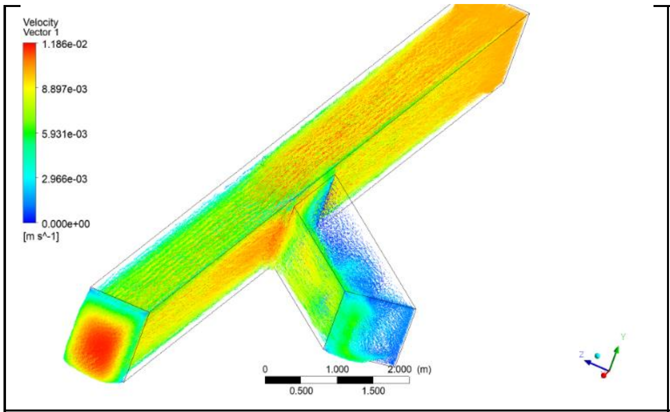


OUTLET 2 VELOCITY PROFILE

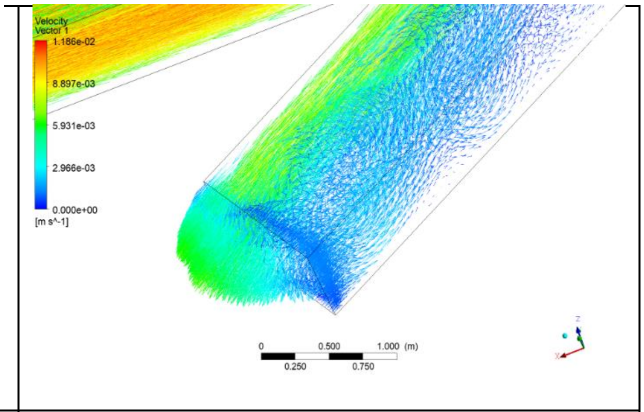
VELOCITY CONTOUR

Figure 5.1.1.14: Velocity profile of various faces of the channel system.

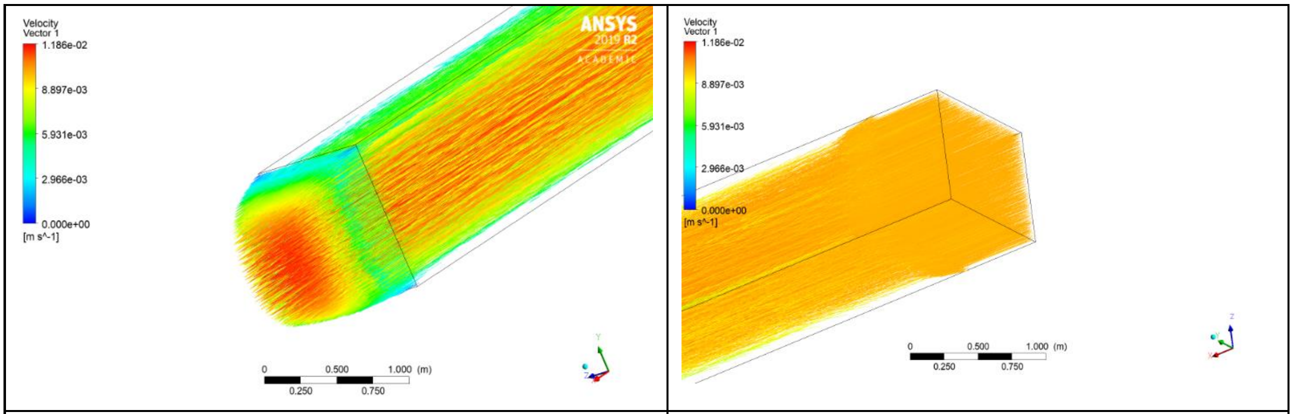
(Figure 5.1.1.14) shows the variation of the velocity contour profile to be more concentrated towards the left face of the outlet 1, whereas the outlet 2 has majority of the flow lines concentrated towards the center section of the channel.



VELOCITY VECTOR



OUTLET 1 VELOCITY VECTOR



OUTLET 2 VELOCITY VECTOR **INLET VELOCITY VECTOR**

Figure 5.1.1.15: Velocity vector profile for different faces of the channel

The variation across the bifurcating canal vertex section showed that with increase in impact angle the pressure distribution and value increased on the section and could lead to sufficient erosion of the vertex section. I.e. the pressure at vertex @60° > the pressure at vertex @ 45° > the pressure at vertex@ 30°. The range of pressure variation occurred in the following sequence such that the peak reached 3.795e-02 and minimum was at 2.335e-02.

Also the velocity vector profile depicted showed the majority flow vectors to be on the left face of the outlet 1, leading to the turbine for power generation hence provision of mouth for inlet for vortex flow should be kept on the right faced section for max inflow and energy output.

The analysis of the cross flow turbine was studied on ANSYS FLUENT and certain details and parameters were taken from previous researches simulating the same case scenarios presented in this research which has been properly mentioned, further comparison with experimental data is represented in the next chapter. Analysis on ANSYS FLUENT can be shown by using graphical displays and numerical outputs. They are utilized to research the inside stream attributes of crossflow turbine. The yields here are to show graphical showcases and numerical yields for a 2-D model of crossflow turbine. The graphical outputs can be displayed either in two dimensional (x-y) plots or in contour plot. CFD analysis has depicted the following results.

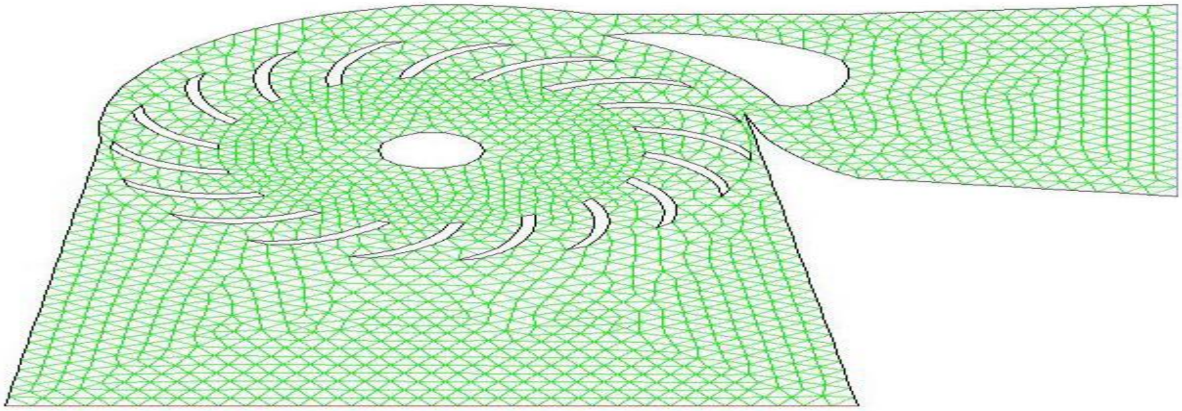


Figure 5.1.1.16: Low head Cross-flow blade meshing

Speed delta limit (velocity inlet) conditions were utilized to characterize the fluid velocity at the stream bay. In the incompressible flow, the inlet total pressure and the static pressure are related to the inlet velocity by Bernoulli's equation. Subsequently, the velocity magnitude and the mass stream rate could be doled out at the inlet boundary. Outflow boundary condition was defined at the outflow of the turbines.

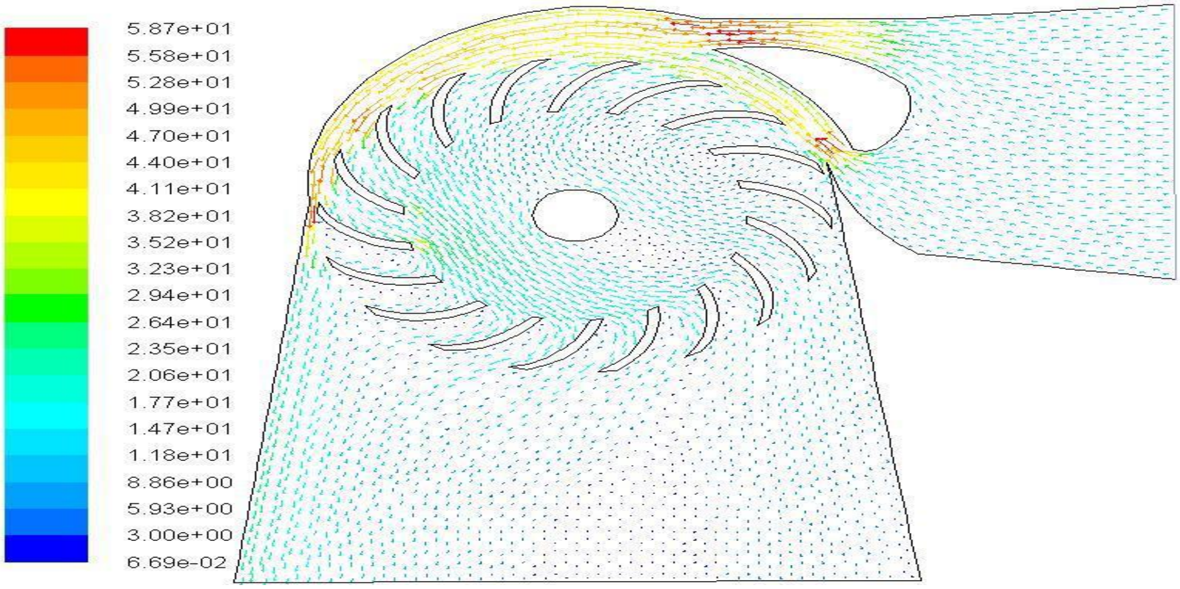


Figure 5.1.1.17: Velocity vector profile of flow across a cross flow turbine blade.

(Figure 5.1.1.17) show the velocity vector colored by velocity magnitudes of cross flow turbine. The velocity magnitude is constant at the inlet of the nozzle and it is going to increases inside nozzle. The stream inside the spout is direct by the guide vane towards the sprinter sharp edge at which the speed turns out to be high.

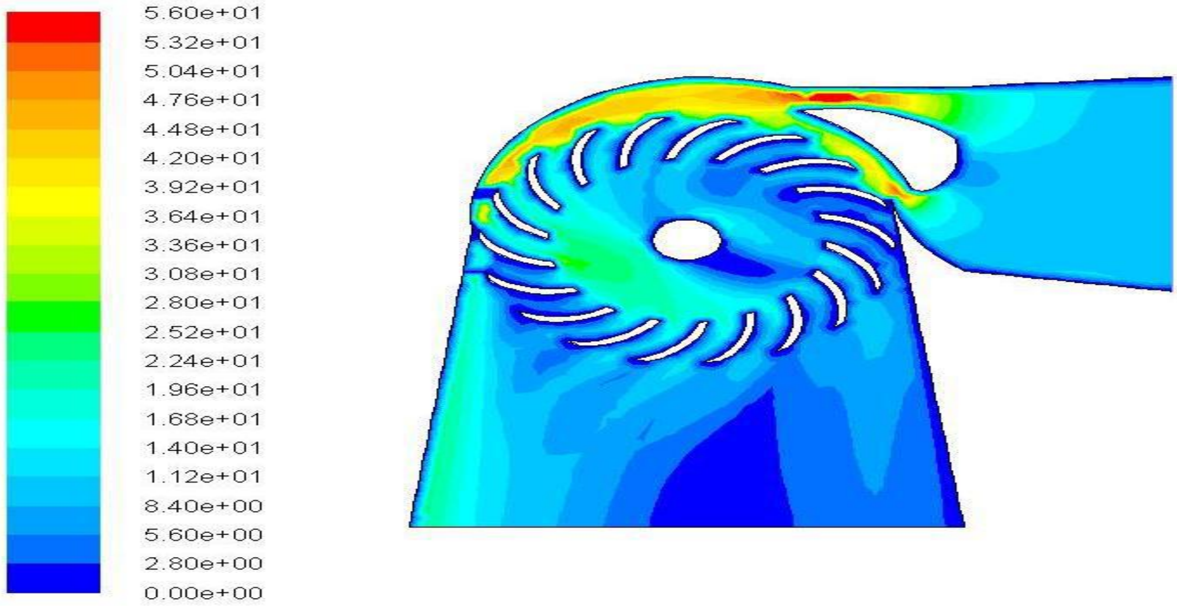


Figure 5.1.1.18: Velocity contour line across cross flow turbine blade system.

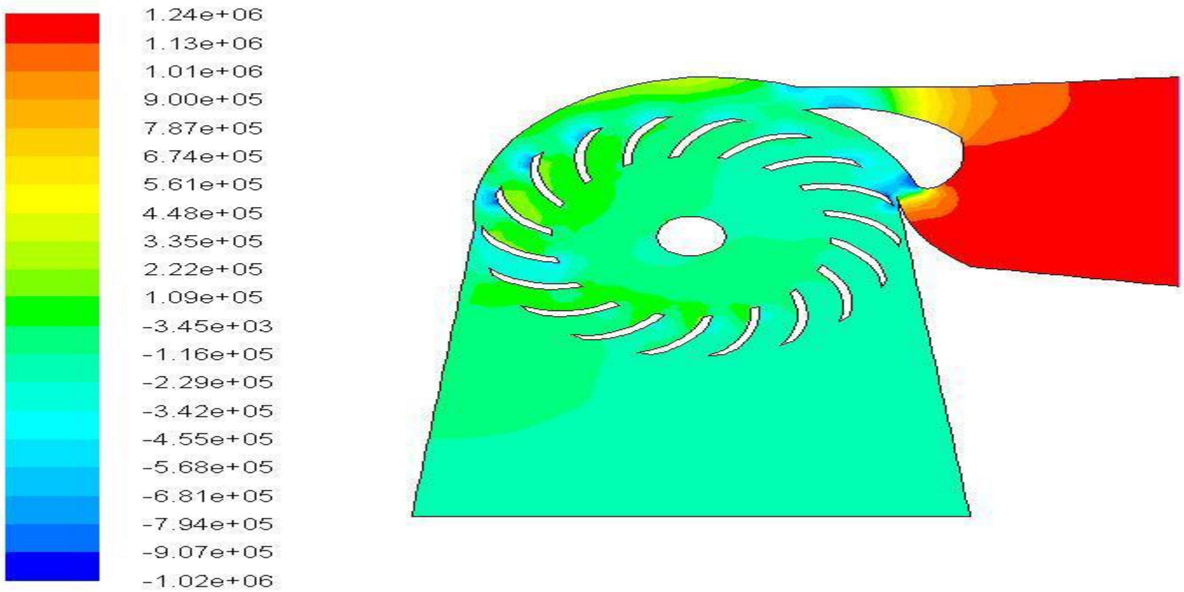


Figure 5.1.1.19: Pressure (static) contour line for flow across cross flow turbine blade.

(Figure 5.1.1.19) shows contour plot of static Pressure of cross flow turbine. As per the above figure the static weight is most extreme inside the nozzle at the inlet region and least at the outlet of the turbine or release region. The static pressure on sprinter's sharp edge is additionally partitioned in to two areas. The main district is called stage one in which the static pressure is with a specific worth and the subsequent one is stage two in which the static pressure is lesser than stage one.

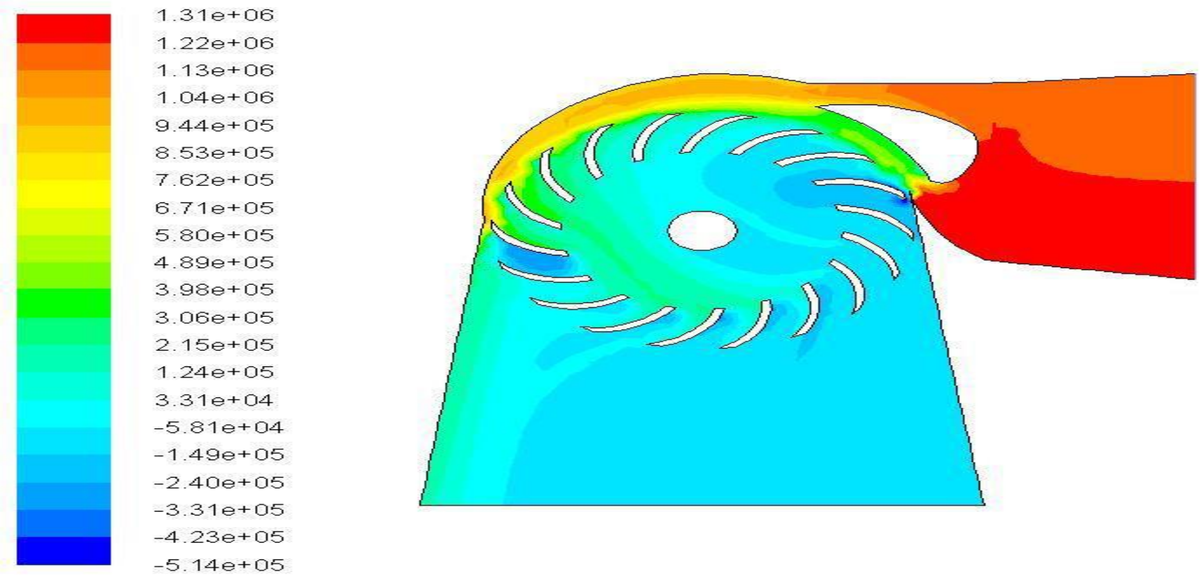
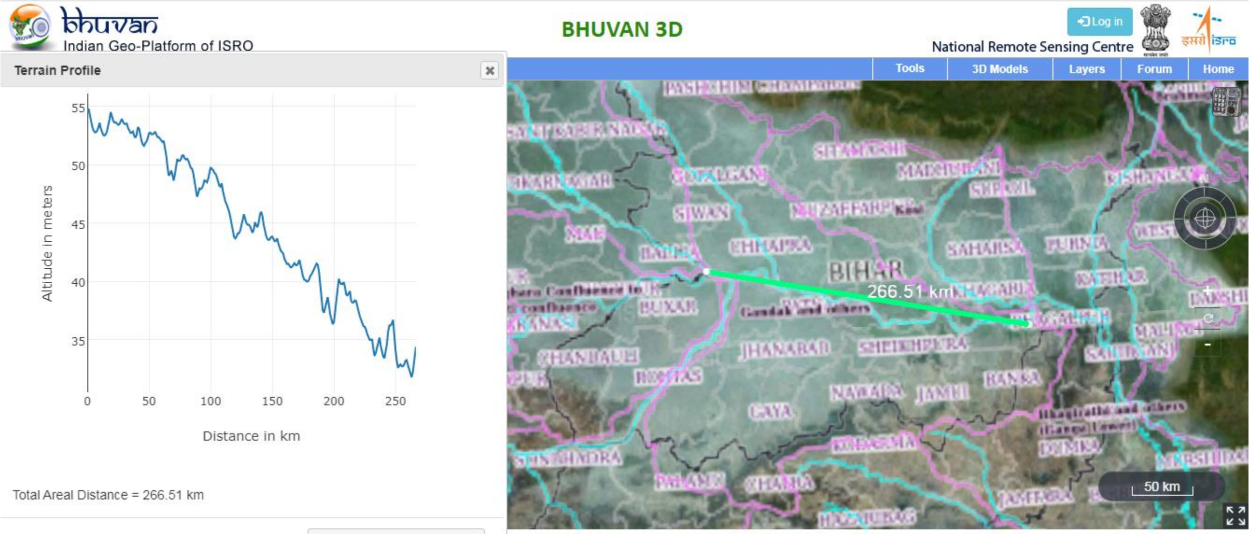


Figure 5.1.1.20: Total pressure contour line across a cross flow turbine blade.

(Figure 5.1.1.20) Show contour of Total pressure of cross flow turbine. The total pressure is high inside the nozzle area. And it's going to decrease in the first and second stage of the runner blade.

5.1.2 BHUVAN (DEM) – An ISRO Geo Portal:

The Geo terrain modelling portal of ISRO uses Cartosat 30 satellite for terrain analysis and determining the elevation across the linear stretch of profile. Except for the terrain profiling it also contains multiple tools related to the analysis of ground water monitoring, land use patter, vegetative mitigation, population density monitoring etc. within its domain of use. The following images are obtained in order to get an in depth view of DEM of the state of Bihar. The DEM has been constructed as per the flow trajectory of the Ganges River across the state to study the flow pattern and identify potential locations for installation of LOW Head/ Run of River turbines.

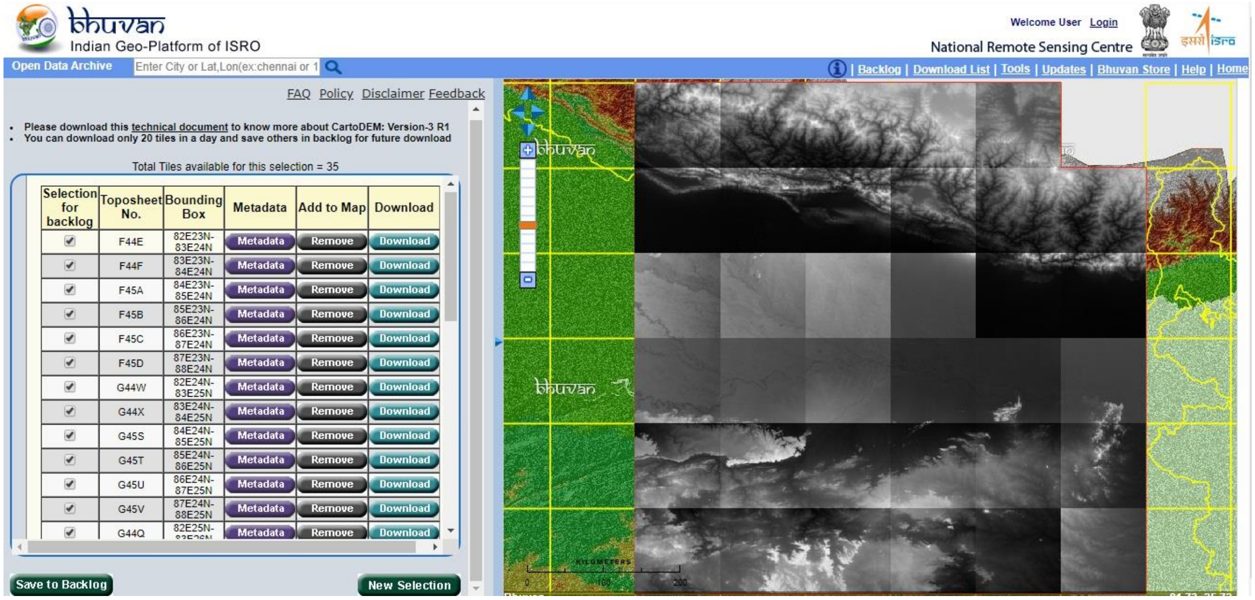


Total Areal Distance = 266.51 km

Figure 5.1.2.1: Digital Elevation Model (DEM) of Ganga River from BUXAR to BHAGALPUR. (Stretch is assumed simple to generate a linear DEM of terrain in Ganga river basin)

Digital elevation image of the river basin as per the satellite image and data were as follows.

These images were delineated in order to obtain the contour lines passing through the terrain to mark the available head we can get at the location. Consecutively the efficiency that will be obtaining at the location is suitable for the setup of the system could also be determined by the same.



- Please download this technical document to know more about CartoDEM: Version-3 R1
- You can download only 20 tiles in a day and save others in backlog for future download

Total Tiles available for this selection = 35

Selection for backlog	Toposheet No.	Bounding Box	Metadata	Add to Map	Download
☑	F44E	82E23N-83E24N	Metadata	Remove	Download
☑	F44F	83E23N-84E24N	Metadata	Remove	Download
☑	F45A	84E23N-85E24N	Metadata	Remove	Download
☑	F45B	85E23N-86E24N	Metadata	Remove	Download
☑	F45C	86E23N-87E24N	Metadata	Remove	Download
☑	F45D	87E23N-88E24N	Metadata	Remove	Download
☑	G44W	82E24N-83E25N	Metadata	Remove	Download
☑	G44X	83E24N-84E25N	Metadata	Remove	Download
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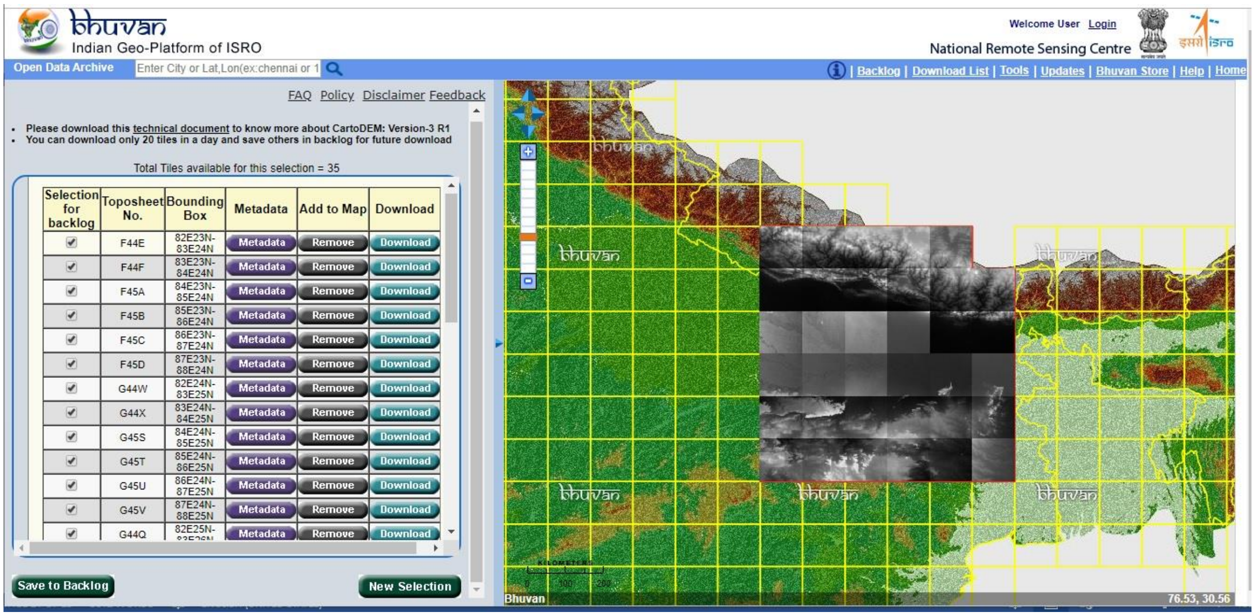
☑	G45T	85E24N-86E25N	Metadata	Remove	Download
☑	G45U	86E24N-87E25N	Metadata	Remove	Download
☑	G45V	87E24N-88E25N	Metadata	Remove	Download
☑	G44Q	82E25N-	Metadata	Remove	Download

Figure 5.1.2.2: DEM data for the state of Bihar with river Ganga flowing in the middle has been presented to get an insight of the terrain profile.



- Please download this technical document to know more about CartoDEM: Version-3 R1
- You can download only 20 tiles in a day and save others in backlog for future download

Total Tiles available for this selection = 35

Selection for backlog	Toposheet No.	Bounding Box	Metadata	Add to Map	Download
☑	F44E	82E23N-83E24N	Metadata	Remove	Download
☑	F44F	83E23N-84E24N	Metadata	Remove	Download
☑	F45A	84E23N-85E24N	Metadata	Remove	Download
☑	F45B	85E23N-86E24N	Metadata	Remove	Download
☑	F45C	86E23N-87E24N	Metadata	Remove	Download
☑	F45D	87E23N-88E24N	Metadata	Remove	Download
☑	G44W	82E24N-83E25N	Metadata	Remove	Download
☑	G44X	83E24N-84E25N	Metadata	Remove	Download
☑	G45S	84E24N-85E25N	Metadata	Remove	Download
☑	G45T	85E24N-86E25N	Metadata	Remove	Download
☑	G45U	86E24N-87E25N	Metadata	Remove	Download
☑	G45V	87E24N-88E25N	Metadata	Remove	Download
☑	G44Q	82E25N-	Metadata	Remove	Download

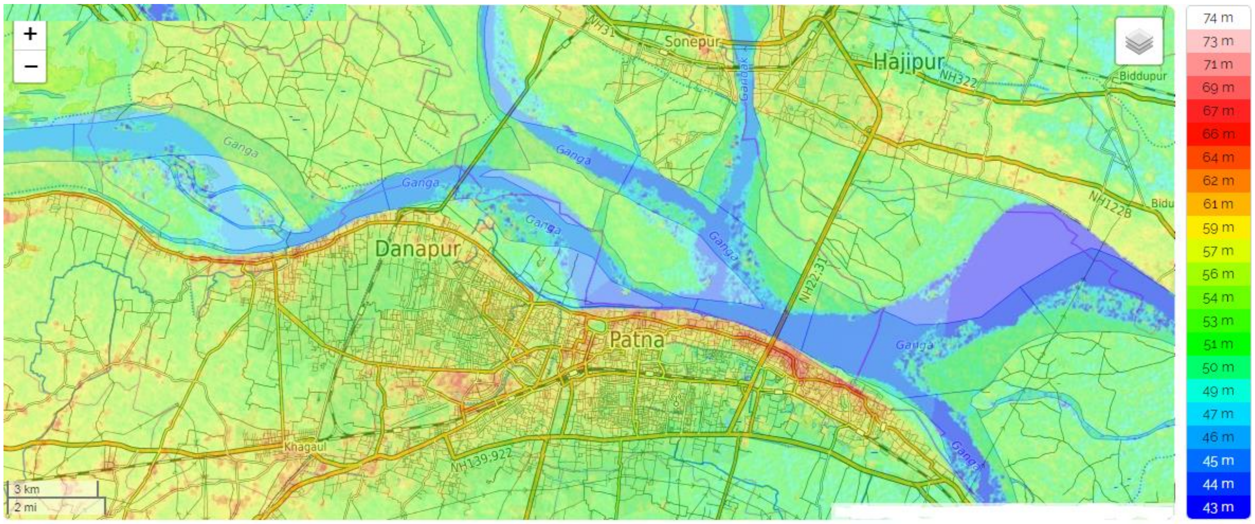
Figure 5.1.2.3: A zoomed out scaled image of the DEM construct of the region.

The exact data can’t be seen in the image due to its raw nature but the Meta data available with distinctive tiles available across the grid, we obtained the nature of profile. Here in the image which can be briefly suggested that the area with darker shades has rapid changes in terrain profile whereas the areas with lighter shade is more of plain in topography.

Black texture = highly varying terrain profile (10 – 25 meters per kilometer)

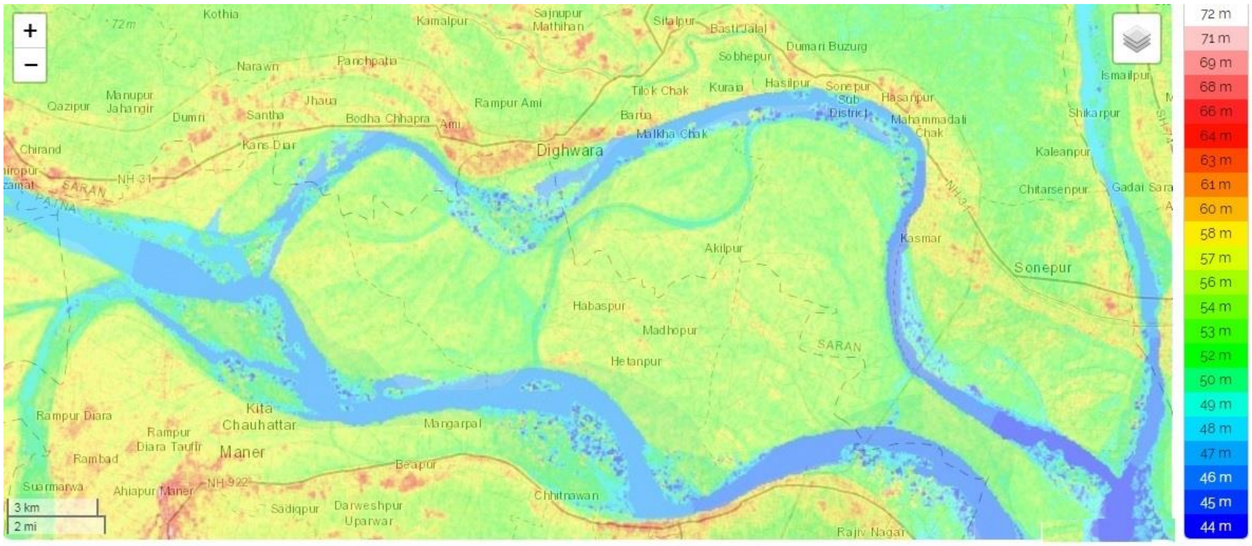
Grey texture = moderately varying terrain profile (8-12 meter per kilometer)

White texture= plain terrain with very minimal variation of 2-5 meters of the terrain profile.



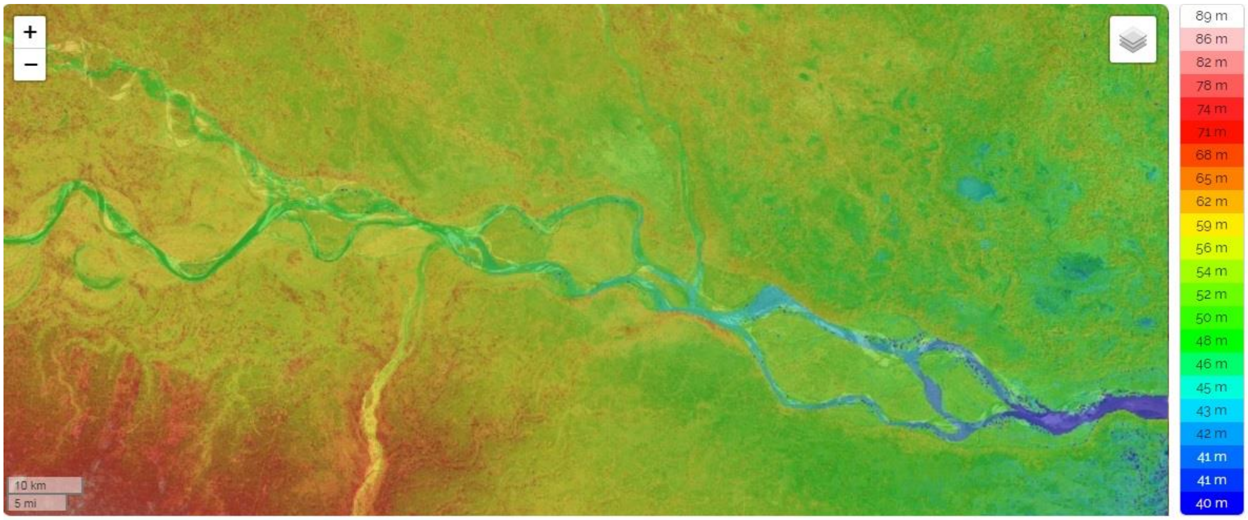
Bihar, India (25.64408 85.90651)

Figure 5.1.2.4: Delineated topographical map of Bihar (PATNA) of singular grid section (GI-S1).



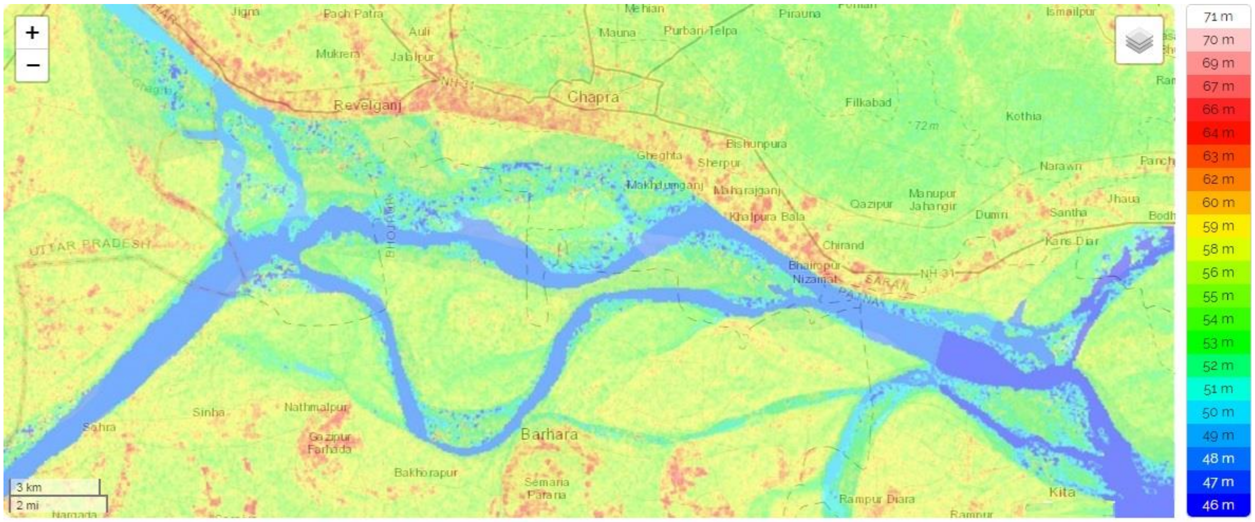
Bihar, India (25.64408 85.90651)

Figure 5.1.2.5: Delineated topographical map of Bihar (DIGHWARA) of singular grid section (GI-SII).



Bihar, India (25.64408 85.90651)

Figure 5.1.2.6: Delineated topographical map of Bihar (GANGA RIVER BASIN) of singular grid section (GII-SI).

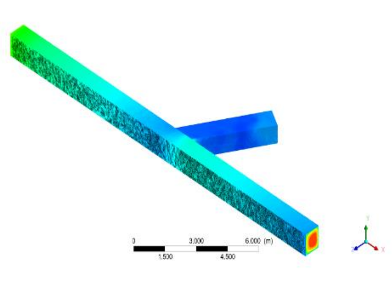
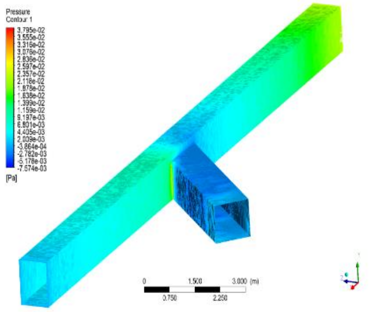
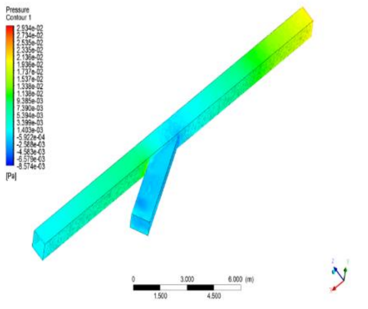


Bihar, India (25.64408 85.90651)

Figure 5.1.2.7: Delineated topographical map of Bihar (CHAPRA) of singular grid section (GII-S1I).

5.2 Discussion on Results

The Ansys (FLUENT) simulation showed that the impact of intake angle varied based on the degree of intake from the main canal. As the angle was changed from 30° to 60° the flow in the intake channel to the vortex chamber varied.

		
Canal Intake angle = 60°	Canal Intake angle = 45°	Canal Intake angle = 30°

The trajectory of the flow based on the streamline diagram produced on ANSYS (FLUENT) simulation showed the flow to be more concentrated towards the left face of the intake channel when seen through the sectional point of view from the vortex chamber.

The maximum velocity intake appeared to be at 30^{o}, beyond which the flow became violent and had a tendency to erode the face and base of the channel. The slope of the simulation was fixed at 5/1000 (5V:1000H), taking the general elevation difference across 2 points in the case location taken for this study. The tendency of flow across the channel at 45^{o} and 60^{o} was very less in terms or parameters like pressure and velocity which lead to the flow not diverging from the main canal or losing its energy while entering the intake canal to the vortex chamber.

Experimental data was obtained based on the turbine setups available in the Hydraulics & Fluid laboratory of Delhi Technological University. Francis and Kaplan Turbine was available for which data was taken and analysis for the particular nature of flow which is nearly uniform and steady. The interpretation of data obtained has been simulated below based on the data of mentioned turbines:

TYPE OF TURBINE	HEAD (m)	DIAMETER OF ROTOR (mm)	MAXIMUM EFFICIENCY (hydraulic)	OVERALL EFFICIENCY(η)
CROSSFLOW	2.5 – 5	300	95%	80- 85%
FRANCIS	40 – 600	300	90-95%	90-92%
KAPLAN	10-70	300	90%	85-90%

- CROSSFLOW TURBINE:-

S.No	Head	Discharge	Velocity	Power Theoretical (kW)	Power Actual	Efficiency
1	0.3	0.363916199	2.426107994	1.071005374	0.676	63.11826405
2	0.4	0.420214231	2.801428207	1.648920643	0.998	60.52444091
3	0.5	0.469813793	3.132091953	2.304436654	1.562	67.78229279
4	0.6	0.514655224	3.431034829	3.029260651	2.097	69.22481231
5	0.7	0.555891176	3.705941176	3.817304708	2.841	74.42423954
6	0.8	0.594272665	3.961817765	4.663851873	3.305	70.86417173

7	0.9	0.630321347	4.202142311	5.565107169	4.311	77.46481548
8	1	0.664417038	4.429446918	6.51793114	5.032	77.20241119
9	1.2	0.727832398	4.852215989	8.568042993	6.516	76.05003856
10	1.4	0.786148841	5.240992272	10.79696818	8.309	76.9567888
11	1.8	0.891408997	5.942726647	15.74050007	11.784	74.86420347
12	2	0.939627586	6.264183905	18.43549323	14.429	78.26750181
13	2.4	1.029310449	6.862069659	24.23408521	18.504	76.35526508
14	2.8	1.111782353	7.411882352	30.53843767	23.205	75.98620549
15	3.3	1.206973488	8.046489918	39.07335272	30.735	78.659746
16	3.7	1.27803169	8.520211265	46.38871624	37.021	79.80604552
17	4.5	1.409441379	9.396275858	62.21978966	49.144	78.98451645
18	5	1.485681662	9.904544412	72.87268551	58.432	80.18367869
19	7	1.757882249	11.71921499	120.713774	96.905	80.27667165
20	9	1.993251113	13.28834075	175.9841408	142.43	80.93342921

Table 5.2.1: Representation of laboratory based experimental data 1.

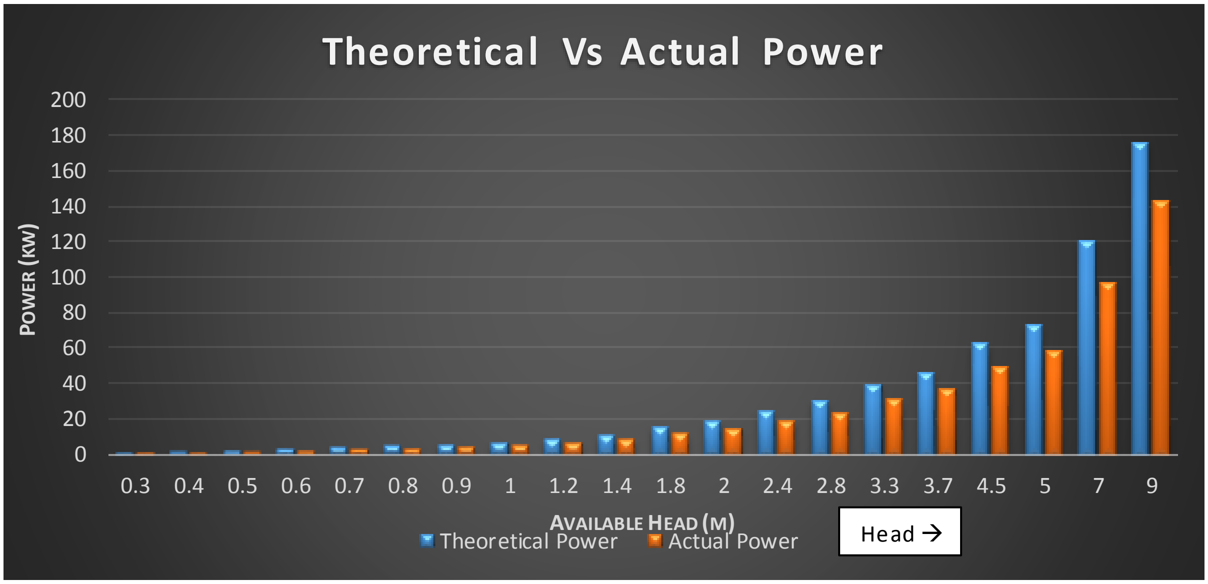


Figure 5.2.1: Graphical analysis of power obtained Theoretically Vs Actual Value from Crossflow Turbine.

Above analysis is done by using the power generation formula:

$$P=\rho Qgh \qquad \ldots. \qquad (1)$$

Where; P = power (Kilowatt)

Q = Discharge (m^3/s)

g = gravitational acceleration (9.81 m/s^2)
h = available head (m)

The theoretical power is calculated assuming there are no losses in the system during the conversion of kinetic energy from water to electrical energy, but in the actual power calculation the losses due to shaft, turbine blade design, generator is considered which reduced the output as compared with the ideal case scenario.

The case situation for vortex was used for the study to impart the continuous circular flow of water across the blades such that maximum energy of the water due to its kinetic motion is transferred to the generator. As the outlet was designed to be of optimum shape &dimension i.e. of 200mm in a Chamber dimension of 800mm, the time duration for the water stream to remain in the vortex condition was ideal. The nature of the flow was categorized as turbulent in nature.

As for the prolonged scenario of the water to remain in the spiral flow condition the blades of the turbine continued to be in rotatory motion even when the flow fluctuated giving a constant output to be measured.

The flowing graphical analysis was done using Crossflow turbine setup in the laboratory and the results obtained were analyzed and presented below:

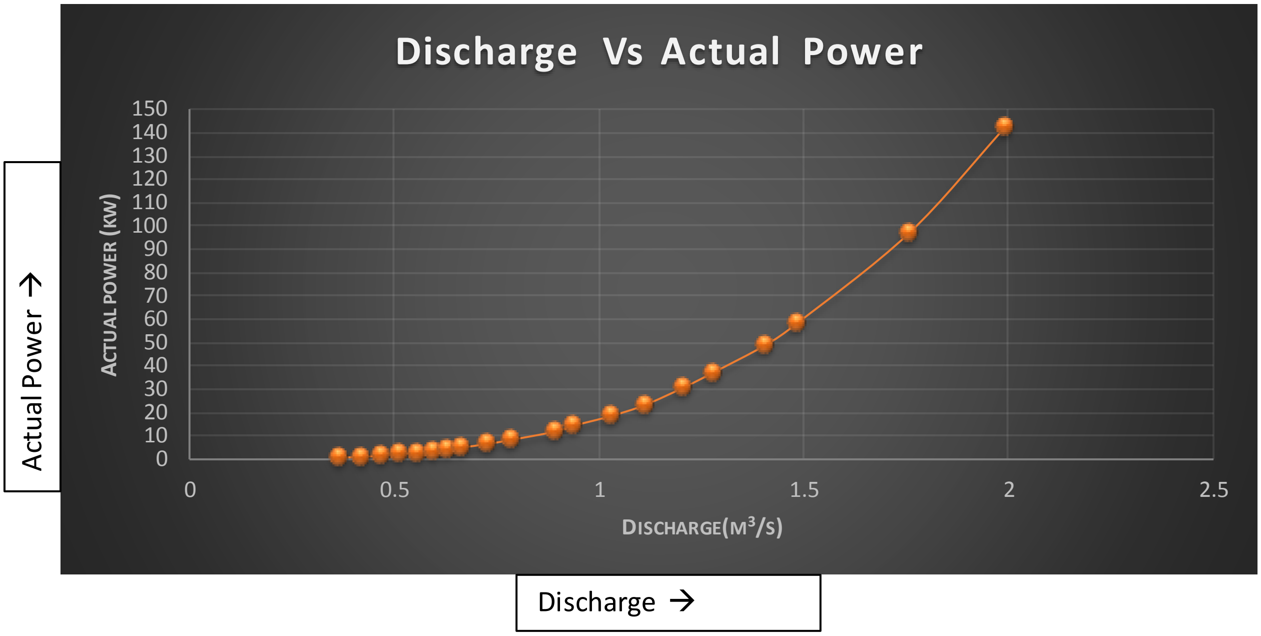


Figure 5.2.2: Graphical analysis of Actual power obtained on different discharge value from Crossflow Turbine.

The above representation depicts the variation of output power obtained after change in the discharge across the vortex section as well as the intake canal, proving the power increases in large values at range of 1 to 1.5 m^3/s of discharge value.

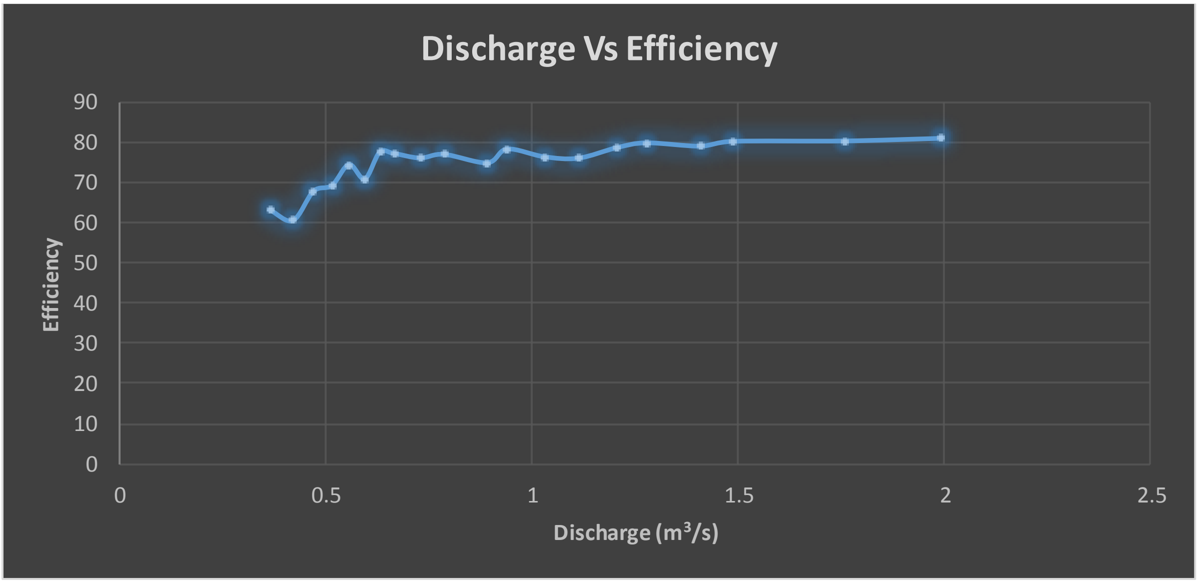


Figure 5.2.3: Graphical analysis of Efficiency obtained on different discharge values from Crossflow Turbine.

The efficiency of the Crossflow turbine varied vastly in the initial range of heads. It tends to normalize and stay within a fluctuating range of 70-80 % depending upon the condition of the flow impacting the installed blades. The cross flow turbine used in this setup was pre-fabricated material built using water cooler blades and exhaust blades. The data represented is a raw form but within the validation rages of the previous researches done in the field.

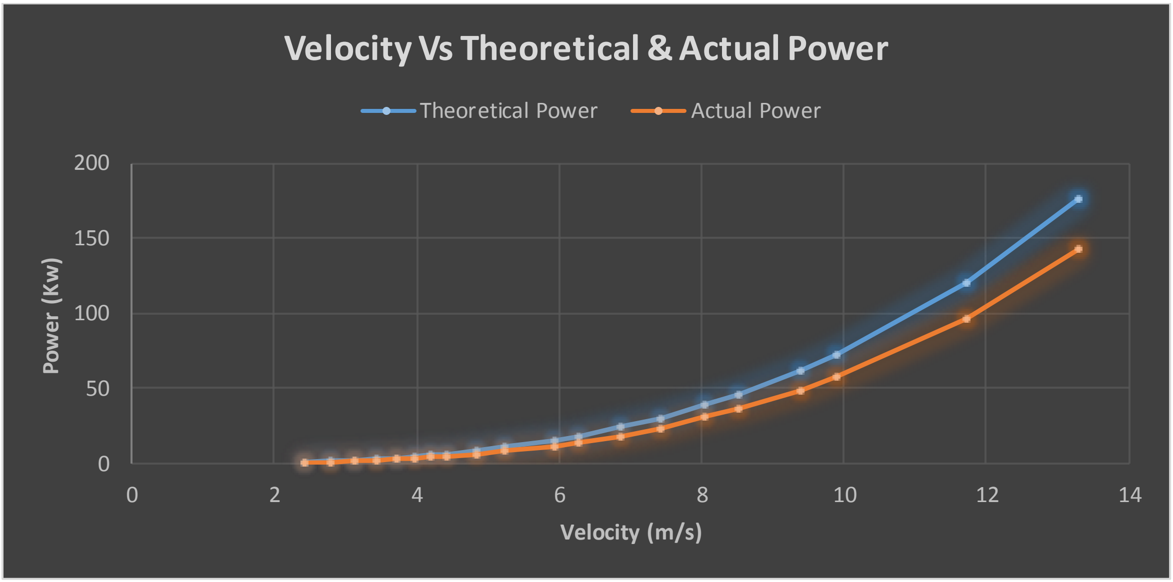


Figure 5.2.4: Graphical analysis of power output's as per the flow velocity across Crossflow Turbine.

The velocity study is one of the dormant parameter in this study as the flow across the intake channel and that to the vortex chamber determines the power output. The vortex will me much efficient if the velocity with which the flow enters the chamber has kinetic potential in it. The losses will be there relative to the nature of the channel and type of flow across the channel. The condition to reutilize the velocity by creating a vortex will, in term help in imparting kinetic energy to the blades and transforming that into electrical.

Without the vortex flow this energy is used once and isn't completely utilized. But with the vortex flow, which will give a natural circular pattern to the flow it will help in re-using this energy to create more electrical output.

Above graphical output depicts that the actual power obtained through the experiment gave the idea that as the head increased the difference in power output jumped vastly. The Similar graphical analysis is obtained for 2 more vastly used turbines, which will be mentioned further in the result discussion.

- KAPLAN TURBINE:

S.No.	Head	Discharge	Velocity	Power Theoretical (kW)	Power Actual	Efficiency
1	0.3	0.363916199	2.426107994	1.071005374	0.67	62.55804277
2	0.4	0.420214231	2.801428207	1.648920643	1.08	65.49739096
3	0.5	0.469813793	3.132091953	2.304436654	1.62	70.2991769
4	0.6	0.514655224	3.431034829	3.029260651	2.223	73.3842431
5	0.7	0.555891176	3.705941176	3.817304708	2.86	74.92197292
6	0.8	0.594272665	3.961817765	4.663851873	3.27	70.11371908
7	0.9	0.630321347	4.202142311	5.565107169	4.28	76.9077732
8	1	0.664417038	4.429446918	6.51793114	5.06	77.63199536
9	1.2	0.727832398	4.852215989	8.568042993	6.77	79.01454283
10	1.4	0.786148841	5.240992272	10.79696818	8.39	77.70699941
11	1.8	0.891408997	5.942726647	15.74050007	11.37	72.23404561
12	2	0.939627586	6.264183905	18.43549323	13.665	74.12332194
13	2.4	1.029310449	6.862069659	24.23408521	18.507	76.36764434
14	2.8	1.111782353	7.411882352	30.53843767	23.95	78.425754
15	3.3	1.206973488	8.046489918	39.07335272	30.298	77.54133672
16	3.7	1.27803169	8.520211265	46.38871624	38.367	82.7076132
17	4.5	1.409441379	9.396275858	62.21978966	51.286	82.42715104
18	5	1.485681662	9.904544412	72.87268551	60.293	82.73744762
19	7	1.757882249	11.71921499	120.713774	99.97	82.81573567
20	9	1.993251113	13.28834075	175.9841408	145.369	82.60346606

Table 5.2.2: Representation of laboratory based experimental data 2.

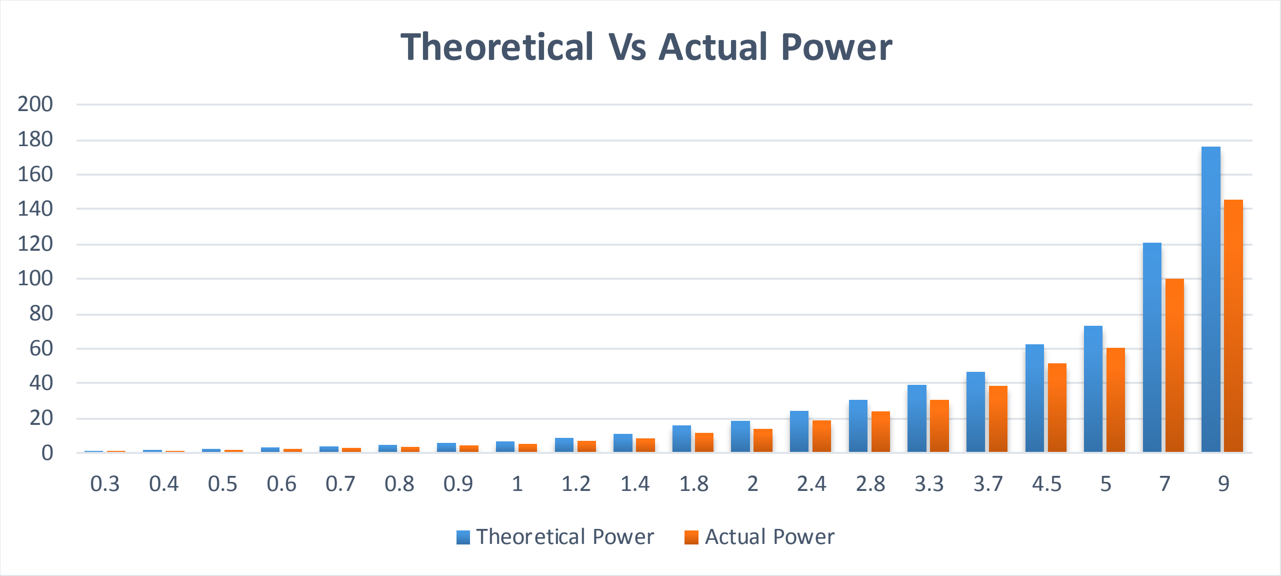


Figure 5.2.5: Graphical analysis of power obtained Theoretically Vs Actual Value from Kaplan Turbine.

As compared to the cross flow turbine the theoretical power obtained as per the standard formula (1) mentioned previously remained same but the actual power obtained across the vortex flow section reduced considerable in the initial head ranging from 0.3 m to 2.4 meter giving efficiency below 50%. Further the data range from 2.8 m to 9 m showed the efficiency of the turbine in term of power output to be in the range of that obtained by the cross flow turbine.

The analysis proved that where a possible head of 3m or above is available the setup can be done using the Kaplan blade turbine. Although the design criteria for the blade design will have a significant impact on the power output, which required a further study.

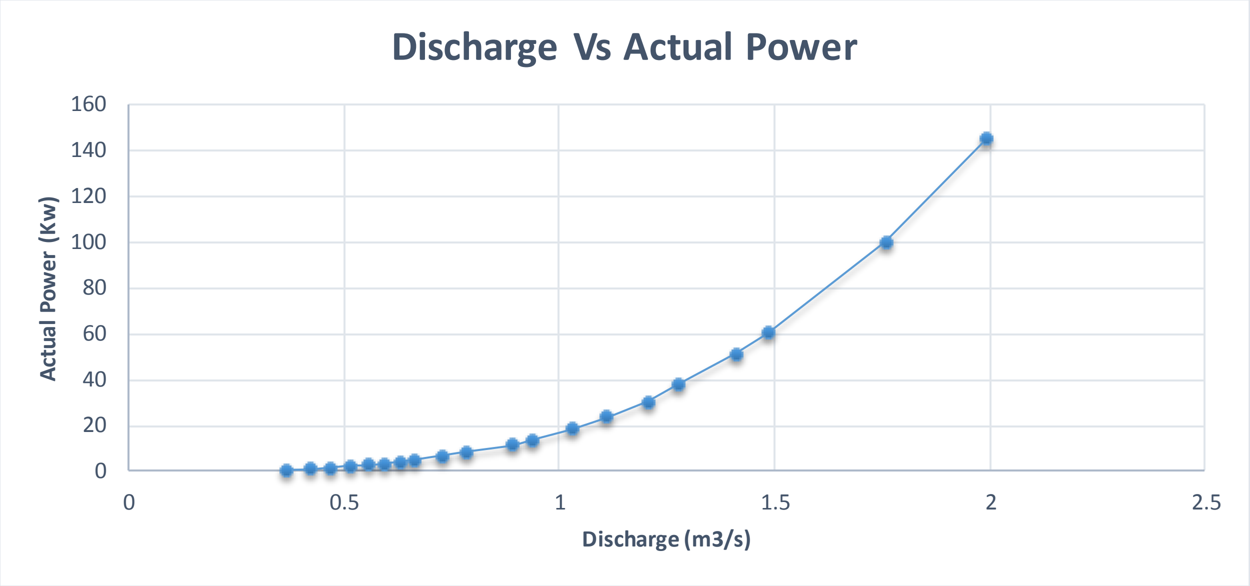


Figure 5.2.6: Graphical analysis of Actual power obtained on different discharge value from Kaplan Turbine.

The value of actual discharge obtained from the Kaplan turbine ranged from 0.67 to 145 KW output based on the vortex flow condition. The power obtained was sufficient to power the basic facilities needed by the rural population. The graph had an exponential increase with the subsequent non uniform increase in discharge values. Having higher jumps in power output starting from 1m^3/s to 2 m^3/s. the maximum was obtained to reach 145KW.

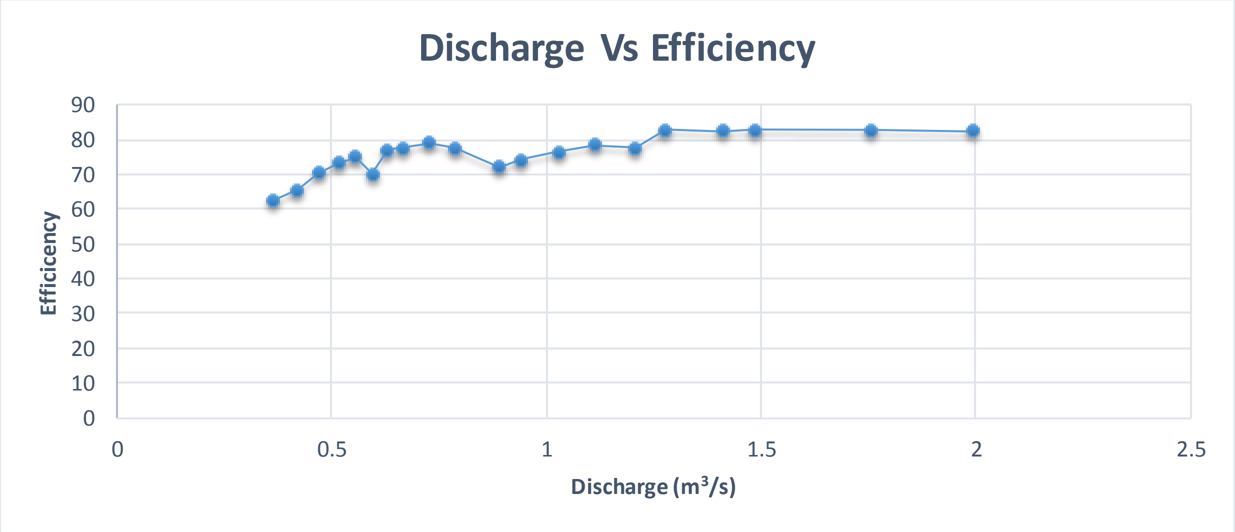


Figure 5.2.7: Graphical analysis of Efficiency obtained on different discharge values from Kaplan Turbine.

The maximum efficiency obtained on the use of Kaplan turbine was about 82 % at the highest head of 9 meters. The efficiency in the lower ranges fluctuated rapidly increasing and decreasing with the flow across the intake canal and vortex chamber but tends to stabilize in the mediocre range having discharge values between 0.89 m^3/s to 1.27 m^3/s.

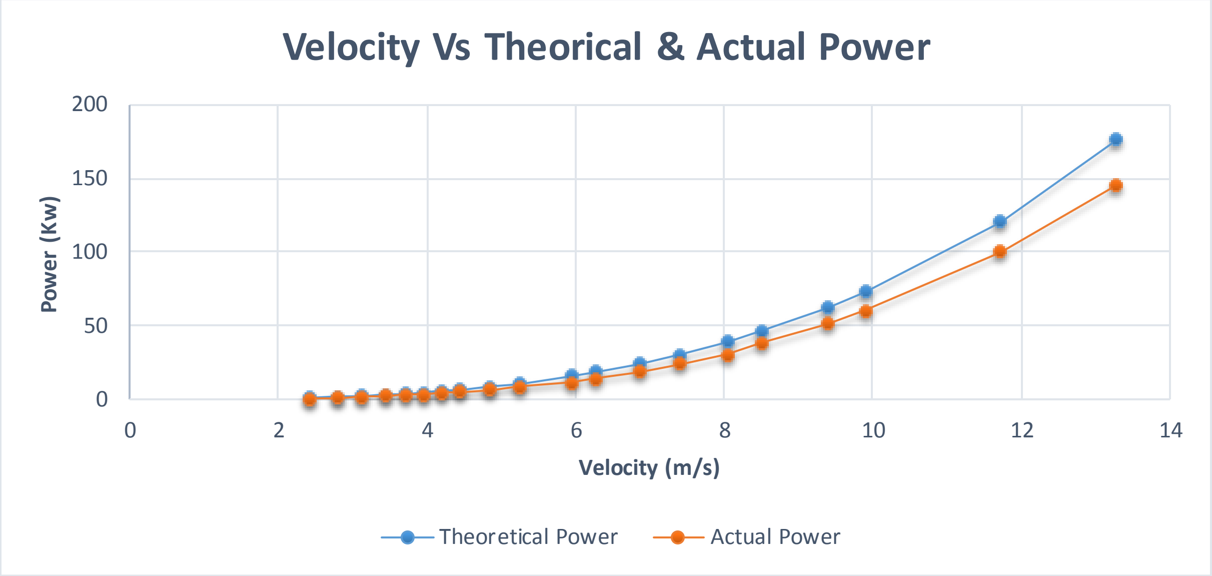


Figure 5.2.8: Graphical analysis of power output's as per the flow velocity across Kaplan Turbine.

The variation of velocity had a direct relation to the power output (theoretical & actual), as the channel section is made to be rigid and the vortex chamber was within a confined dimension of initial design based on previous work done in this field of research. As the velocity increased the power output increased due to increased flow across the vortex section imparting direct kinetic energy to the blades of the turbine. As per the design of the Kaplan turbine blades which were made of fiber the curved surface of the blade design made for smooth motion and less viscosity due to motion in water helped in better efficiency. The surface area of the blades were in direct contact with the flowing water and as the velocity increased depending upon the discharge variation the motion of vortex changed and lead to the above mentioned output profile which was increasing exponentially.

- FRANCIS TURBINE:

S.No.	Head	Discharge	Velocity	Power Theoretical (kW)	Power Actual	Efficiency
1	0.3	0.363916199	2.426107994	1.071005374	0.34	31.74587245
2	0.4	0.420214231	2.801428207	1.648920643	0.65	39.41972604
3	0.5	0.469813793	3.132091953	2.304436654	1.08	46.86611793
4	0.6	0.514655224	3.431034829	3.029260651	1.98	65.36248373
5	0.7	0.555891176	3.705941176	3.817304708	2.03	53.17888288
6	0.8	0.594272665	3.961817765	4.663851873	3.36	72.04345446
7	0.9	0.630321347	4.202142311	5.565107169	4.02	72.23580567
8	1	0.664417038	4.429446918	6.51793114	4.68	71.80192456
9	1.2	0.727832398	4.852215989	8.568042993	5.98	69.79423429
10	1.4	0.786148841	5.240992272	10.79696818	8.03	74.37273006
11	1.8	0.891408997	5.942726647	15.74050007	11.48	72.93287983
12	2	0.939627586	6.264183905	18.43549323	13.743	74.54641883
13	2.4	1.029310449	6.862069659	24.23408521	18.31	75.55473971
14	2.8	1.111782353	7.411882352	30.53843767	23.2	75.96983268
15	3.3	1.206973488	8.046489918	39.07335272	29.24	74.83360901
16	3.7	1.27803169	8.520211265	46.38871624	33.48	72.1727237
17	4.5	1.409441379	9.396275858	62.21978966	46.88	75.34580276
18	5	1.485681662	9.904544412	72.87268551	54.02	74.129284
19	7	1.757882249	11.71921499	120.713774	90.05	74.59794935
20	9	1.993251113	13.28834075	175.9841408	133.49	75.853426

Table 5.2.3: Representation of laboratory based experimental data 3

.

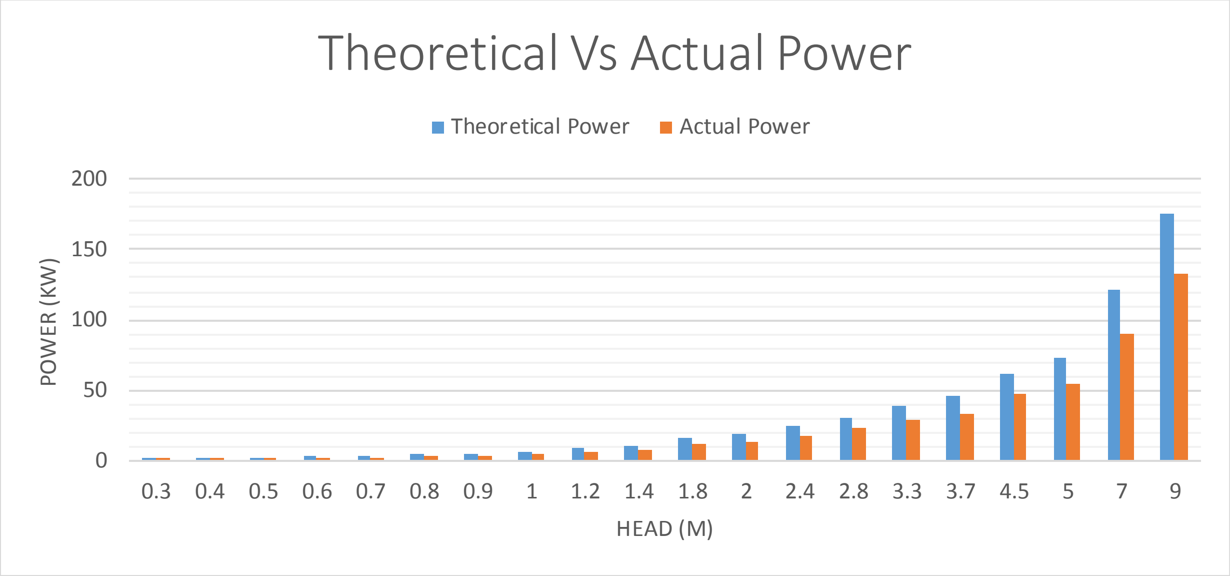


Figure 5.2.9: Graphical analysis of power obtained Theoretically Vs Actual Value from Francis Turbine.

The application of Francis turbine for SSHP's is not feasible as the output generated has subsequent losses and provides lesser power than the other sibling turbines (i.e. cross flow and Kaplan). In the initial range of heads the power output is considerable very low to be useful for anything and higher head availability is very rare in SSHP locations. But at certain location, head and slope the application for Francis turbine could be feasible and utilized for future extension of the SSHP based on its potential to generate energy.

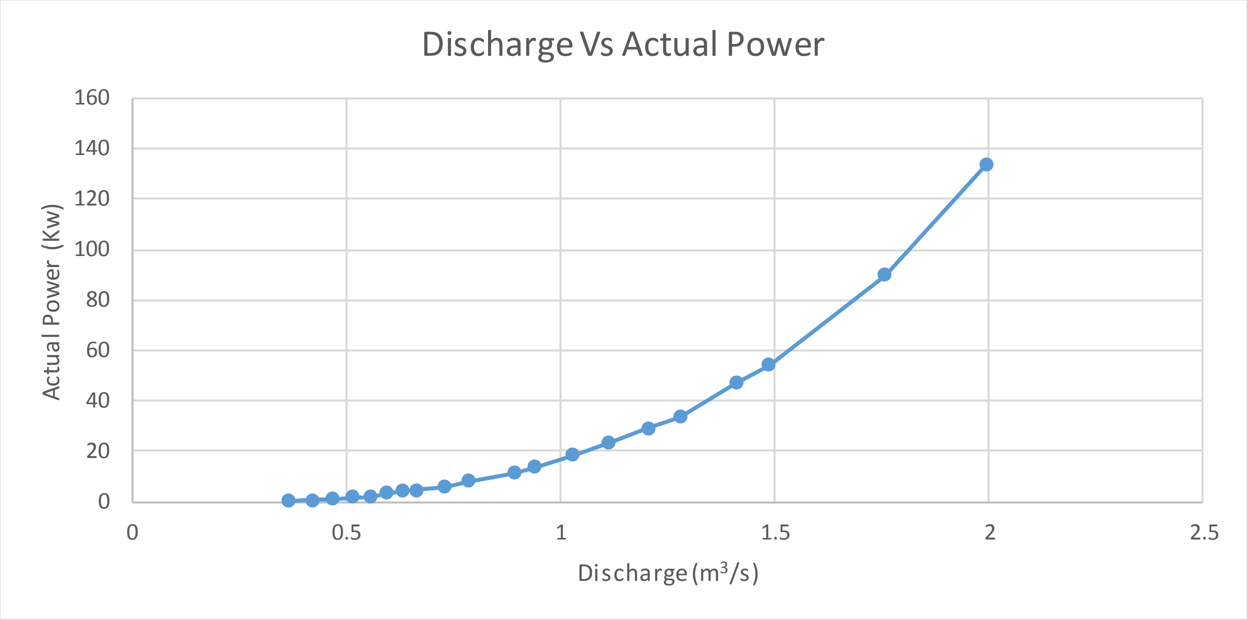


Figure 5.2.10: Graphical analysis of Actual power obtained on different discharge value from Francis Turbine.

Exponential growth of power was seen at higher discharge scale, but as compared to cross flow and Kaplan turbine it was lesser in value. Hence opting for this type of turbine is not feasible for the studied flow parameter. As the turbine is classified as medium head turbine and has better working efficiency in the range of 40 to 150 m. it could been used at location having potential for storage and not on the run of river model type SSHP.

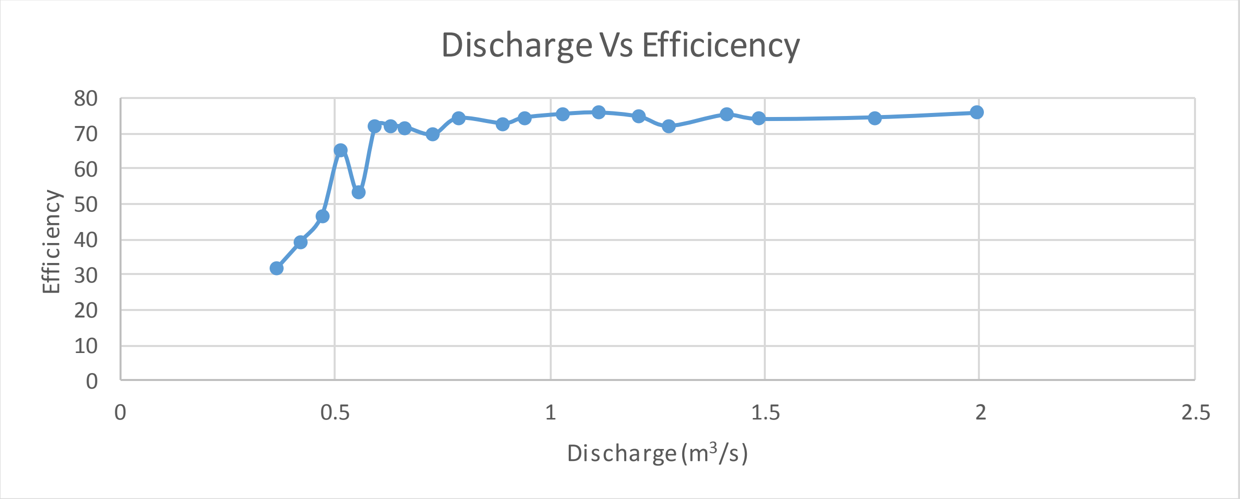


Figure 5.2.11: Graphical analysis of Efficiency obtained on different discharge values from Kaplan Turbine.

The graphical analysis showed large variation in the efficiency chart of the turbine with maximum efficiency barely reaching 75%. This was lower than what was achieved in the past test with the other 2 turbines and got to the conclusion that Francis can only be used in the location where large heads with respect to SSHP i.e. 8 m or above is available. Which as per the current study parameter is not widely available. Certain location have promising heads within their vicinity to support the energy demand of the neighboring village's or populations but these are very few in number.

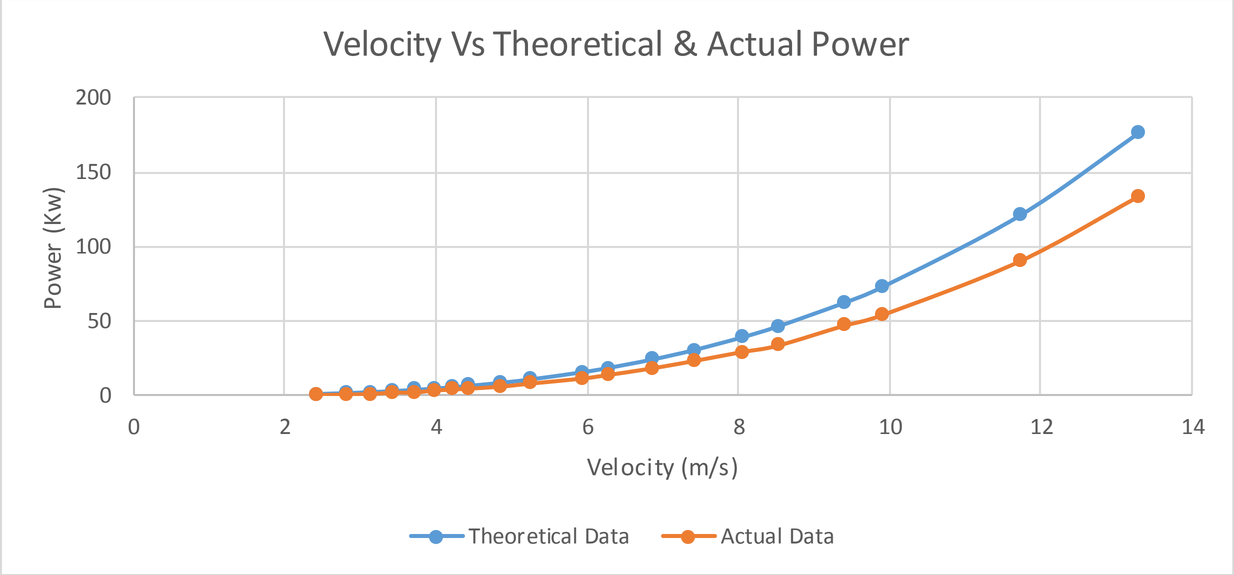


Figure 5.2.12: Graphical analysis of power output's as per the flow velocity across Francis Turbine.

The general idea after the analysis of the above graph lead to the conclusion that in comparison to the previous graphs represented in Fig. 5.2.8 and Fig. 5.2.4, the actual power output of the Francis turbine was way lesser than previous turbine taken into study. Hence isn't suitable for operation for SSHP's having head up to 9 m.

Finally a comparative graphical analysis describing the power output with their respective heads for all the 3 turbines are represented for conclusion and validation of the data related to previous studies of the similar research ideas.

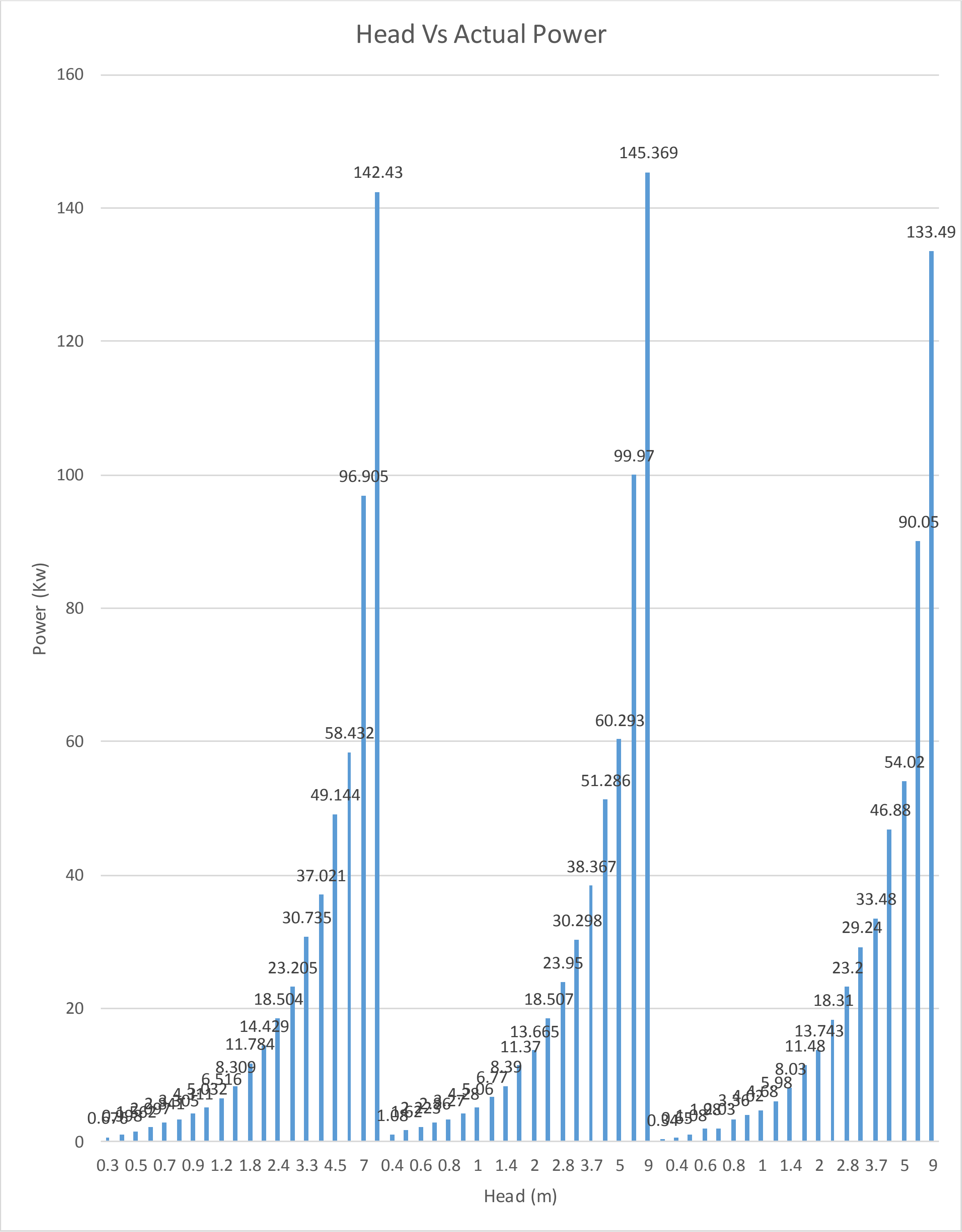


Figure 5.2.13: Graphical representation of Power Output Vs Available Head for SSHP's.

Chapter 6

Conclusion & Future Work

6.1 Conclusion

Finally the conclusion of the study undertaken, lead to the result that the Intake angle for the canal which will be bifurcated from the main river stream should hold an angle of 30° w.r.t the bank of the river. This conclusion was based on the CFD analysis of the system done on ANSYS (FLUENT) software.

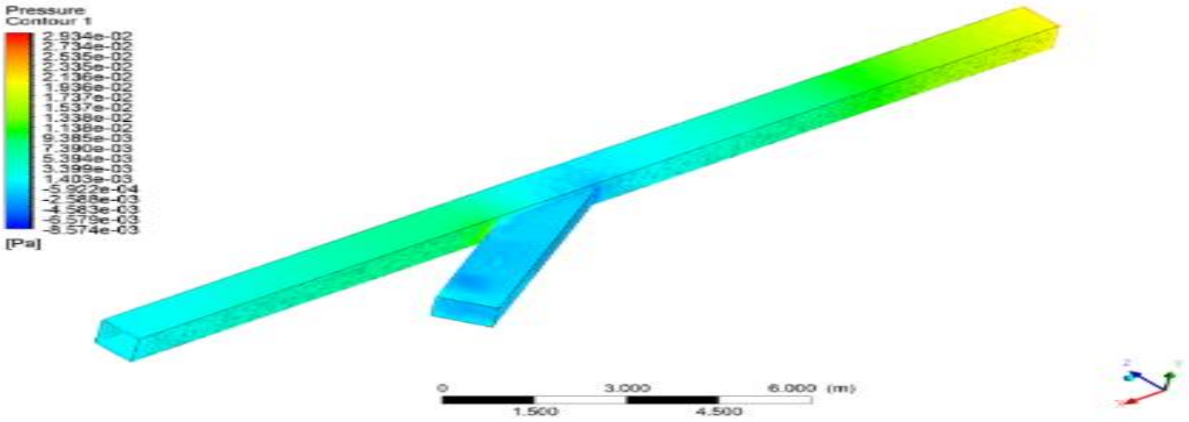


Figure 6.1.1: ANSYS CFD analysis of Intake canal bifurcating from main canal having angle =30°.

Further the designing criteria for individual locations should be assessed as per the terrain profile and available slope, such that adequate flow should pass through the vortex chamber and make sufficient energy output.

The data represented in the study is purely experimental in nature and is conducted in Hydraulics and Fluid Mechanics lab, with laboratory grade turbine setup which gives a close idea of the Small Scale Hydro-power Plant system. The analysis of data represented above lead to the staging of result such as mentioned below:

Turbine Type	Head Range (m)
Cross Flow	0.3 to 3.30
Kaplan	3.31 to 9.0

The CFD analysis validated the theoretical velocity obtained through the standard formula for open channel flow (manning's equation). The analysis for CFD ANSYS (fluent) was done with the Naiver-Stokes equation, with the 3 conservative equations to be analyzed by the software simultaneously at all the nodes selected in the geometry of the system constructed in the software.

The 3 conservative equation were as follows:

1. Conservation of mass
2. Conservation of momentum
3. Conservation of energy

Further to add the application of Geographic Information System to create portals such as BHUVAN helped in delineation of the topographical terrain of multiple location giving a basic idea of the terrain profile, water bodies within the vicinity, location of residential/ human population from the source. The geo location for setup of SSHP's were relied on the data obtained from these analysis of the different terrains. Further calculation of slope and head availability was also determined using the available data across the selected linear terrain profile.

The study revealed that even in a plain terrain there is certain sources for energy production such that it could meet with the local demands of the rural isolated population, for which transportation of electricity from centralized grid isn't feasible nor economical. As per the current growth in the energy demand and its use across the present population, i.e. the demand is increasing and this decentralized approach could be used to meet with a certain section of the demand for these isolated regions.

The future relies on energy, as everything is based on electrical energy nowadays and to create an environment to cope up with the demand of the future, these individual system based on the pre analysis of DEM of location, the available head , the capacity to generate electricity and the required demand could be the solution to it.

6.2 Related Work

The Vortex flow SSHP's aims at providing decentralized level of electricity to isolated and rural users in the distant population. Very little work has been done on Vortex flow with terrain topology through DEM network. Most of the previous work has been on reducing end-to-end demand of electricity with different needs and designing strategies.

6.3 Future Work

Future study involves installation of different SSHP's in serial or parallel mode, with in depth study of the vortex flow. Study with different vertical axis turbines and Archimedes screw can be done such that comparison could be done for better efficiency at different locations. Further a decentralized storage and micro grid setup for the transfer of power from the SSHP's source to local consumers could be analyzed and designed. Refining of technological aspects about the design of turbine blades and their behavior in vortex flow could be studied in detail.

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