International Journal of Innovations in Science & Technology

Vortex Powerplant Implementation in A Coastal Community

Muzammil Anayat[1], Sajjad Miran[1*], Nazam Siddique[2], Waseem Arif[1], Yasir Hussain[1], Atta ul Hassnain[1]

[1]Department of Mechanical Engineering, University of Gujrat, Pakistan.

[1]Department of Electrical Engineering, University of Gujrat, Pakistan.

*** Correspondence:** Sajjad.miran@uog.edu.pk

Citation | Anayat. M, Miran. S, Siddique. N, Arif. W, Hussain. Y, Hassnain. A, "Vortex Powerplant Implementation in A Coastal Community", IJIST, Special Issue. pp 220-235, March 2025

Received | Feb 23, 2025 **Revised |** March 07, 2025 **Accepted |** March 13, 2025 **Published |** March 16, 2025.

A gravitational water vortex power plant is an eco-friendly device that generates electricity from renewable energy sources. In this system, a turbine extracts energy from the vortex created by tangentially channeling water into a circular basin. This article aims to explore the feasibility of implementing vortex power plant technology in coastal communities using an experimental model. The study investigates the potential of wastewater as a renewable energy resource by analyzing the relationship between flow rate, torque, and efficiency under different material and pipe configurations, particularly in urban areas. For experimental purposes, Gujrat city was selected. The wastewater outlet points near Bolley Bridge discharge approximately 74,714,000 liters per day. Based on our survey, the average household water usage in Gujrat city is 500 liters per day. An experimental model was designed to estimate potential energy generation. The model's design focused on optimizing the basin shape, inlets, outlets, and turbine configuration.

Using different pipes (cast iron and steel), the average water velocity and discharge rates were evaluated. The steel pipe produced higher velocity. Efficiency and production were further analyzed using LED lights, revealing that at 60 RPM, the system achieved significant efficiency and output voltage.

Keywords: GWVPP (Gravitational Water Vortex Power Plant), EFT (Eco-Friendly Technology), Hydropower, Wastewater, Turbine.

Introduction:

The increasing global demand for sustainable and decentralized energy solutions has driven significant interest in renewable energy technologies that utilize naturally available resources. Traditional energy sources, such as fossil fuels and grid-based electricity, not only contribute to carbon emissions and environmental degradation but also pose challenges in cost and accessibility, particularly for coastal and urban communities with limited infrastructure for large-scale renewable energy deployment. In response to these challenges, Gravitational Water Vortex Power Plants (GWVPPs) have emerged as a promising alternative, offering a low-maintenance, environmentally friendly method for small-scale power generation. While most studies have focused on implementing GWVPPs in natural streams and rural hydropower projects, the potential for harnessing urban wastewater discharge as a renewable energy source remains largely unexplored. The growing global emphasis on sustainable energy solutions has led to the exploration of innovative technologies that balance efficiency and environmental conservation. Among these, Gravitational Water Vortex Power plants (GWVPs), as shown in Figure 1, have emerged as a promising method for generating energy from low-head water flows. Unlike conventional hydropower systems, which often require large infrastructure and cause environmental disruption, GWVPs offer a low-impact alternative.

A typical GWVP system consists of an inlet channel to guide water, a circular basin where the water circulation forms a vortex that converts kinetic energy into mechanical energy, a water outlet or discharge point at the base, and turbine blades connected to a shaft. This shaft drives the generator, enabling the conversion of mechanical energy into electrical energy. GWVPPs operate by directing water through a specially designed basin to create a stable vortex, which drives a turbine connected to a generator. Unlike conventional hydropower plants, which require significant elevation differences and large water flow rates, vortex power plants function efficiently in low-head water environments, making them suitable for urban wastewater applications. Several studies have investigated turbine design, vortex stability, and generator efficiency in rural implementations, demonstrating that GWVPPs can achieve high energy conversion rates with minimal ecological impact [1]. However, limited research has been conducted on optimizing GWVPP systems for wastewater-driven applications, particularly in coastal regions where urban water discharge is abundant.

This study aims to bridge this research gap by evaluating the feasibility of implementing GWVPP technology in an urban wastewater setting, focusing on coastal communities with high discharge volumes. A key aspect of this research is the optimization of basin shape and turbine design to maximize energy extraction efficiency. Additionally, this study compares the performance of different generator configurations, specifically a 12V DC motor and a Permanent Magnet Alternator (PMA), to determine the most effective energy conversion mechanism. The results of this study could contribute to the development of decentralized, small-scale hydropower solutions that integrate seamlessly with existing urban wastewater infrastructure, reducing reliance on traditional power sources while promoting environmental sustainability.

Beyond technical feasibility, this research also explores the economic and practical implications of wastewater-driven GWVPP implementation. By assessing power generation potential, system efficiency, and scalability, this study provides insights into how coastal urban areas can leverage wastewater as a renewable energy source. Furthermore, evaluating the economic viability, return on investment (ROI), and potential policy incentives will help determine whether GWVPP technology can be adopted at a municipal or community level. Ultimately, this research aims to establish a new paradigm for wastewater-based energy solutions, contributing to the broader goal of integrating renewable energy into urban sustainability initiatives.

This study evaluates the eco-friendly nature of vortex power plant technology by comparing it with conventional hydropower systems. It explores ways to enhance the plant's efficiency through the experimental optimization of basin shape, inlet and outlet configurations, and turbine design. Additionally, the study examines the cost-effectiveness and potential scalability of GWVPs for decentralized energy generation.

Objectives of the Study:

The primary objective of this study is to evaluate the feasibility and efficiency of a Gravitational Water Vortex Power Plant (GWVPP) for small-scale renewable energy generation in coastal urban communities. The specific objectives include:

- To design and implement a GWVPP system utilizing wastewater discharge for sustainable and decentralized energy production.
- To analyze the impact of basin shape and turbine design on power generation efficiency, optimizing system performance.
- To compare the effectiveness of different generator configurations (12V DC motor vs. Permanent Magnet Alternator) in improving energy output and efficiency.

Novelty Statement:

The novelty of this study lies in demonstrating the potential for implementing GWVPPs in small-scale urban settings, enabling cities to generate electricity from water outlets. Unlike traditional hydropower plants, this research explores the use of wastewater as a sustainable energy source, presenting an innovative solution for urban energy needs. The study specifically focuses on deploying GWVPPs in coastal communities, where such technology has yet to be widely tested. A key finding is that conical basins are more efficient than cylindrical ones, enhancing basin design for improved performance. Additionally, the study evaluates different pipe materials (cast iron and steel) to assess their impact on water velocity and discharge.

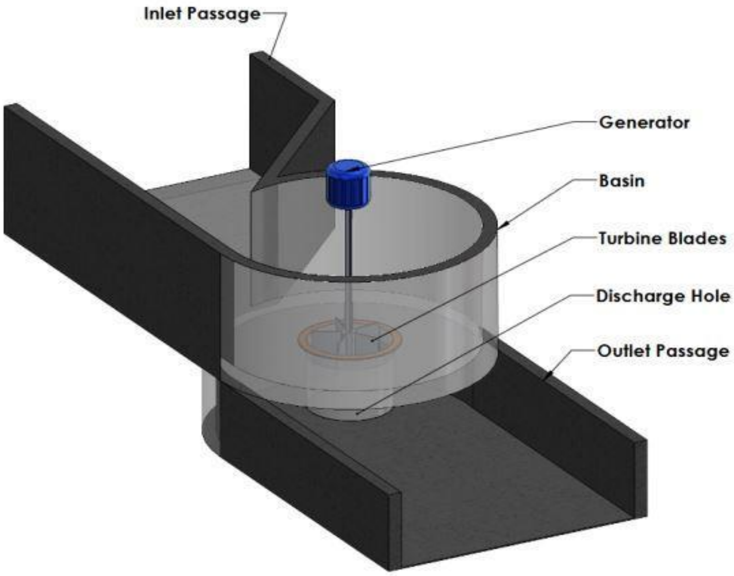

Figure 1. A Sketch of GWVP

Literature Review:

By channeling water into a circular basin, these systems create a vortex that powers turbines to generate electricity [2]. Their scalability, simplicity, and ability to operate in rivers, canals, and other low-gradient water systems make them ideal for decentralized energy production in underserved areas [3]. Coastal regions are especially suitable for adopting GWVP due to their easy access to water sources. These systems are particularly useful in such areas because they are scalable, easy to use, and can function efficiently in various water bodies, including rivers and canals [4]. Coastal areas benefit from steady water flows from rivers and tidal streams, which makes them well-suited for GWVP installation. These regions often face energy shortages and rely heavily on diesel generators or unstable grid connections [5]. GWVPs can help address these issues by reducing dependence on fossil fuels, promoting local energy self-sufficiency, and providing a reliable, renewable, and eco-friendly energy source [6]. Additionally, their compact size and minimal land requirements allow them to be installed in different environments without significantly altering the natural landscape [7].

From an environmental perspective, GWVPs offer significant advantages. They enable unhindered fish migration and prevent water stagnation, which is common in dam-based systems, thereby helping to protect aquatic ecosystems [8]. Moreover, GWVPs produce no carbon emissions during operation, supporting global efforts to combat climate change and transition to renewable energy [9]. These features make GWVPs particularly attractive to developing countries, where the demand for sustainable energy solutions is growing. Despite their benefits, several challenges hinder the widespread adoption of GWVPs. Technical issues, such as managing sediment buildup in the vortex basin and improving turbine efficiency, need to be addressed to enhance performance and reliability [10]. Financial barriers are also significant, as the high upfront costs of turbines and infrastructure can be prohibitive for resource-limited communities. Additionally, the lack of legal frameworks and government incentives often limits large-scale implementation [6].

This study explores the potential of GWVPs for coastal communities by examining their technical feasibility, environmental impact, and economic benefits. By analyzing existing applications and critically evaluating the technology, the research aims to offer valuable insights into GWVPs as a sustainable energy solution.

Comparison between GWVPP and Other Hydropower Plants:

The ultra-low head of the GWVPP ranges between 0.7 and 3 meters, whereas traditional hydropower plants require a large head height of over 10 meters [5]. Unlike conventional plants that depend on dams, GWVPPs can operate without them, allowing factories and cities to construct water outlets instead [1]. Additionally, due to its ultra-low head, the initial setup cost of GWVPP is significantly lower compared to other hydropower facilities [3]. GWVPPs offer flexible design specifications, unlike other plants that demand more specific configurations [4]. While traditional plants often require large, remote areas far from cities, GWVPPs can be installed within city limits [11]. They also need fewer workers and require only moderately skilled staff, unlike conventional plants, which rely on highly experienced and qualified personnel [2]. Moreover, GWVPPs demonstrate high operational efficiency [8].

Methodology:

The research team conducted various field measurements, including assessing the width and topography of the canal and identifying existing structures and suitable locations for building the powerhouse. The proposed project site is located approximately 20 minutes from the University of Gujrat and 15 minutes from Gujrat City. To select the most suitable site, multiple surveys were carried out, and public input was gathered during the process. Community meetings were also held at different times to collect feedback. Additionally, the transmission and distribution routes for the water pipeline were measured to ensure proper planning.

Given the growing energy demand, it is crucial for the government of Pakistan to focus on such low-head, cost-effective hydropower solutions. The study emphasizes the need to raise government awareness about the potential of GWVHP systems to generate electricity at city water outlets. A detailed cost estimate and analysis were prepared for the proposed GWVHP system, considering local labor rates and the availability of construction materials. The plan takes into account both skilled and unskilled labor, ensuring feasibility.

Electromechanical components were priced according to market rates or installer prices to maintain cost-effectiveness. However, the cost of these components may vary depending on market fluctuations over time. Figure 2 illustrates the step-by-step sequence followed in the methodology.

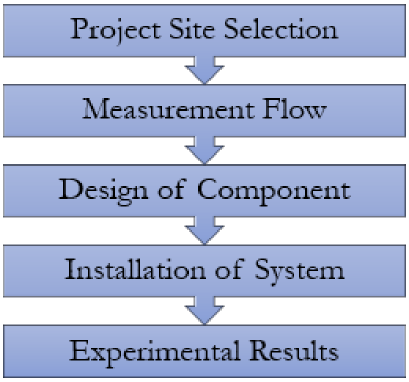

Figure 2. Flow Diagram of Methodology

The proposed project site is located approximately 12 km from the University of Gujrat, a distance that takes around 20 minutes by vehicle. It can also be easily accessed from Gujrat City via an earthen road. The site is situated near a wastewater outlet, where water exits from various points in Gujrat. Most of the city's wastewater flows through the Bollay Bridge stream, the oldest wastewater channel in the area. At Bollay Bridge, water from different city exit points converges, and a well has been drilled to collect the wastewater. A pump is installed in the well to discharge the collected water into the Bollay stream. The diameter of the discharge pipe was measured, and the flow velocity was recorded at 3.3 m/s. Based on these measurements, the design discharge rate was calculated as 61.46 liters per second. Accurate measurement of flow rates is essential for managing wastewater, as fluctuations can significantly impact treatment processes [12].

The proposed Gravitational Water Vortex Power Plant (GWVPP) will not disrupt nearby villages that have water rights, as it requires only a small volume of water. Additionally, during the growing season, the power plant will have no adverse effects on the irrigation system, ensuring that water usage remains unaffected. Since the GWVPP is designed to utilize wastewater as a source of electricity, it can be installed at city outlets. To estimate wastewater availability, data was collected from Gujrat City. The city has 149,428 households, with 87,189 located in urban areas [13] A survey of 50 households revealed that each household uses approximately 500 liters of water per day. The detailed data is summarized in Table 1.

Table 1. Average data for daily houses wastewater

Sr. No	Daily Waste Water	Liter/day
1	Washing and Bathing	150
2	Kitchen Sink	40-50
3	Toilet	50-60
4	Clothing Washing Machine	70
5	Floor Washing	40-50
6	Other uses	120

With an average household size of 4 to 5 people, the wastewater generation per capita per day may vary. This variation depends on several factors, including water conservation practices, household appliances, family size, and climate conditions. The Gravitational Water Vortex Power Plant (GWVPP) represents an innovative approach to energy generation, distinguished by its unique design and minimal civil construction requirements. Its structure and operational principles differ significantly from those of conventional micro-hydropower plants. The intake section plays a crucial role by providing a proper passage for water to flow into the system. This section channels water from the input to the basin, with steel intake walls measuring 3 mm in thickness.

At the outflow of the intake system, a conical basin is connected. Conical basins are preferred over cylindrical ones due to their superior efficiency. The system utilizes water flowing through the intake channel, which enters the basin via a notch in the canal, rotates within the basin's system, and exits through the basin's bottom. Key design parameters for the basin include the canal's length, width, height, and notch dimensions, which must be carefully considered [14]. During system testing, high voltage output and high revolutions per minute (rpm) were observed at the center of the basin, indicating efficient energy generation[15]. This technology is particularly well-suited for applications such as ice-making factories and wastewater outlets in cities, where it can effectively utilize wastewater to produce electricity.

The system's efficiency can be enhanced by increasing the water head from 0.7 meters to 3 meters, which increases the flow rate and power output. Additionally, experiments conducted on peaches demonstrated that the system is suitable for use in food processing and fish farming. The symmetrical blade design ensures that no contact points exist that could harm fish, further enhancing its suitability for aquaculture applications.

Calculations:

Area and Discharge:

The cross-sectional area is the ratio between Discharge and velocity of the fluid.

$$A = Q/v. \qquad (1)$$

After simplifications velocity obtained 3.3 m/s and calculated area is 0.018 m².

The following formula can be used to find the flow rate in m³/s:

$$Q = Av \ (2)$$

Obtained water flows through the circular pipe at a rate of 61.46 L/s. The flow bay and basin were designed to have a flow rate (Q) is 0.06146 m³/s. It has been considered that the flow velocity (V) through the water fore Bay is 3.3 m/s. Let the width and height of the passage be according to design; it will prevent the overflow of the water, and we take a factor of safety as 2.

The height of the canal can be calculated from

$$H = \text{Width} * \text{Safety Factor} \ (3)$$

Governing Equations:

In this experiment with conical basin and single stage turbine used with the discharge of 61,46 L/s as constants in all variations.

To find the best performance to rotor basin and turbine blade shape.

$$\omega = \frac{2\,\pi\,N}{60} \quad (4)$$

ω is the rotational speed of the turbine and it can measure by tachometer apparatus to check the performance based on the load.

$$F = mg \ \ (5)$$

The load value acts as a braking torque, meaning the measured load on the load cell represents the total mass (m) of the turbine. The torque (T) on the turbine is determined using the force measured by the load cell, which is generated by the rope brake system. This system produces the total mass acting on the turbine, allowing for an accurate calculation of the applied force. The power output of the system can be expressed as:

$$P_{in} = \rho g Q H \ (6)$$

Water flows into the basin with specific discharge formed vortex by rotationally movement at certain height ρ is fluid density, g is the gravitational acceleration, Q is the flow rate, and H is the effective water head.

$$P_m = T\omega \ (7)$$

The mechanical power of the turbine (Pm) is the power generated by the rotation of the shaft, which depends on the applied torque and rotational speed. In this context, **T** represents the torque (N·m), and **ω** denotes the angular velocity (rad/s). The basin, shown in *Figure 3*, consists of a rotating system installed in areas that are not prone to flooding and can be managed throughout the year. The structure of the rotational tank system can be constructed using concrete. The dimensions of the concrete basin are specifically designed to meet the hydropower system's head drop and flow rate requirements. The basin of the Gravitational Water Vortex Power Plant (GWVPP) is appropriately sized to ensure both an optimal head drop and efficient vortex flow into the hydropower plant. Additionally, the rotational system is designed to be waterproof, which protects it from water pressure and the impact load of water entering the basin. This feature enhances its durability and effectiveness in practical applications.

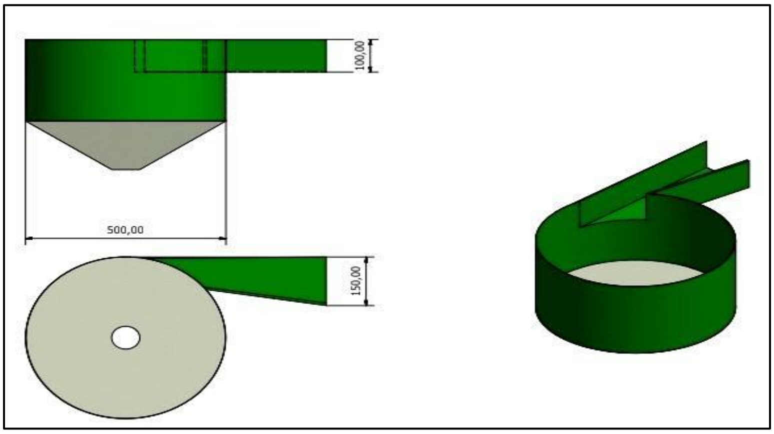

Figure 3. Basin Design

The proposed conical design, shown in *Figure 4*, forms the basis of the basin's structure due to its higher efficiency [7]. The top of the basin has a diameter of 400 mm. According to previous research, the optimal cylindrical basin diameter for maximizing power production should be between 14% and 18% of the system's key parameters [16]. The bottom diameter of the basin is 60 mm, while the height of its conical section is 225 mm. The total height of the basin is 400 mm. Based on these findings; the conical basin was designed to enhance performance. The cylindrical portion of the basin has a diameter of 500 mm, with an exit hole diameter of 60 mm. Additionally, our research suggests that the optimal cone angle for maximum efficiency is within a specific degree range, based on experimental analysis.

Mechanical Components:

This technology requires fewer mechanical components compared to conventional systems, such as screw turbines, contributing to its simplified design and lower maintenance needs.

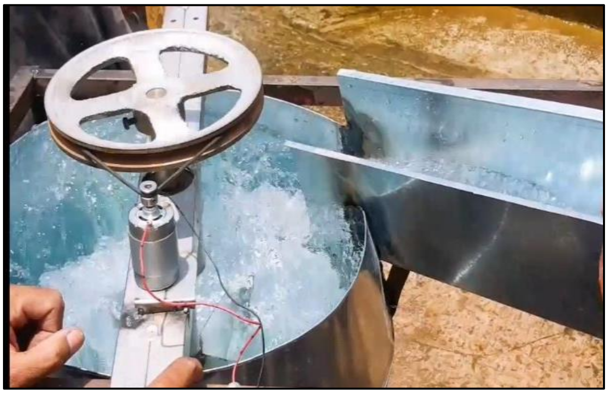

Figure 4. Gravitational water vortex Model

Flow Regulating Gates: The structure includes two proposed gates. One gate is located at the turbine's intake section to regulate water flow during maintenance. The second gate controls the bypass flow in the stream.

Turbine Runner: The turbine runner (Figure 5) was designed as part of the project conducted at the University of Gujrat, Hafiz Hayat campus, in the Department of Mechanical Engineering. The design was based on the following parameters:

- Inner and outer diameter of the basin
- Height
- Inlet and outlet blade angles
- Tapered angle
- Number of blades: 4
- Impact angle

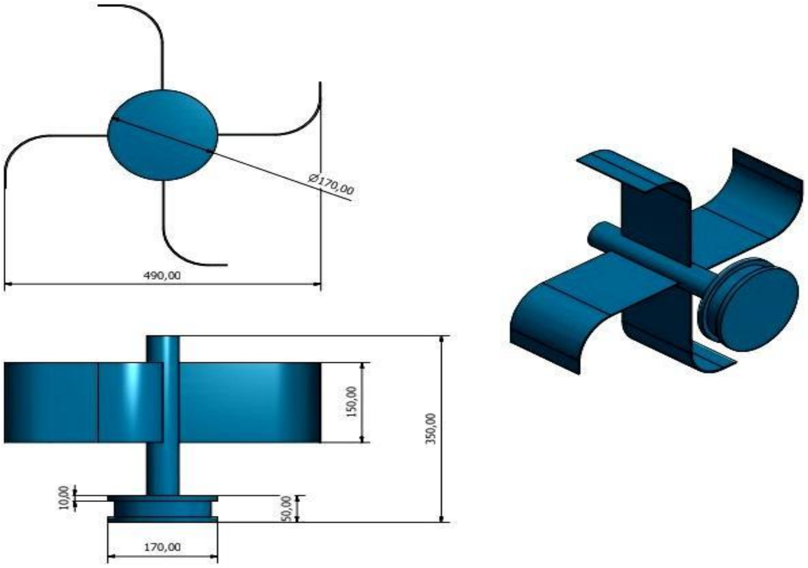

Figure 5. Turbine Runner

Material and Shape of Turbine Blades:

1. Steel (Curved)
2. Cast Iron (Curved)

Specifications of the Proposed Turbine:

- **Type:** Gravitational Water Vortex
- **Motor-to-Turbine Speed Ratio:** 1:25 (RPM)

Electrical Components:

Power Transmission and Drive System:

Mechanical energy is transferred from the turbine shaft to the generator's rotor through a rope drive system, as shown in Figure 6. The rated speeds for the DC motor and turbine are 1440 rpm and 60 rpm, respectively, requiring a speed ratio of 1:24. To achieve this, pulleys and a planetary rope system are recommended. Additionally, a self-lubricating mechanism is used to reduce wear and prevent fatigue.

Control and Protection System: Overvoltage, undervoltage, over frequency, underfrequency, and overcurrent relays are used to protect the system from unfavorable conditions. Before powering on the system, all electrical components must be thoroughly inspected.

Figure 6. Rope Drive System

Transmission and Distribution: The distance between the load and the power source determines the length of the distribution lines. The gravitational water vortex power plant generates 9.5 V, which is monitored using a voltmeter. The distribution details are presented in Table 2.

Table 2. Generator Specifications

Transmission/Distribution	Capacity
Motor	12 V
Permanent Magnate Alternator	200W to 300W at 60 RPM
Capacitor	25 microfarads
Voltmeter	16 V
Connector 2 LED	length 3 m

Power calculation formula:

$$Power_{in} = V \, x \, I \quad (8)$$

12V-DC Motor: The motor's output power can be evaluated by supplying input to the system. A 12V motor with a 2A current (producing 24W) was used, and an effective output power of 18W was obtained, resulting in a motor efficiency of 75%. Due to heat and friction, the motor experiences a power loss of 6W. The turbine's efficiency was measured at 5.59%. Table 3 provides a breakdown of the 6W power loss across various stages of the Gravitational Water Vortex Power Plant (GWVPP). These losses occur due to factors such as hydraulic inefficiencies, mechanical friction, electrical resistance, and transmission losses, as detailed in Table 3.

Permanent Magnetic Alternator:

In our experimental model, the turbine pulley had a diameter of 12 inches, while the motor pulley measured 0.5 inches. This created a speed ratio of 1:24, indicating a significant speed mismatch, which led to power transmission losses. As shown in Table 2, the permanent magnet alternator produced between 160W and 200W, demonstrating that the efficiency of the Vortex Power Plant increased from 5.59% to 55.19%.

Estimation of Work Volume:

The estimated amounts were based on the selected site area. A low work volume was used since this project was designed for demonstration purposes.

Results and Discussions:

The primary focus of this power plant is its potential implementation in urban areas, with Gujrat city selected as a case study. However, performance evaluations are also necessary to analyze the plant's overall efficiency. Hydraulic efficiency was measured to assess the Vortex Power Plant's performance, and graphs were used to show the relationship between torque and hydraulic head. The hydraulic head represents the available power at different flow rates, while torque at various rotational speeds reflects the extracted power.

During the experiment, it was observed that a lower head of 0.7 meters resulted in higher efficiency compared to a 3-meter head, as mechanical losses were proportionally smaller at lower head levels. Fluid velocity was also examined using three different types of pipes: cast iron, steel grade XS, and steel grade SSX. Each pipe had a diameter of 2 inches, and the discharge rate (Q) was 61.47 L/s. It was found that velocity was higher in steel pipes of types Schedule 40 and Schedule 80.

Table 3. Breakdown of Power Losses in each stage

Stage	Cause of Loss	Estimated Loss (W)
Hydraulic Losses	Energy dissipation due to turbulence in water vortex. Frictional losses in water flow through the conical basin and inlet.	1.2W
Turbine Efficiency Losses	Imperfect blade angle reducing energy conservation. Friction between water and turbine blades.	1.0W
Mechanical Friction Losses	Friction between turbine shaft and bearing. Energy losses due to misalignment or wear in moving parts.	0.8W
Generator Losses	Heat dissipation in permanent magnet alternator (PMA) windings. Resistance in electrical windings reducing output efficiency.	1.2W
Transmission Losses	Power loss due to speed mismatch between turbine and generator. Losses in belt/pulley system transferring mechanical energy.	1.0W
Electrical Losses	Initial resistance in 12V DC motor and wiring. Power loss due to impedance in electrical components.	0.8W

Turbine efficiency calculated as:

$$\frac{P_{\ motor}}{Turbine_{provided}} \ x\ 100 \quad (9)$$

Torque vs. Speed (12V - DC Motor):

The turbine supplied 24W of power, resulting in a useful power output of 18W at a motor speed of 60 RPM. The calculated turbine torque was 2.87 Nm. Figure 7 illustrates the inverse relationship between torque and speed: as speed increases, torque decreases at constant power. Additionally, Figure 8 shows that DC motor efficiency was notably high at 60 RPM.

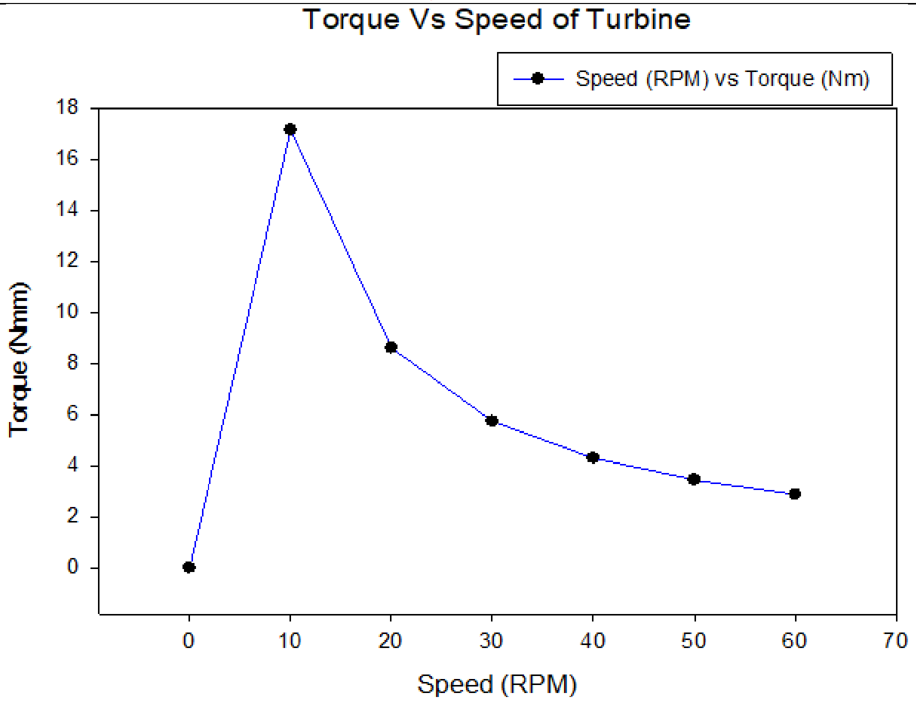

Figure 7. Torque Vs Speed

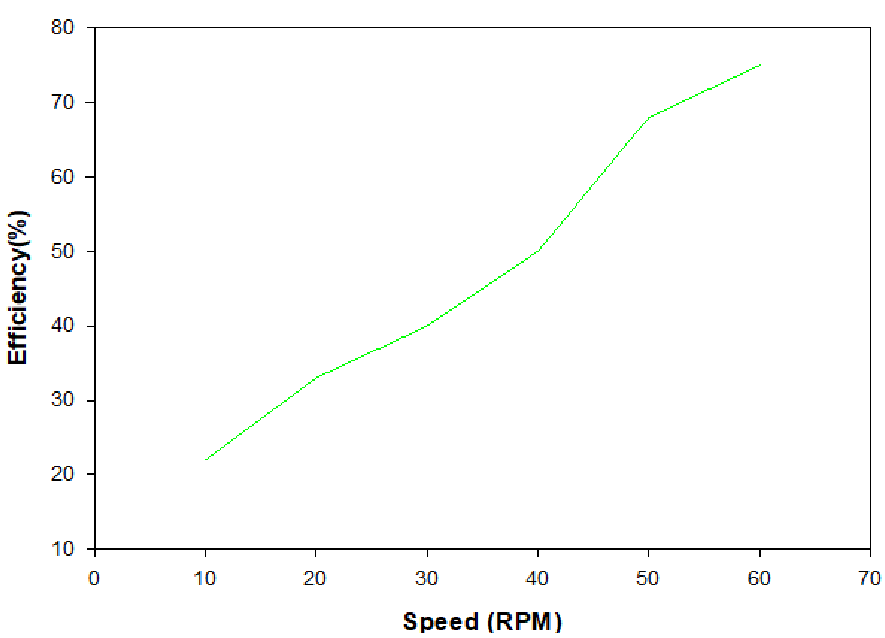

Figure 8. Motor Efficiency vs Speed (RPM)

Torque vs. Power (Permanent Magnet Alternator):

In the experimental model, the turbine's efficiency using a 12V DC motor was measured at 5.69%, which was relatively low due to the speed mismatch between the turbine and the generator. To improve power output, a permanent magnet alternator (PMA) was introduced, which generated between 160W and 200W. Given that the turbine supplied 422.11W of power, the use of the PMA resulted in an output efficiency of 49.5%. The torque produced by the PMA ranged from 25.46 Nm to 31.83 Nm, as shown in Figure 9. The vortex power plant achieved an optimal efficiency of 55.19%, as illustrated in Figure 10.

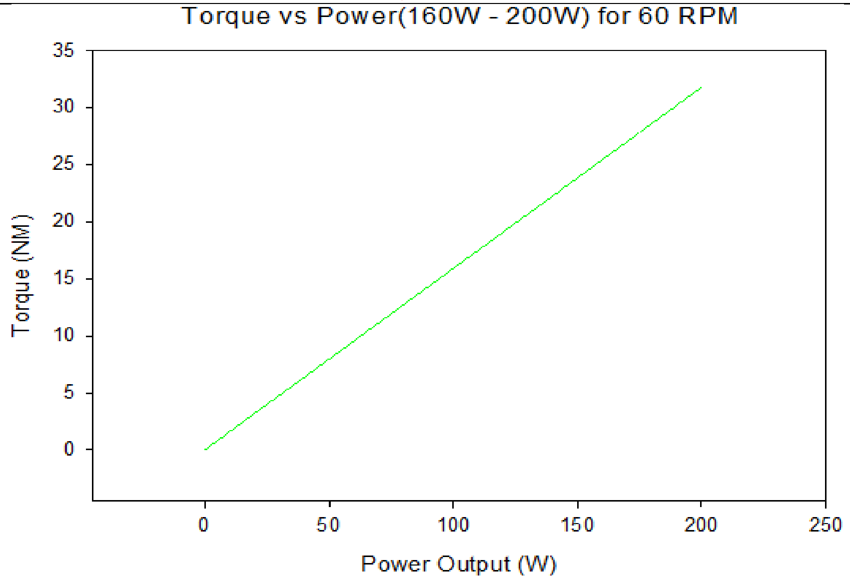

Figure 9. Torque vs Power

Power vs Efficiency:

Figure 10 presents the output power based on the experimental model of the vortex power plant. The input and output power were calculated, resulting in a power efficiency of 75%. This indicates that the vortex power plant is quite efficient in converting electrical power into useful output. The voltmeter displayed an output of 9.5 volts from a 12-volt DC motor. The 2W power loss may be due to internal losses in the motor, circuit impedance, or minor inefficiencies in electrical components. To improve motor performance, a 25μF capacitor was added, which helps stabilize the voltage and reduce fluctuations. Figure 11 displays the output voltages measured by the voltmeter during the experiment.

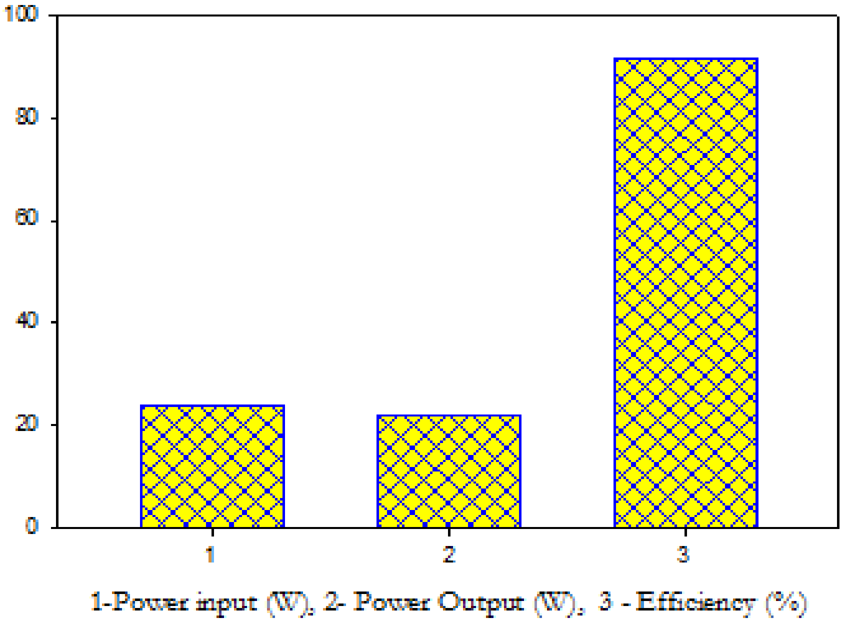

Figure 10. Power vs Efficiency

Figure 11. Voltage measuring

Discharge vs Velocity:

As shown in Figure 12, each 2-inch diameter pipe maintains a constant discharge. The velocity recorded for the steel pipe (Schedule 40 to 60 type) is 3.9 m/s, while the cast iron pipe has a velocity of 3.3 m/s. The Y-axis represents a discharge value of 61.46 l/s.

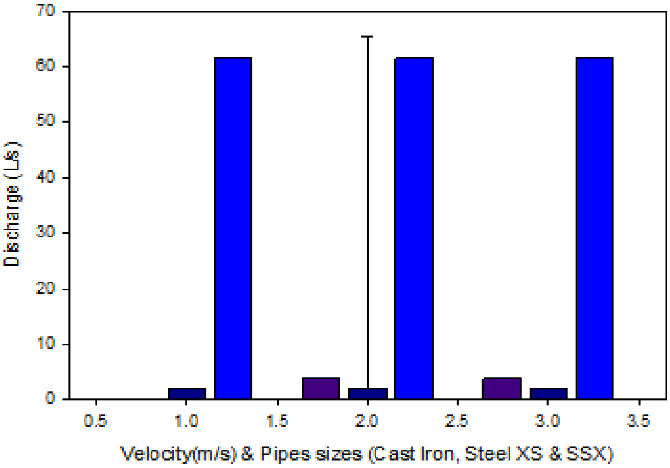

Figure 12. Discharge vs velocity

Typical Day Production:

The highest discharge and maximum efficiency were recorded at 5 PM, as shown in Figure 13.

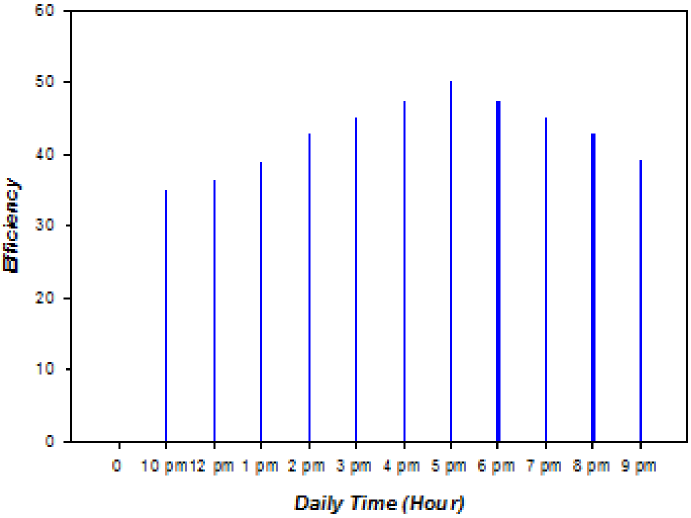

Figure 13. Efficiency % during the typical day

Discussion:

The experimental model of the Gravitational Water Vortex Power Plant (GWVPP) demonstrated an efficiency of 55.19% when using a Permanent Magnet Alternator (PMA), aligning with efficiency rates reported in similar vortex power plant studies. [2] and [3] documented efficiencies ranging from 50-60%, while [7] emphasized the role of optimized basin geometry and turbine design in enhancing performance. A key finding of this study was that lower head heights (0.7 meters) produced higher efficiency compared to head configurations of 3 meters. This aligns with [17], who attributed improved performance in low-head systems to reduced mechanical losses. [8] suggested that efficiency could be further enhanced by incorporating multi-stage turbines.

The study also found that achieving an arc angle of 90° and a blade angle of 50° could further boost efficiency. The power output recorded (160–200W) was consistent with findings from earlier studies. For instance, [4] reported outputs ranging from 200 to 300W, suggesting that increasing discharge rates and improving turbine materials could enhance power generation. Similarly, [5] found that using steel turbine blades resulted in outputs of 150–250W. [8] also highlighted that the lower initial power output (24W) observed in this case was due to a mismatch between turbine and generator speeds. This issue was mitigated by employing a Permanent Magnet Alternator (PMA), which significantly improved performance. Further improvements could be achieved by using a variable-speed generator or a more efficient gearbox. Additionally, adjusting the turbine runner position for optimal water flow could enhance output.

The study confirmed that conical basins are more efficient than cylindrical ones, supporting findings by [16]. The recommended cone angle in this study aligns with previous research, which identified a 60° cone angle as the most effective.

Moreover, the study demonstrated the feasibility of generating electricity using municipal wastewater. Previous research by [1] and [12] also identified wastewater as a potential energy source, though they noted that performance may be affected by variations in discharge rates. [10] observed that sedimentation in wastewater can reduce system efficiency. To maintain consistent energy generation in wastewater streams with fluctuating flow rates, adaptive intake systems are necessary. Additionally, energy extraction could be enhanced by increasing the vortex's rotational speed, potentially through a double-stage vortex system.

Conclusion:

- The primary focus of this thesis research is on hydraulic phenomena and their applications in engineering, particularly in micro hydropower plants serving coastal communities. Gravitational Water Vortex Power Plants (GWVPPs) have attracted significant global attention due to their environmentally friendly nature. Based on the research findings, recommendations can be made on selecting the most efficient turbine system for various micro hydropower projects.
- We concluded that Gujrat and other resource-rich towns could harness wastewater to generate sufficient power. Additionally, we found that this power plant can be installed as a compound plant and offers environmental sustainability. However, the key challenges to its development in different regions of Pakistan include political interference and competing agendas. Governmental instability and a lack of interest in adopting new technologies further hinder progress in this area.
- This type of power plant is highly effective for irrigation systems and is remarkably simple to construct and install. In our experimental setup, the gravitational water vortex power plant successfully generated 12 volts using a 12-volt DC motor. Efficiency could be further improved by optimizing the blade angle, refining the basin shape, and selecting an appropriate generator.

- Several opportunities exist to modify the plant's design to generate additional mechanical energy, which can then be converted into electrical energy using specific tools and equipment.
- To achieve higher efficiency, the inlet blade angle should ideally be around 50°, and the blade arc angle should be set at 90°.
- Our findings suggest that if the channel is parallel to the water surface, lower efficiency is observed. By adjusting the channel's orientation and design, we achieved significantly improved efficiency. Additionally, enhancing the blade design and optimizing their positioning can increase the rotational speed of the turbine blades, thereby enhancing overall performance.

Limitations:

This study is based on a small-scale experimental model, which may not fully represent real-world conditions in larger applications. It focuses on specific flow rates derived from Gujrat's wastewater data, which may not be applicable to all coastal communities. Additionally, the proposed efficiency improvements depend on certain materials, such as steel pipes, which may not be readily available in all regions. The turbine efficiency, while promising, remains lower than that of conventional hydropower systems due to speed mismatches, highlighting the need for further optimization. The study also does not address potential legal, environmental, and regulatory challenges associated with large-scale deployment. Although cost analysis is discussed, actual implementation costs may vary considerably depending on local infrastructure and government incentives. While the system is well-suited for small-scale applications, large-scale adoption of GWVPP may require significant modifications to existing water management systems.

Acknowledgement:

All authors have contributed equally to the conception, design, analysis, and writing of this manuscript. The authors declare no conflicts of interest regarding the publication of this paper.

References:

[1] Gonzalez, J. et al, "Policy frameworks for emerging renewable technologies," *Energy Policy*, vol. 39, no. 4, pp. 120–133, 2021.

[2] Müller, R. et al, "Ecological benefits of low-head hydropower systems," *Environ. Sci. Technol.*, vol. 52, no. 3, pp. 215–230, 2020.

[3] A. M. N. Sagar Dhakal, Ashesh B. Timilsina, Rabin Dhakal, Dinesh Fuyal, Tri R. Bajracharya, Hari P. Pandit, Nagendra Amatya, "Comparison of cylindrical and conical basins with optimum position of runner: Gravitational water vortex power plant," *Renew. Sustain. Energy Rev.*, vol. 48, pp. 662–669, 2015, doi: https://doi.org/10.1016/j.rser.2015.04.030.

[4] Iskandar, S. et al, "Implementation of gravitational vortex plants in Indonesian coastal regions," *J. Renew. Energy*, vol. 56, no. 2, pp. 78–89, 2020.

[5] Ahmed, S. et al, "Renewable energy potential in coastal environments," *Renew. Energy J.*, vol. 64, no. 3, pp. 45–57, 2022.

[6] Gonzalez, J. et al, "Policy frameworks for emerging renewable technologies," *Energy Policy*, vol. 39, no. 4, pp. 120–133, 2021.

[7] A. Sedai, G. Singh, R. Dhakal, B. B. Kumal, N. Ghimire, and B. K. Yadav, "Technical and Economic Analysis of Site Implementations of Gravitational Water Vortex Power Plant," *Proc. - 2021 IEEE Int. Conf. Intell. Syst. Smart Green Technol. ICISSGT 2021*, pp. 128–133, 2021, doi: 10.1109/ICISSGT52025.2021.00036.

[8] Ravi, P. et al, "Integration of gravitational vortex systems in hybrid renewable energy frameworks," *J. Energy Syst.*, vol. 45, no. 2, pp. 120–130, 2022.

[9] M. a O. B. Yaakob, "A Review on Micro Hydro Gravitational Vortex Power and

Turbine Systems," *J. Technol.*, 2014, [Online]. Available: https://www.slideshare.net/slideshow/a-review-on-micro-hydro-gravitational-vortex-power-and-turbinepdf/262095086

[10] J. J. Paweł Tomczyk, Krzysztof Mastalerek, Mirosław Wiatkowski, Zeshan Asghar, "Assessment of a Francis Micro Hydro Turbine Performance Installed in a Wastewater Treatment Plant," *Energies*, vol. 16, no. 20, p. 7214, 2023, doi: https://doi.org/10.3390/en16207214.

[11] C. Martinez, "Community-driven renewable energy projects in Southeast Asia," *Energy Dev.*, vol. 8, no. 1, pp. 89–101, 2022.

[12] C. Xu, "Study of wave interaction with vertical piles integrated with oscillating water columns," *Univ. Hawaiʻi Mānoa*, 2018, [Online]. Available: https://core.ac.uk/download/211329122.pdf

[13] GUJRAT DISTRICT, "https://www.pbs.gov.pk/census-2017-district-wise/results/048," *Pakistan Bur. Stat.*, 2023.

[14] HAMID BASHIRI & ANGELOS FINDIKAKIS, "Hydrolink 2020/2. Hydraulic Transients," *Int. Assoc. Hydro-Environment Eng. andResearch*, 2020, [Online]. Available: https://core.ac.uk/reader/535022280

[15] S. M. Mosè Rossi, Massimiliano Renzi, David Štefan, "Small-Scale Hydropower and Energy Recovery Interventions: Management, Optimization Processes and Hydraulic Machines Applications," *MDPI AG*, 2022, doi: https://doi.org/10.3390/books978-3-0365-5553-9.

[16] J. A. Chattha, T. A. Cheema, and N. H. Khan, "Numerical investigation of basin geometries for vortex generation in a gravitational water vortex power plant," *2017 8th Int. Renew. Energy Congr. IREC 2017*, May 2017, doi: 10.1109/IREC.2017.7926028.

[17] N. Dhakal, Sagar & Timilsina, Ashesh & Dhakal, Rabin & Fuyal, Dinesh & Bajracharya, Tri & Pandit, Hari & Amatya, "Mathematical modeling, design optimization and experimental verification of conical basin," Gravitational water vortex power plant. Accessed: Apr. 07, 2025. [Online]. Available: https://www.studocu.com/ph/document/wesleyan-university-philippines/research-methods/mathematical-modeling-design-optimization-and-experimental-verification-of-conical-basin-gravitational-water-vortex-power-plant/23168539