Original Research Article

Assessing the Feasibility of Gravitational Vortex Turbines for Sustainable Energy Production in Remote Hilly Areas of Bangladesh

ABSTRACT

This research paper presents a comprehensive study of the design, optimization, and performance analysis of a gravitational vortex water turbine for small-scale hydropower applications in the Chittagong Hill Tracts of Bangladesh. The urgent need for cleaner and more efficient energy sources to address global energy challenges drives the development of innovative renewable energy solutions. The proposed turbine harnesses the power of gravity-induced water flow to efficiently convert rotational energy from a water vortex into electrical energy. The research employs advanced computational fluid dynamics (CFD) analysis using ANSYS Fluent to investigate the intricate flow behavior and velocity distribution. Through CFD calculations, the study provides valuable insights into the turbine's performance, allowing for optimization of its design parameters. The influence of blade numbers on turbine efficiency contributes to a better understanding of the turbine's operational characteristics. The paper discusses the advantages of decentralized energy systems and emphasizes the potential of gravitational vortex turbines for small-scale hydropower projects. It highlights the importance of mathematical analysis and performance results, further supported by the CFD analysis, demonstrating the turbine's capabilities. The power outputs achieved by the turbine align with or surpass the potential power capacities of identified small hydro sites, reinforcing its viability as a clean and reliable energy solution. While the research findings showcase the turbine's potential, it emphasizes the need for further feasibility studies and site-specific assessments to ensure successful real-life implementation. The study underscores the significance of utilizing advanced computational techniques in developing efficient and environmentally friendly hydropower solutions. The findings offer lessons for researchers, engineers, and policymakers for cleaner and more sustainable energy sources.

Keywords: Vortex turbine; CFD; Chittagong Hill Tracks; Decentralized System; Environment Friendly; Reliable Source of Energy.

1. INTRODUCTION

The modern world faces the urgency for cleaner, more efficient energy sources to mitigate the declining days of fossil-fuel-based electricity and address environmental concerns. As a result of the projected 30% surge in global energy demands by 2040, coupled with a burgeoning population, the prioritization of sustainable and renewable energy solutions becomes paramount [1]. Hydropower, harnessing the power of water, emerges as a promising alternative due to its clean, abundant, and cost-effective nature. While large-scale hydropower projects have limitations, small hydropower offers significant potential, particularly in hilly regions and areas near rivers and lakes worldwide [2]. This research paper centers on the design and optimization of a gravitational vortex water turbine., specifically tailored for the Chittagong Hill Tracts of Bangladesh, which possess substantial hydro-potential. A gravitational vortex water turbine is an impulse turbine that uses gravity to create a water vortex. The turbine collects the rotational energy from the vortex and converts it into electrical energy [3]. By harnessing the downstream flow of water induced by gravity, the turbine adeptly transforms the rotational energy derived from a water vortex into electrical energy efficiently. The application of a smart vortex turbine aims to generate clean, cost-effective, and renewable electricity, with a particular emphasis on remote areas. This technology reduces the environmental impact and enhances the sustainability and health of rivers and water bodies. Innovative features, such as a sealed generator assembly integrated within the water flow, minimize energy losses and optimize overall efficiency. The research paper aims to contribute to sustainable energy by presenting the design and optimization of a gravitational vortex water turbine [4]. By leveraging the hydroelectric potential of the Chittagong Hill Tracts in Bangladesh, this innovative small hydropower solution addresses the increasing demand for clean and reliable electricity. Advanced manufacturing methodologies, such as additive manufacturing or 3D printing, pave the way toward a more sustainable future by enabling the production of environmentally conscious systems. The primary objective of this research is to design a highly efficient vortex turbine by adjusting various turbine blade parameters, including blade material, blade angle, and the addition of baffle plates. Dhakal et al. (2015) investigated different basin shapes, and the conical basin was the most efficient due to stronger vortex generation compared to cylindrical basins [5]. Turbine blades are crucial for energy conversions and reported maximum efficiencies of approximately 30%, while commercial companies claimed up to 50% efficiency for power generation ranging from 500 W to 20 kW. Efficiency influenced by turbine blade profiles, and. (2017) found that curved blade profiles achieved an efficiency of 82.4%, outperforming other blade designs [6]. Material choice also affected efficiency, with Sritram et al. (2015) identifying aluminum turbine blades (34.79% efficiency) as more efficient than steel blades due to their lighter weight and higher speed [7]. Bajracharya et al. (2020) studied blade angle, height ratio, and blade number, finding that curved blades with angles between 50° and 60° and a runner height-to-basin height ratio of 0.31-0.32 led to higher efficiency. A runner with five blades was deemed the most efficient [8]. Sritram and Suntivarakorn (2019) also confirmed the superiority of runners with five blades [9].

In the current energy landscape, with rising demand and the impact of the COVID-19 pandemic, renewable energy sources, including hydropower, have gained importance. In Bangladesh, a country rich in rivers and canals, harnessing hydropower from underutilized water sources becomes crucial. The Gravitational Water Vortex Power Plants concept has emerged as a viable option for generating energy from low headwater sources without large dams. The approach allows for small-scale hydraulic power generation using common rivers and waterways with low heads and flow rates [10]. Given the global focus on renewable energy and the potential of small-scale hydroelectricity, initiatives like the Gravitational Water Vortex Power Plant can contribute significantly to energy sustainability and environmental conservation. By harnessing the hydropower potential of natural water sources, Bangladesh and other countries can reduce their dependence on fossil fuels and move towards a greener and more sustainable energy future [11].

2. LITERATURE REVIEW

2.1 Decentralized Energy Systems

Decentralized systems, characterized by localized energy production and distribution on a smaller scale, offer many benefits. These systems enhance energy resilience by reducing reliance on centralized grids, ensuring an uninterrupted energy supply, particularly in remote areas. By diversifying energy sources and reducing dependence on a single infrastructure, decentralized systems enhance energy security and stability [12]. They localize energy production, minimizing transmission and distribution losses and increasing overall system efficiency. Decentralized systems are well-suited for integrating renewable energy sources, contributing to a cleaner energy mix.

2.2 Exploration of Gravitational Vortex Turbines

Hydroelectric power, a renewable energy technology, capitalizes on the kinetic energy of descending or moving water to generate electricity effectively. These turbines take advantage of the natural force of gravity to create swirling vortexes, converting the kinetic energy of the water into mechanical and electrical energy. With their scalability, gravitational vortex turbines can be implemented in various water sources, making them suitable for small-scale and large-scale applications. This system focuses on the following advantages:

- Access clean energy from untapped river or canal sources
- Provide electricity for communities and villages with 50 to 500 households
- Generate annual energy output ranging from 120,000 to 560,000 kWh per turbine
- Simple civil works required for installation
- Reliable and consistent energy source, unlike intermittent renewables such as wind or solar power
- Continuous Energy supply 24 hours a day and 365 days a year
- Focus on developing a comprehensive ecosystem that prioritizes biodiversity preservation and maximizes positive impacts on the surrounding area.
- Incorporate fish-friendly design features, such as a slow RPM impeller with low shear stress, ensuring the safe passage of fish and aquatic life.
- Foster local development by empowering and transferring sustainable energy to the local communities [13].

3. METHODOLOGY

3.1 Design Parameters and Operating Conditions

The HFLH (High Flow Low Head) vortex turbine blades are precision-optimized for peak performance within specific flow and head ranges. The open flow design requires careful selection of the head-flow combination to ensure optimal performance at each site. Standard turbine impeller dimensions range from 1.3 to 1.9 meters, enabling efficient energy extraction. The standard electrical power outputs range from 15 to 70 kW. For demands of a higher power, multiple standard turbine models can be combined and installed in clusters.

Table 1. Performance parameters of HFLH turbine system [14]

Parameters	Minimum	Maximum	Units
Flow	1.5	4.7	m^3/s
Head (Inflow channel to Tail-water level)	1.4	2.7	m
Hydraulic efficiency at BEP	0.65	0.75	-
Inflow channel water depth	1.3	2.3	m
Impeller diameter	1.3	1.9	m
Impeller rotational speed	40	100	rpm

Table2.Turbine specifications and performance for standard power output range [14]

Impeller Diameter	1.3 m	1.5 m	1.7 m	1.9 m
Hydraulic output (kW)	17	34	56	78
Electrical output (kW)	15	30	50	70
Maximal energy generation (per year) (kWh)	130k	260k	440k	610k
Design flow (m³/s)	1.6	2.5	3.4	4.3
Design head (m)	1.7	2.2	2.4	2.6
Rotational speed (rpm)	75	95	75	75
Dimensions core unit (L×W×H) (m³)	1.8	3.5	5.4	7.9
Impeller and Support weight (kg)	240	380	590	870
Generator and gearbox weight (kg)	310	470	700	1070
Core unit total weight (kg)	550	850	1290	1940

3.2 Measurement Process

The initial step in assessing the hydropower potential of a site involves measuring or estimating the head and flow parameters.

Flow: This refers to the minimum volume of water that remains consistently available for at least nine months of the year. It pertains to the amount of water that descends the stream.

Head: It represents the vertical distance or variation in height between the upper and lower levels of water and refers to the vertical separation between the intake and the outflow of the turbine. Both head and flow are frequently exaggerated, and the flow rate can vary throughout the year. It is common to encounter incorrect data, making it highly recommended to verify the existing information.

Determination of height: This procedure involves measuring the vertical variation between the water level at the outflow point and the higher water level in multiple sections. The measurements are conducted at regular intervals along the distance, with each section separated by the length of a plank or string. Summing up the individual height differences using a designated formula, the total head is as follows:

$$H_y = H_1 + H_2 + H_3 \dots\dots\dots\dots + H_n$$

Estimation of flow:

- Locating an area with consistent water flow, extending for a specified length, denoted as L in meters.
- Determining the cross-sectional area of the identified region by measuring the width, represented by B in meters, and the height, denoted as H in meters. Area (A) is the product of B and H: A = B x H.
- Measuring the time, denoted as T in seconds, takes a float to traverse the determined length L. Ensure that the float has sufficient time to accelerate before the measurement starts.
- Calculating the velocity (V) by dividing the length L by the time T: V = L / T, expressed in meters per second.
- Computing the flow rate (Q) by multiplying the velocity V by the cross-sectional area A: Q = V x A. The flow rate in cubic meters per second (m^3/s).

Fish survival: The turbine's design differs from conventional turbines, lacking inlet guide vanes and leading to a swirling flow pattern. Computational fluid dynamics (CFD) calculations provide insights into the velocity distribution within the turbine, and the average Euler head is determined. The research follows the NEN 8775 standard, which outlines fish collisions between the runner blades and fish [8].

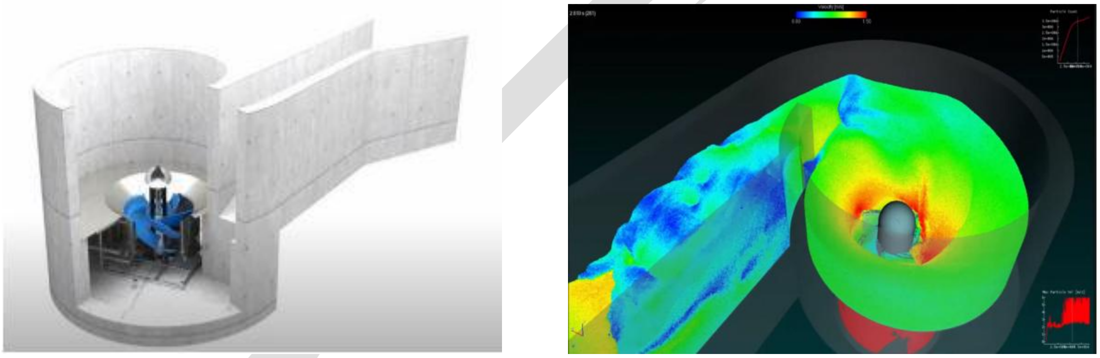

Figure 1. Installation of a runner in the scroll casing showing the flow path through the turbine.

The swirling velocity near the entrance changes from approximately 2.5 m/s at the hub to 3.8 m/s at the blade tip. It indicates a rotational flow pattern resembling the speed of the blades. Along the turbine, the circumferential velocity remains below 0.7 m/s. Figure 1 (below) portrays the CFD visualization, demonstrating the free surface of the vortical flow within the scroll and showcasing the distribution of swirl velocity in a cross-section of the turbine. These findings correspond to a flow rate of 1.1 m^3/s, a system head of 1.1 m, and a rotational speed of 52 rpm.

3.3 CFD Analysis

Computational Fluid Dynamics (CFD) analysis was employed to study the flow behavior and performance of the gravitational low-head vortex turbines. The numerical model and methodology used in the CFD analysis are as follows:

Mesh Generation: An optimized mesh generated to capture the complex flow patterns and vortices within the turbine system. A structured grid ensured grid quality and minimized numerical errors. The mesh refinement was done near the turbine blades and other critical regions to capture the flow details accurately.

Solver and Turbulence Model: A commercial CFD solver, such as ANSYS Fluent, was employed to solve the governing equations of fluid flow within the computational domain. The study adopted a turbulence model, such as the Shear Stress Transport (SST) modeling or the k-ε model, to simulate the turbulent flow behavior in the turbine system.

Boundary Conditions: The boundary conditions were defined based on the physical characteristics of the turbine system. The inlet boundary condition specified the water velocity entering the turbine, while the outlet boundary condition represented the atmospheric pressure at the turbine exit. The no-slip to the walls of the turbine components ensures zero velocity at these surfaces.

Post-Processing:
After completing the simulation, post-processing performed analyzation of the results. Various parameters, such as velocity profiles, pressure distribution, and efficiency, were extracted and visualized. Velocity vectors and streamlines depicted insights into the flow characteristics, while contour plots of pressure and efficiency assess the turbine's overall performance.

Validation: The numerical model's accuracy was confirmed by comparing it with experimental data or analytical solutions, ensuring that the CFD simulation faithfully represented the real-world behavior of the turbine system.

Sensitivity Analysis: A sensitivity analysis may have to study the effect of various input parameters on the turbine's performance. This analysis helps to identify critical design parameters and optimize the turbine for better efficiency.

Limitations: The CFD analysis may have shortcomings as simplifications in modeling certain flow phenomena or assumptions in the turbulence model. Additionally, computational resources and simulation time may restrict the level of detail in the numerical model. By employing this numerical model and methodology, the CFD analysis provided valuable insights into the flow behavior and performance of the gravitational low-head vortex turbines. The results obtained from the analysis contributed to understanding and optimizing the turbine design for efficient energy conversion from flowing water.

3.4 Potential Hydro Sites

BPDB (Bangladesh Power Development Board), BWDB (Bangladesh Water Development Board), and IFRD (Institute of Fuel Research and Development) of BCSIR (Bangladesh Council of Scientific and Industrial Research) has conducted a comprehensive study to identify potential sites for small-scale hydroelectric power generation in Bangladesh. The study has revealed that due to the predominantly flat topography of the country, the Chittagong Hill Tracts region holds the majority of the hydroelectric potential. This region is characterized by hilly terrain and a higher elevation, making it suitable for harnessing the power of flowing water to generate renewable energy through small hydropower projects.

Table 3. Potential small hydro sites identified by BPDB and BWDB [16]

District	Name	Potential Power (KW)
Khagrachari	Nunchari Tholipara	3
Bandarban	Bangchari	25
Bandarban	Liragaon	20
Rangamati	Kamalchar	20
Rangamati	Thang Khrue	30

Bandarban	Monjaipara	7.5
Chittagong	Foy's Lake	4
Chittagong Hill Tracks	Sealock	81
Chittagong	Lungi chara	10
Chittagong	Budia Chara	10
Sylhet	Nikhari Chara	26
Sylhet	Ranga Pani Gung	61
Bandarban	Taracha Khal	20

3.5 Feasibility Assessment

In the computational model, the stationary domain set with an inlet velocity of 0.3 m/s and an outlet static pressure equivalent to atmospheric pressure (1 atm). The boundary condition of air and water is adjusted to ensure consistency and accurate representation within the computational model. The rotating component identified within the computational model rotates in the anticlockwise direction, with angular velocities varying from 40 to 100 rpm.

Figure 2 (above) illustrates the depicted boundary conditions. The observed flow behavior and velocity distribution, as in Figure 2 (down), indicate that the rotating blade will encounter a vortex pool with an approximate velocity of 1.3 m/sec within the radial range of 60mm to 120mm. The velocity value holds importance in torque generation on the shaft via the blade. Moreover, by examining the streamlines, it is inferred that they will encounter the region where the water stream has the maximum impact.

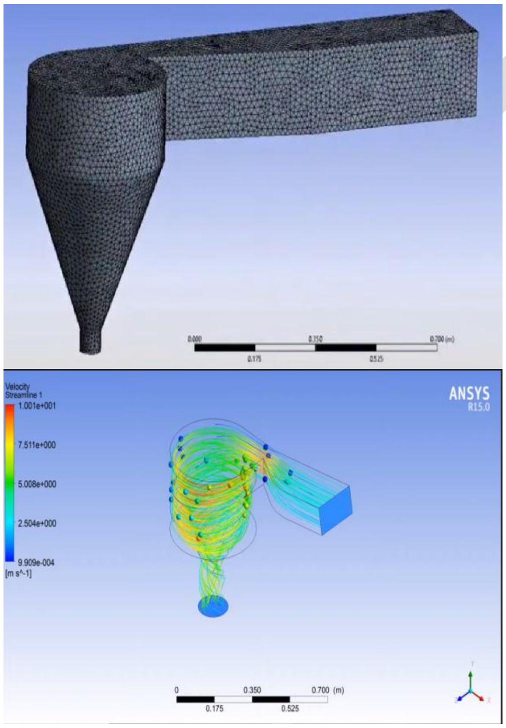

Figure 2. Optimized meshing for streamlining flow in the stationary domain considering the ideal runner position.

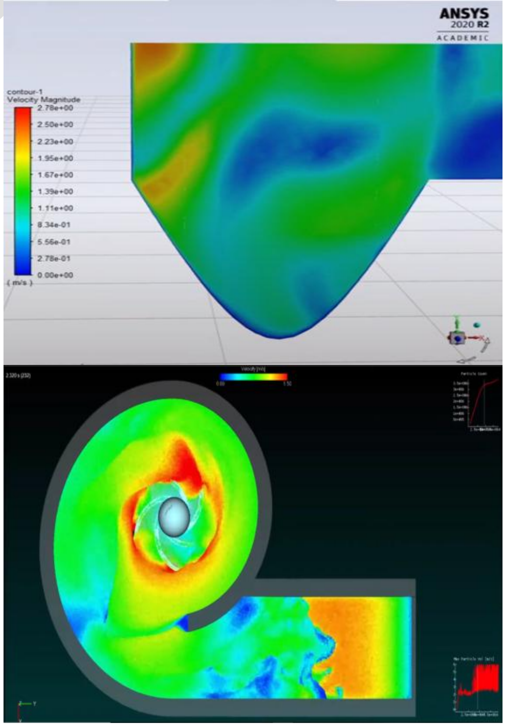

Figure 3. Velocity vectors and potential energy conversion at the free surface.

Figure 3 illustrates the velocity vectors at the free surface, showcasing a gradual increase in velocity in the radial direction due to rotational swirling and the conversion of potential energy. The homogeneous multiphase Eulerian fluid method allows for the boundary identification between air and water. Within this boundary, a vortex core filled with air facilitates the advantageous aeration of water, leading to positive environmental effects [17].

Figure 4. Vortex turbine - generator system.

Figure 4 illustrates the integration of the vortex turbine, which captures energy from a fluid flow, with the generator, which converts the mechanical energy into electrical energy. The blades in a vortex turbine generator play a crucial role in the conversion of fluid flow energy into mechanical energy that drives the generator. The blade profile, shape, and angle of attack are important factors that determine energy conversion efficiency [18]. The design aims to maximize the energy extraction from the fluid flow while minimizing losses due to turbulence and friction.

4. MATHEMATICAL ANALYSIS

The theoretical aspect of the analysis involved employing mathematical techniques, while a mathematical model involved developing and implementing using a Google spreadsheet.

4.1 Formulas Considered

The equations presented in the book “Basic Fluid Mechanics and Hydraulic Machines” are given below [18]:

Actual velocity, $v = \frac{Q}{A} = \frac{4Q}{\pi d^2}$ (1)

Q = Experimental flow rate, d = Diameter of the nozzle

Peripheral velocity, $U = \frac{\pi DN}{60}$ (2)

U = Peripheral velocity, D = Outer diameter of the turbine, N = Rotational speed

Inlet hydraulic power, $P_i = \delta Q H$ (3)

Q = Experimental flow rate, H = Head available at the nozzle, δ = Specific weight

Turbine output power, $P_o = \eta Q H g\rho$ (4)

η = Hydraulic efficiency, ρ = Density of water

Hydraulic efficiency, $\eta = \frac{2U(V_1-U)(1+\cos\beta)}{v_1^2}$ (5)

U = Peripheral velocity of the turbine, V_1 = Absolute velocity of the jet before striking the blades, β = Turbine blade angle

5. RESULTS

Table 4. Calculated performance analysis of gravitational low-head vortex turbine (Using the values of Table 1 and Table 2)

Flow Rate (m^3/s)	Height (m)	Power Output (KW)
1.5	1.4	11
2	1.6	16
2.5	1.8	23
3	2	30
3.5	2.2	35
4	2.4	48
4.5	2.6	59
4.7	2.7	63

Table 5. Efficiencies with blade number

Blade-Number	Efficiencies	Blade Angle
2	14.15	20
3	20.10	25
5	28.15	30
8	26.41	35
10	24.66	40

The study aims to investigate the influence of different blade numbers on the efficiency of vortex turbines in Table 5 and Figure 6. Through the experiments, we tested turbine configurations with 2, 3, 5, 8, and 10 blades while keeping all other parameters constant [20]. The findings of the study revealed interesting insights. The turbine with five blades exhibited the highest efficiency among all the configurations, achieving a remarkable percentage of 28.15%. The design of five blades was the most effective in harnessing the energy from the water vortex. Furthermore, we observed a notable increase of 4% in the power coefficient when the blade number was increased from 4 to 5.

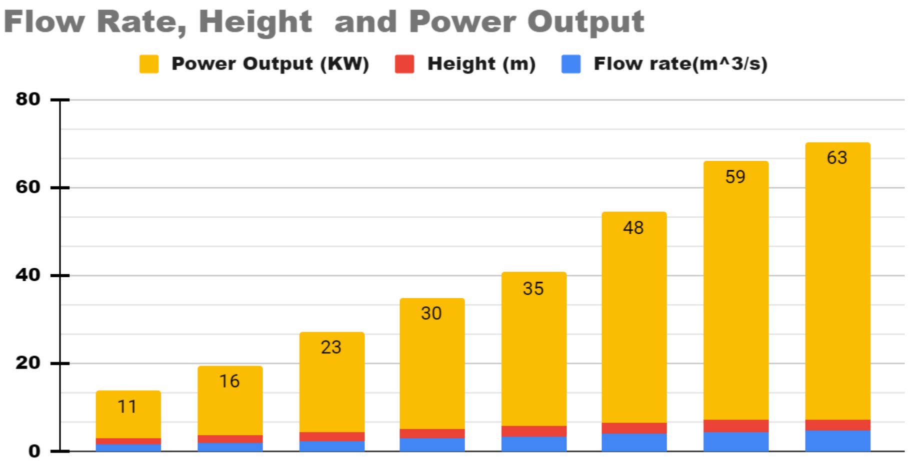

Figure 5: Representation of performance analysis

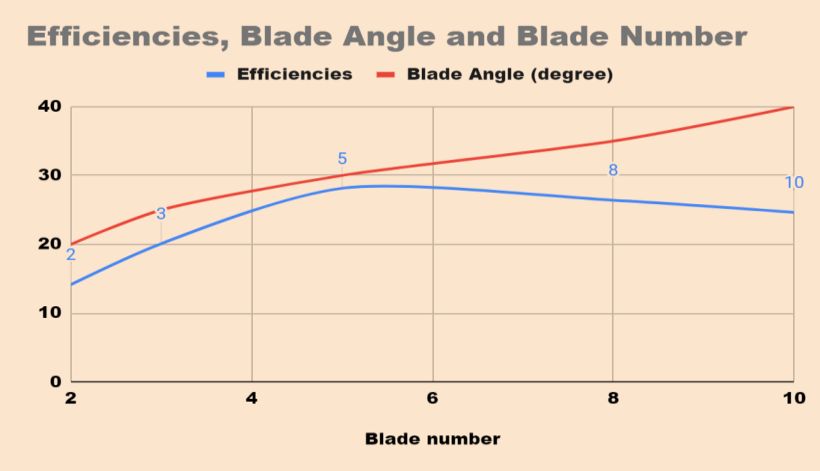

Figure 6: Efficiency and blade angle of gravitational vortex turbine with different blade numbers.

5. DISCUSSION

The comprehensive study on potential small-scale hydroelectric power generation sites in Bangladesh's Chittagong Hill Tracts region has revealed promising opportunities for harnessing renewable energy from flowing water. By carefully analyzing Table 3 and the calculated performance analysis in Tables 4 and 5, we can draw insightful conclusions regarding the suitability of gravitational low-head vortex turbines and the influence of blade numbers on their efficiency.

High Hydroelectric Potential: The Chittagong Hill Tracts region, with its hilly terrain and higher elevation, presents Bangladesh's hydroelectric potential. The identified sites in Khagrachari, Bandarban, and Rangamati show promising potential power outputs, ranging from 3 KW to 81 KW, making them ideal locations for small hydropower projects.

Vortex Turbines for Efficient Energy Conversion: The research focuses on gravitational low-head vortex turbines as an efficient means to generate renewable energy. These turbines utilize the power of flowing water to produce electricity, offering a sustainable alternative to conventional energy sources.

Optimal Blade Number: The turbine with five blades demonstrated the highest efficiency, reaching 28.15%. This finding highlights the significance of blade design in maximizing energy extraction from water vortices in low-head scenarios.

Increasing Efficiency with Blade Number: The power coefficient exhibited a 4% increase when moving from four to five blades. This result reinforces the idea that higher blade numbers positively impact turbine efficiency, emphasizing the importance of blade optimization in hydroelectric projects.

Practical Implications: The research outcomes offer practical implications for small-scale hydroelectric projects in Bangladesh. Vortex turbines with five blades show significant potential in harnessing energy from water vortices in the hilly terrains of the Chittagong Hill Tracts. The region can tap into its hydroelectric potential and contribute to Bangladesh's energy security and sustainability goals.

Further Research: While this study provides valuable insights, there remains scope for further research and development. Long-term performance monitoring of vortex turbines under varying flow conditions and operational scenarios will be essential to validate their effectiveness in real-world applications.

6. CONCLUSION

- The Chittagong Hill Tracts region in Bangladesh offers significant hydroelectric potential due to its hilly terrain and higher elevation.
- Gravitational low-head vortex turbines are efficient for small-scale hydroelectric power generation, presenting a sustainable alternative to conventional energy sources.
- The study identified potential sites in Khagrachari, Bandarban, and Rangamati with promising power outputs, making them suitable for small hydropower projects.
- Implementing vortex turbines with five blades in the Chittagong Hill Tracts region can harness its hydroelectric potential, contributing to energy security and sustainability.
- Continued research is essential to validate the long-term performance of vortex turbines under various flow conditions and operational scenarios.
- In the design and implementation of small-scale hydroelectric projects, practical and environmental factors must be taken into account..
- By leveraging the findings of this research, Bangladesh can progress towards a greener and more sustainable energy future.
- Tapping into the renewable energy potential of the Chittagong Hill Tracts will play a significant role in achieving the nation's energy goals and fostering a cleaner and more resilient energy landscape.

7. REFERENCE

1. L. E. P. Doman. 28% increase in World Energy Use by 2040. EIA Projects. 14 September 2017 [online]. Available: https://www.ogj.com/general-interest/article/17288978/world-energy-consumption-to-increase-28-by-2040
2. BP. Statistical Review of World Energy. 06 August 2018 [Online]. Available: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-ofworld-energy.html
3. Y. Nishi T. Inagaki. Performance and Flow Field of a Gravitation Vortex Type Water Turbine. Int. J. Rotating Mach, Vol. 2017. DOI: https://doi.org/10.1155/2017/2610508
4. UNIDO: World Small Hydropower Development Report- 2019 (case studies). International Center on Small Hydro Power. Available: https://www.unido.org/our-focus-safeguarding-environment-clean-energy-access-productive-use-renewable-energy-focus-areas-small-hydro-power/world-small-hydropower-development-report
5. S. Dhakal, A.B. Timilsina, R. Dhakal, D. Fuyal, T.R.Bajracharya, H.P. Pandit, N. Amatya, and A.M.Nakarmi. Comparison of Cylindrical and Conical Basins with the Optimum Position of Runner: Gravitational Water Vortex Power Plant. Renew. Sustain. Energy Rev. Vol. 48, pp. 662–669, 2015. DOI: http://dx.doi.org/10.1016/j.rser.2015.04.030
6. R. Dhakal, T.R.Bajracharya, S.R.Shakya, B. Kumal, K. Khanal, S. J. Williamson, S. Gautam, and D. P. Ghale. Computational and Experimental Investigation of Runner for Gravitational Water Vortex Power Plant. 2017 6th Int. Conf. Renew. Energy Res. Appl. ICRERA 2017, vol. 2017-January, pp. 365–373, 2017, DOI: https://doi.org/10.1109/ICRERA.2017.8191087
7. P. Sritram, W. Treedet, and R. Suntivarakorn. Effect of Turbine Materials on Power Generation Efficiency from Free Water Vortex Hydropower Plant. IOP Conference Series: Materials

Science and Engineering, Volume 103, 4th Global Conference on Materials Science and Engineering (CMSE 2015) 3–6 August 2015, Macau, China

8. T. R. Bajracharya, S. R. Shakya, A. B. Timilsina, J. Dhakal, S. Neupane, A. Gautam and A. Sapkota. Effects of Geometrical Parameters in Gravitational Water Vortex Turbines with Conical Basin. J. Renew. Energy, Vol. 2020, no. Figure 1, pp. 1–16, 2020. DOI: https://doi.org/10.1155/2020/5373784
9. Alstone, P., Gershenson, D. & Kammen, D. Decentralized energy systems for clean electricity access. *Nature Clim Change* 5, 305–314 (2015). https://doi.org/10.1038/nclimate2512
10. P. Sritram and R. Suntivarakorn. The Effects of Bade Number and Turbine Baffle Plates on the Efficiency of Free-Vortex Water Turbines. IOP Conf. Ser. Earth Environ. Sci., vol. 257, no. 1, pp. 1–9, 2019, DOI: http://dx.doi.org/10.1088/1755-1315/257/1/012040
11. B. Looney. Statistical Review of World Energy Globally Consistent Data on World Energy Markets and Authoritative Publications in the Field of Energy. Rev. World Energy Data, Vol. 70, pp. 8–20, 2021. Available: https://www.bp.com/content/dam/bp
12. M. M. Rahman, J. H. Tan, M. T. Fadzlita, and A. R. Wan Khairul Muzammil.A Review on the Development of Gravitational Water Vortex Power Plant as Alternative Renewable Energy Resources. IOP Conference Series Materials Science and Engineering 217(1):012007. DOI:http://dx.doi.org/10.1088/1757-899X/217/1/012007
13. 15 to 70 KW Tech Sheet from Turbulent Hydro Company https://www.turbulent.be/downloads
14. The Fish-Friendly Report by TU Delft https://www.turbulent.be/downloads
15. J. I. Razan, R. S. Islam, R. Hasan, S. Hasan, and F. Islam. A Comprehensive Study of Micro-Hydropower Plant and Its Potential in Bangladesh. ISRN Renew. Energy, vol. 2012, pp. 1–10, 2012, DOI: http://dx.doi.org/10.5402/2012/635396
16. H. M. Shabaraa, O. B. Yaakoba, Yasser M. Ahmeda, A. H. Elbatrana, Muhammad S. M. Faddira. CFD Validation for Efficient Gravitational Vortex Pool System. Jurnal Teknologi 74(5):97-100. DOI: 10.11113/jt.v74.4648
17. P Sritram and R Suntivarakorn. The effects of blade number and turbine baffle plates on the efficiency of free-vortex water turbines. IOP Conference Series: Earth and Environmental Science, Volume 257, 2019 9th International Conference on Future Environment and Energy 9–11 January 2019, Osaka, Japan. 257(1):012040. DOI: 10.1088/1755-1315/257/1/012040

18. Z. Hussian, Z. Abdullah, and Z. Alimuddin, Basic Fluid Mechanics and Hydraulic Machines. 2008.
19. Md. Mizanur Rahman, Tan Jian Hong, Raymond Tang, Ling Leh Sung, Fadzlita Binti Mohd Tamiri. Experimental Study of the Effects of Water Pressure and Turbine Blade Lengths & Numbers on the Model Free Vortex Power Generation System. International Journal of Current Trends in Engineering & Research (IJCTER), Volume 2 Issue 9, September 2016 pp. 13 – 17.
20. Rabin Dhakal, Raj Kumar Chaulagain, Triratna Bajracharya, and Sulochana Shrestha. Economic feasibility study of Gravitational Water Vortex Power Plant For the Rural Electrification of Low Head Region and Comparative Study with Low Head Power Plants. Volume 3 Number 1, January-June 2015 DOI: 10.13140/RG.2.1.4383.4483