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HARNESSING FREE SURFACE VORTICES FOR CLEAN ENERGY: TECHNICAL AND EXPERIMENTAL REVIEW OF GRAVITATIONAL WATER VORTEX POWER PLANT (GWVPP)

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Abstract
The extracted discharge from fossil fuel operational systems and power generating plants is considered a huge concern for the developed countries since they are accountable for several epidemics, lung diseases, and environmental hazards. Hydroelectric power-generating plants provide an alternative solution to the recent energy contingency of the world, since they utilize the stored energy in a free stream of water to deliver electricity instead of utilizing oil and other fuels. Gravitational Water Vortex Power Plant (GWVPP) under the class of Mini Micro Pico Hydropower have been observed as a suitable technology to produce power from the flow of water with a hydraulic head of 0.7 - 3.0 m with a flow rate as low as 0.05 $m.s^{-1}$. This type of turbine is used in regions where the water-powered head isn't high, with high to medium stream rates. Since this technology is still in its infancy, experimental validation of theoretical work is the utmost necessity to cover the gap between claimed and achieved efficiencies. In this review work, an attempt has been made to gather the findings of experimental studies carried out by different researchers & pilot projects installed worldwide, to present the actual scenario and determine the gap between the claimed and desired results. Technical, economic, and ecological parameters of GWVPP are compared with those of other micro hydro power plants, and it is concluded that GWVPP is the most efficient of all these, having low cost, being environmentally friendly, and most useful for aquatic life.

1.1. Introduction to Hydroelectric Power

The exhaust emissions from fossil fuel-operated systems and power-generating plants are a huge threat to the current world, since they are responsible for a number of epidemics, lung diseases, and environmental degradation [1], [2]. Among the green accessible resources of energy, hydropower has a notable worth on account of its economic, self-maintainability, and natural advantages [3], [4].

Hydro-electric power generating plants can act as an alternative for the current energy crisis of the world, since they utilize a free stream of water to produce electricity to create power instead of utilizing different fuels & oil. In hydro power plants, water is put away at a higher potential. This water is then permitted to enter the cutting edges of a pressure-driven turbine. Utilizing the turbine, mechanical energy can be delivered from the potential and dynamic energy of the moving water. When mechanical energy has been converted, then, at that point, this mechanical energy can be converted to electrical power which might be sent through electric lines for use [5]. Hydropower potential can be arranged as "Pico" less than 0.005 MW, "Micro" less than 0.1 MW, "Mini" less than 1 MW, "Small" less than 10 MW and "Large" greater than 10 MW hydropower plants.

1.2 Introduction to Micro-Hydro Electric Power Plants

The high cost of maintenance and construction required for the large hydro power plants has made micro and pico hydropower more popular in rural areas. Recent increase in diversion towards Micro-hydro technology is due to the low cost of installation, higher recorded efficiency, operation and maintenance, portability, as well as low environmental impacts compared to higher capacity hydro power plants (Williamson *et*, 2014). In addition, off-network electrification in regions of rural population is an essential operator for the execution of micro, mini, and pico hydro generating power, especially in regions that are developing [World Bank 2006]. Small-scale hydropower plants having a capacity ranging from 5-100 kW are categorized as Micro hydropower plants, and hydropower plants with a capacity < 5 KW are observed to be Pico hydropower (Annual Report FY 2067-2068 (2010-2011), 2018).

1.3 Pakistan's Potential in Micro-Hydro Power Plants

Fortunately, Pakistan has a very vast capacity for micro hydro power plants, but due to the social and financial problems encountered in the country, this potential has not yet been utilized in a proper way. The huge potential of Pakistan in micro hydro Plants is due to the abundant small rivers which are located in the planar and mountainous regions of Pakistan. The Hydropower generation capacity of Pakistan has been estimated to be approximately 70,000 MW which is almost 10 times more than the recent hydal power produced [6].

This tremendous potential is because of the uneven landscapes comprising countless trenches and waterways. By the right use of these water assets, a ton of energy can be delivered. The huge number of waterways, streams, and cascades situated in Pakistan, specifically Khyber Pakhtunkhwa (KPK), is a reasonable spot for the establishment of miniature hydro power plants. Countless miniature hydro power plants have effectively been introduced in Chitral, Mardan, Dir, Shangla, and Mansehra [6].

At present, the Government and different NGOs are dealing with the establishment of SHPPs in the region [7]. PCRET introduced nearly 678 SHPPs that go from 5 to 100 kW throughout the region. These plants were introduced from 1978-2016 and produce 9.507 MW of hydroelectric power [8]. Among non-administrative associations and organizations, SRSP has had a major influence in providing power to remote regions that are not associated with the public grid. As per a study conducted in Malakand Division, KPK, (25%) of the entire population is still not electrified. SRSP has introduced 166 SHPPs in 12 years (2006 – 2014) with an expense of Rs. 1.25 million, which supply 9.6 MW of hydroelectric capacity to more than 0.242 million individuals. Though the quantity of hydro power plants introduced has expanded to 422 out of two consecutive years because of the expansion in power interest. These 422 SHPPs produces 33 MW of power and energize practically 0.7 million individuals [9]. These plants are made functional with an expense of Rs.3.2 billion. PEDO is additionally dealing with SHPPs which will supply 2156 MW of electric force by 2020. The hydro power plants installed and made operational by PEDO are expected to have rate of return within 5 years.

Alongside these hydro power projects, WAPDA has found more destinations, where the hydro plant of 60 GW limit can be introduced [12]. While the absolute introduced size and limit of hydroelectric power is 7407 MW as of today. That shows that just 11% of its found assets is used. Consequently, the need emerges to create electrical energy from these recognized sources. The higher part 39717MW of these perceived assets can be obtained from the stream Indus, followed by the Jhelum River 5624MW. The extent of every stream is given in Fig. 1.

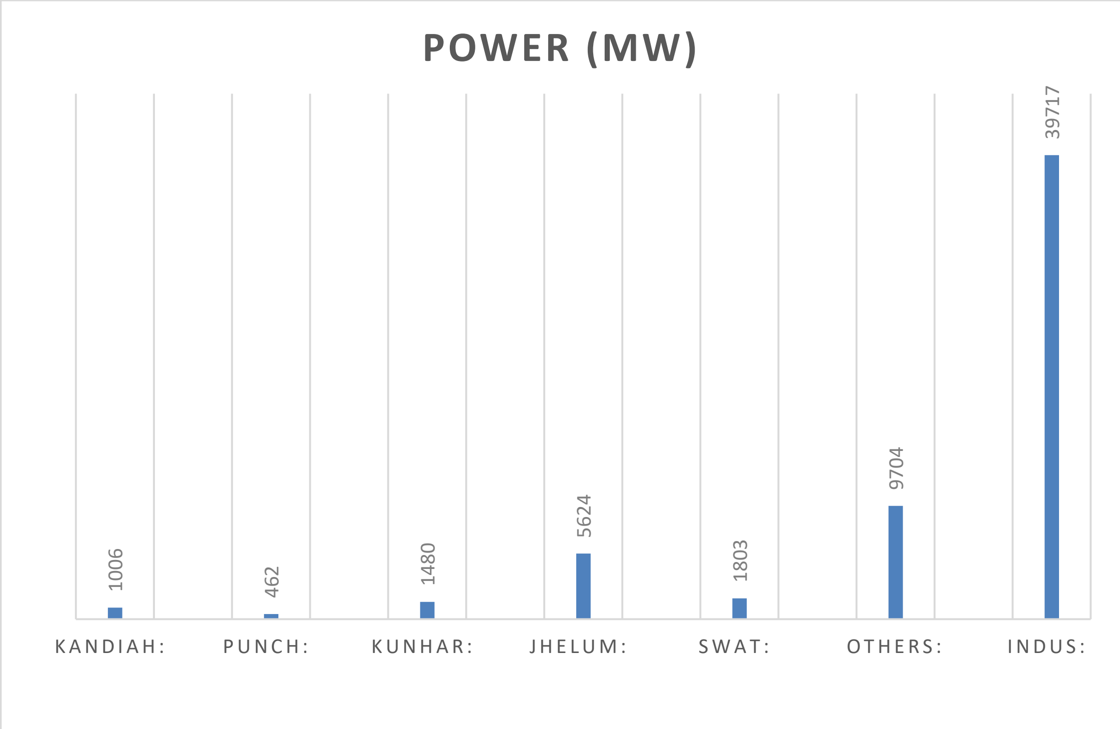


Fig. 1.1 Spotted Power on main rivers [10]

As indicated by the area-wise arrangement of hydroelectric power, 40 % of existing hydropower assets are accessible in KPK. However, 36% of the distinguished assets are accessible in Gilgit Baltistan.

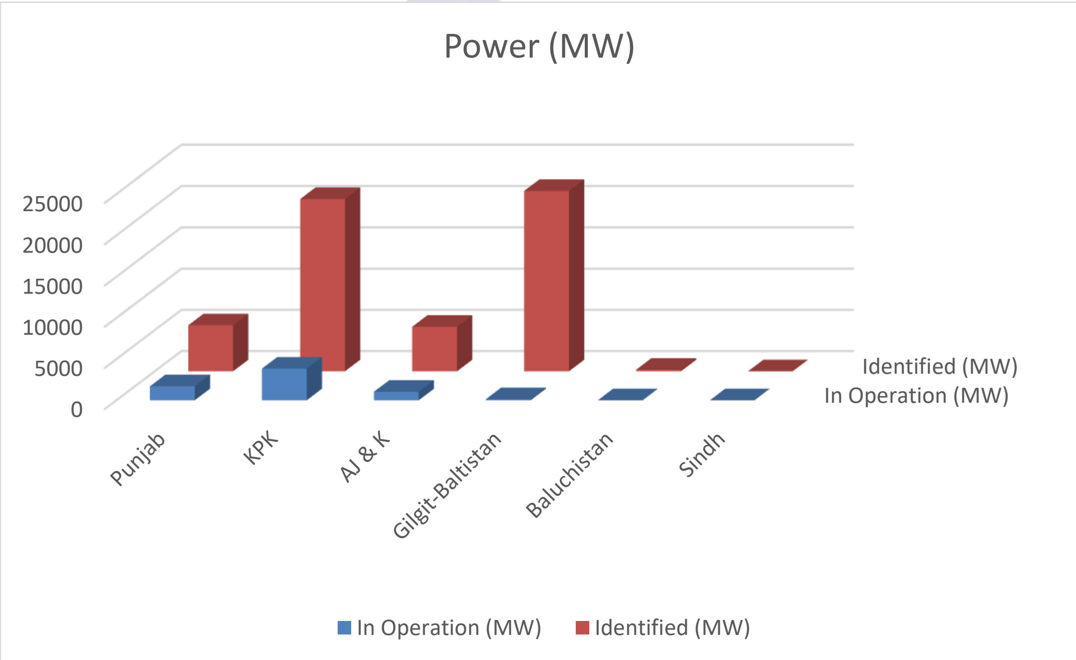


Fig. 1.2 Identified and operational hydropower plants in Pakistan [10]

1.4 Gravitational Water Vortex Power Plant (GWVPP)

These systems, under the category of mini micro pico hydropower plants, have been observed as a suitable technology to produce power from the flow of water with a hydraulic head of 0.7 - 3 m with a flow rate as low as 50 L/sec. This system consists of inflowing channeled water into the circular basin tangentially. The transfer of energy from water to the runner is due to the whirlpool of vortex generated on the open surface of the basin, and the flow is controlled by the exit hole at the bottom of the basin. This turbine is used in regions where head doesn't require to be high, and high-medium flow rates (Timilsina, 2018). The cost of construction of the Gravitational Water Vortex Power Plant is comparatively low, as it is easy to build with no need for a dam and can likewise be made possible utilizing regional raw materials (Dhakal et al., 2017). Irrigation canal sites offer favorable economic cost reduction for the installation of the Gravitational Water Vortex Power Plant (Dhakal et al., 2017).

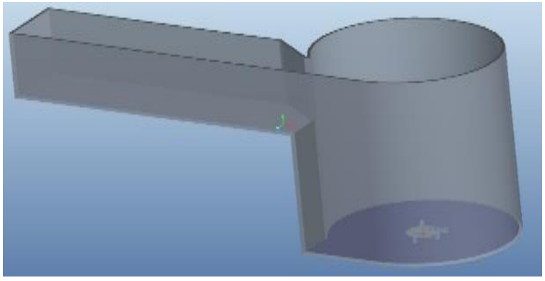


Fig.1.3 CAD model of a cylindrical basin

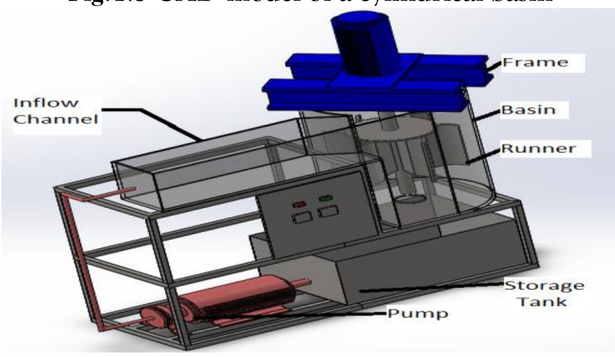


Fig.1.4 CAD model of the laboratory test setup of GWVPP

GWVPP was introduced first by Zotloterer in Austria. Zotloterer patented his turbine in 2004. This plant utilized a flow rate of 1 m^3 s and a head of 1.3 m. According to Zotloterer, 80% efficiency of the plant was obtained. This plant had a capacity of producing 10 kW of electric power [1]. Those factors that decide the selection of a specific hydropower plant for execution in far-off and rural regions are cost, simplicity of establishment, efficiency, transportability, and maintenance [Demetriades, 1995, Williamson. 2014]. Amongst the turbines, Francis and Kaplan were observed to have much better performance for low-head power-generating plants; however, their design and manufacturing is generally costly and complicated [Demetriades, 1995] and specifically experience huge costs of maintenance [Engelke, 2006]. The down portion of the runner's bearing for the turbine is the consistent reason for collapse, and moreover, windings of the generator, additionally, seals also fail on a continuous basis, and spillage of moving water to the generator also creates problems [Paish & Green 2017]. Compared to GWVPP, one of the other disadvantages of these turbines (Kaplan and Francis) is the requirement of relatively high flow rates to get the productive efficiency that will, in general, deliver little flow to waterway or household applications, which is unreasonable. For low stream and lower applications of head, the screw turbine of Archimedes is viewed as a promising competitor giving positive and consistent efficiencies over the working conditions, in addition to having a lower rate of maintenance [Aggidis & Waters 2015]. Furthermore, the working and operating scope of the Archimedes turbine is restricted to almost 1-5m and will likewise have a huge development impact compared to different innovations operating in a similar force range.

A new technology that appeared to be a promising hydro power candidate to compete with the conventional systems. The principal benefit of this force plant lies in a super low head requirement, just as harmless to the ecosystem [13]. Specifically, low head SHP is gaining consideration as conventional turbines, like the Pelton and Kaplan turbines, are ordinarily restricted to water heads of more than 3m. Because of its super low head necessity, the plant doesn't work on the pressure difference, but rather on the power created by the vortex in the basin [13]. Subsequently, the development and power-delivery costs are extremely low in the GWVPP when contrasted with other hydro power technologies.

All the micro hydro power plants have some upper hand over one another. Yet, the GWVPP enjoys certain unique benefits over the remaining kinds of micro hydro power plants, such as:

- Contrasted with other hydroelectric power producing systems, the GWVPP has the most noteworthy potential at low head regions and, in contrast to traditional reaction or impulse turbines, they have the possibility for keeping up with high efficiencies even as the water head moves toward almost zero. Because the head is only required to produce an artificial vortex, and there is no other benefit of a higher head for this turbine system [14].
- It works at a low rpm and is not involved in diverting the normal stream of water; consequently, it doesn't harm the marine and aquatic life [15]
- In contrast to GWVPP, common run-of-river technologies are easier and simpler, and so turbine costs are minimized.
- Its simple design also permits it to be fabricated in local workshops, allowing the design to be replicated across the world.
- It builds the water surface region and subsequently expands the course of air circulation immediately because of the great speed of stream on the water surface region to help the self-decontamination of water with organisms and water plants. So, it improves the concentration of dissolved oxygen therefore it is useful for the aquatic and marine life as compared to other small hydro power plant [16].
- Increases the head of evaporation and helps to reduce the rising temperatures in the summer. [16].
- It can be installed and made operational on the run of the waterway, so there is no requirement for dam development.
- No reservoir for water storage is required for GWVPP.
- For similar stream conditions, GWVPPs produce more yield power when contrasted with other miniature hydro power plants [17].
- It's a low-head (0.7-3 m) miniature turbine innovation and can be effortlessly introduced on water trenches, streams of water, and waterways [15].
- A few numbers of this type of turbines can be implemented on a single river in a cascaded shape, such that they are unable to affect the flow of the consecutive turbines in the system [12].

1.5 Aim and Objectives

A lot of theoretical work has already been done on the topic but since this is a new technology and it needs validation through experimental work. So, the author has tried to provide a comprehensive and defining review on past experimental setup and pilot installations that are operational throughout the world, in order to decide the gap in the vortex power plant innovation advancement through past experimental works.

A bunch of exploration suggestions from the findings of this work will be developed as an effort to accelerate the technology for pilot installations of GWVPP on sites.

2. Background and Overview

GWVHP innovation is as yet viewed as in its initial stages. Even so, since its very first implementation in 2006, the investigation shows that there has been plenty of both scholarly and commercial activities of research conducted on this framework in the course of recent 10 years, which is fostering a more profound comprehension of the framework taking into consideration changes and adjustments to work on both execution and water powered mechanical efficiencies. There is a huge number of literature available on theoretical and numerical analysis after its first deployment but still there is a lack of experimental validation as numerical and theoretical studies claims to have higher efficiencies up to 80%. Therefore, literature review has been taken by author on experimental setup and pilot installations of Gravitational water vortex power plant.

The initially published studies of experimental setup on basin for low head power were attempted by Mulligan & Casserly in 2010, Mulligan & Hull in 2011, and finally Mulligan in 2012. From this test assessment, the creators pondered the consequences of the plan of the basin and changed the distance across of leave opening, utilizing a d/D extent, where "D" was supposed to be the width of the basin. They assumed that ideal vortex strength conveyed when 14 percent ≤ d/D ≤18 percent. They furthermore assumed that the lower portion and upper extent for d/D correlate to lower and higher water-driven head locales separately.

The most punctual distribution concerning GWVPP is by Marian et. al. in the year 2012. The primary motivation behind their exploration work is to determine the impacts of basin setup on the turbine's performance. Various sizes of Francis turbines at various degrees of depth are a sensible alternative for GWVPP. From reenactment, it is additionally perceived that the vortex formed was relatively straightforwardly with the speed of revolution without the presence of turbines; however, in the presence of a turbine, the vortex height changed in general, resulting in a decrease in efficiency.

Bajracharya & Chaulagai [2012] conducted assessments on bowls/basins, where the base portion of the inflow stream is higher than the base portion of the bowl. Having the headway of a straight slider system, it has been observed that the strength of the vortex was steady from the channel towards the vortex bowl and leading towards the leaf opening. Since the leave opening of these plans was extended, it was concluded that the framework couldn't make and keep a consistent vortex and accordingly a high delivery was needed.

Dhakal in [2013] altered a runner (impulse in nature) and made Bajracharya & Chaulagai in [2012] past plan into another cone shaped basin. The acquired findings revealed that a higher upheaval of stream can be gained in the cone like basin. Additionally, power conveying effectiveness seem to be higher in the cone like formed bowl for a comparative stream condition as tried in the Bajracharya & Chaulagai's basin.

Additionally, examinations on the impeller showed that there seem to be a compelling bending of vortex stream when enormous no. of blades were used [Dhakal 2013]. In an examination, comparative blade designs were investigated in order to cultivate runners having three, six and twelve number of sharp edges with comparable external radius. Estimation of power, speed of runner, and torque estimation concluded production of power decreases with increase in no. of blades.

Sritram [2015] observed experimentally the various materials of turbine like aluminum and steel. In this investigation, it was discovered that materials having lighter weight, for example, aluminum utilized in the impulse type runner had the option to withstand the stream conditions and brought about higher efficiencies because of the decrease of self-weight of turbine.

Rahman [2016] tried experimentally distinctive profiles of vortex for three diverse hydraulic head setup and efficiencies of 4 unique turbine profiles in these three bowls/basins. The outcome obtained elaborate that for higher revolving speed of the turbine doesn't altogether mean higher efficiency. Like the discoveries of Mulligan & Casserly [2010].The greatest effectiveness come about when revolution speed of the runner was half of the tangential speed of the moving vortex. The exploration shows that most effective efficiency come about with the runner having less no. of blades. Yet, the discoverers didn't give full data about the diameter of basin and procedure used for the prediction of hypothetical design.

"Wichian & Suntivarakorn" in the year [2016] inspected the adequacy of the baffle turbine on the effectiveness. The runner made out of five sharp edges arranged reliably across the boundary with the plates fitted at the top and lower part of the blade. Five remarkable designs having distinctive baffle plate regions were reviewed. The altered runners were likely tried at three unmistakable stream rates. Assessment assumed that a runner having plates makes a higher usefulness to those without plates. An impeller having 50 % of plates seemed to be the best; however, a further extension in the amount of baffle plates reduces the force.

Christine et. al. discovered that proficiency of hydro-electric plant is expanded, when quantities of blades were increased from 2 to 4.

Power [2016] directed a parametric experimental investigation to clearly comprehend the diverse operating and working conditions of the GWVHP. Keep on varying a few parameters, like height of the vortex, rotational speed, and the slowing down power, were estimated. Among the 5 parameters analyzed for examination, the ones that were linked to the impeller were the blade number and its size. It was tracked down that vortex height diminishes with an increment in size of blade however, braking force increments (because of increase weight of impeller henceforth the efficiency) delivering the increase in hydro power yield in this way the efficiency. A comparable outcome was achieved with an increase in the number of blades as it adds to the mass. However, past some threshold value of mass, the speed of the runner diminishes, resulting in a loss of power. The input capacity of the system was changed by modification in stream flow and height of the inflow pipe, among which the most extreme effectiveness is brought about as a result of the greatest value of flow & height.

3. Results & Discussions

This section summarizes the findings of the whole study based on the methodology that the authors have applied to gather critical information.

3.1. Experimental research insights on GWVPP

Author	Year	Research Methodology	Research Parameters	Major Findings
Turbine Configurations				
ulligan and Casserly	2010	Experimental	*Diameter of outlet orifice. *Runner speed.	For maximum vortex strength, the outlet dia. should be in between 14–18% of the basin diameter. The efficiency of the runner is max. at 0.5*speed of vortex.
Chaulgai and Bajrachrya	2012	Experimental	Turbine Runner	Governing idea of water vortex turbine has been suggested.
Marian et. al.	2013	Theoretical + Experimental	osition of turbine	Maximum energy is extracted if the position of the turbine is kept near the outlet of the basin.
sh Dhakal et. al.	2014	Experimental	*Number of blades of turbine.	Power decreases as the no. of blades of a turbine is increased.
Sagar Dhakal	2015	Experimental	osition of runner	Vortex velocity for the basin is max. when the position is approached closer to the outlet of the basin. Maximum power in the conical shaped basin is extracted if the position of runner is kept 65-75 % times of the overall height of basin, examined from the basin's top.
Sitram. al.	2015	Experimental Study	Turbine material	Aluminum metal for turbine is more effective compared to steel

Christine et. al.	2016	Experimental	No. of blades of runner	The efficiency of the turbine is directly proportional to the no. of blades.
Rahman et al.	2016	Experimental	Runner	Maximum efficiency is obtained when the speed of the runner is one-half of the vortex velocity.
Wichin. al.	2016	Experimental and CFD	Baffle plates	Baffle plates installed in the turbine increase its efficiency, but are limited to a definite range only.
Gautm. al.	2016	Experimental and CFD	Turbine Runner	Efficiency is recorded to be increased by 6 % at optimum conditions, when three of the runners are attached at three different spots on a single shaft.
Power. al.	2016	Experimental Study	Turbine Runner	A runner having a heavier mass is more effective; however, power output is observed to be decreased after the optimum mass.
Khan	2016	Experimental and CFD	Turbine Runner	Those blades that have a curved profile are more effective. (Curved blades for vertical plane)
Dhakal. al.	2017	Experimental and CFD	Turbine Runner	Those blades observed to be more effective have a curved profile. (Curvedblades for horizontal plane)
Kueh. al.	2017	Experimental Study	Turbine Runner	Blades that are curved (vertical axis at outlet) are more efficient.
Fatimah et al.	2020	Experimental	Number of Blades	6 blades gave a max power output of 5 mW with higher torque.
Faraji et al.	2022	Numerical + Experimental	Runner Profile	Curved blades increased total efficiency by 3.65%.
Faraji et al.	2024	Experimental	Runner design	Efficiency ranged 9.84 - 25.35 %; exergy efficiency 43.58%.

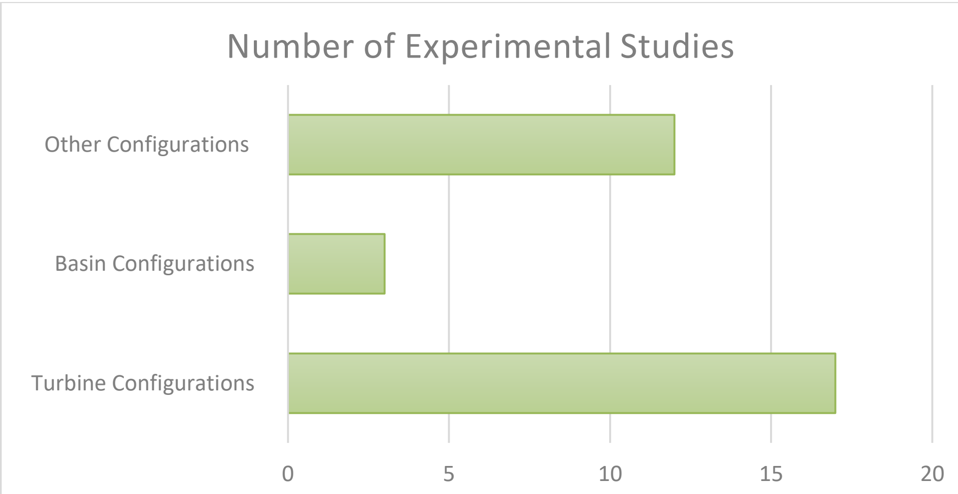
Table 3.1 Summary of experimental research on the runner of GWVPP

Author	Year	Research Methodology	Research Parameters	Major Findings

Basin Configurations				
Dhakal et al.	2013	Experimental	Comparison of basin	Conical basin has a high vortex strength produced in it as compared to "Chaulagi and Bajracharya's" basin.
S. Dhakal. al.	2015	mental and CFD	Comparison of basin (Cylindrical VS Conical) structure	Conical basin observed to be more efficient than cylindrical basin in terms of vortex velocity, that leads to vortex strength and in turn power extracted.
P.S.V.V Srihari	2019	Experimental	Intensification with conical basin	Intensifying nozzles fortify the vortex intensity in the cone like basin.
Other Configurations				
Wanchat et. al.	2013	Experimental	Varied outlet diameter	Range of outlet basin diameter is 0.20m to 0.35m
Shabara et. al.	2015	CFD and Experimental	Varied outlet diameter	Outlet speed is inversely proportional to exit diameter. Max. exit speed is acquired at most noteworthy H_{inlet}.
Christine et. al.	2016	Experimental	*Inlet flow rate *$H_{channel}$	Efficiency is most noteworthy at max. bay stream. Ideal $H_{channel}$ is at 33% of basin's stature.
D.L Zariatin	2020	Experimental	Three different runners	Denser turbine material will be heavier and will generate more energy.
Tri Ratna Bajracharya,	2020	Numerical + Experimental	Geometrical Parameters in GWVPP turbines with conical basin	It suggests that height of the runner is the best and critical boundary to be considered in the plan of a turbine runner for GWVPP.
Ashish Sedai	2020	CFD + Experimental	Scale down model of GWVPP (1:20)	Efficiency of the GWVPP greatly reduced as you scaled down the model. Higher capacity plant (e.g 12KW) is more efficient than low capacity.

Aziz et al.	2020	Experimental	losed GWVT	69.39 W power at 6.3 L/s flow, efficiency 16.06%.
Adarsh Gupta	2021	CFD + Experimental	Different runner blade profiles	A curved blade profile with measured angle of 18° to 24° among the blade and the hub is best for the small hydro power plant with an efficiency of over 50 %.
USU Study	2021	Pilot Testing	1 kW GWVPP Prototype	Prototype achieved 49% plant efficiency at 1 kW output.
Edirisinghe et al.	2023	Numerical + Experimental	Industrial Wastewater Application	60.5% prototype efficiency; scaled model produced 6 kW at 63.3%.
Huwae et al.	2023	Experimental	Inlet Channel Design	Strainer 5 cm from channel increased power output by 60%.
Burbano et al.	2023	Experimental & CFD	Inlet Channel Geometry	Trapezoidal channels improved output by reducing viscous losses.

Table 3.2 Summary of experimental research on basin and other configurations



The plot shows the number of studies across different Research Focus Areas in GWVPP.

It is evident that the majority of research has focused on experimental studies of turbine runners, while significantly fewer studies have been conducted on basin and other configurations. The basin, being the critical component of GWVPP where the artificial vortex is generated, plays a crucial role in enhancing the vortex strength, which in turn can improve both the efficiency and power density of the plant. While some researchers have explored basin configurations through CFD analysis, GWVPP remains a relatively new technology, and numerical analyses require validation through experimental work. Therefore, it is strongly recommended to prioritize experimental studies on the basin, as this will not only optimize its structure but also contribute to improving the overall efficiency of the GWVPP.

4. Full-scale installation survey:

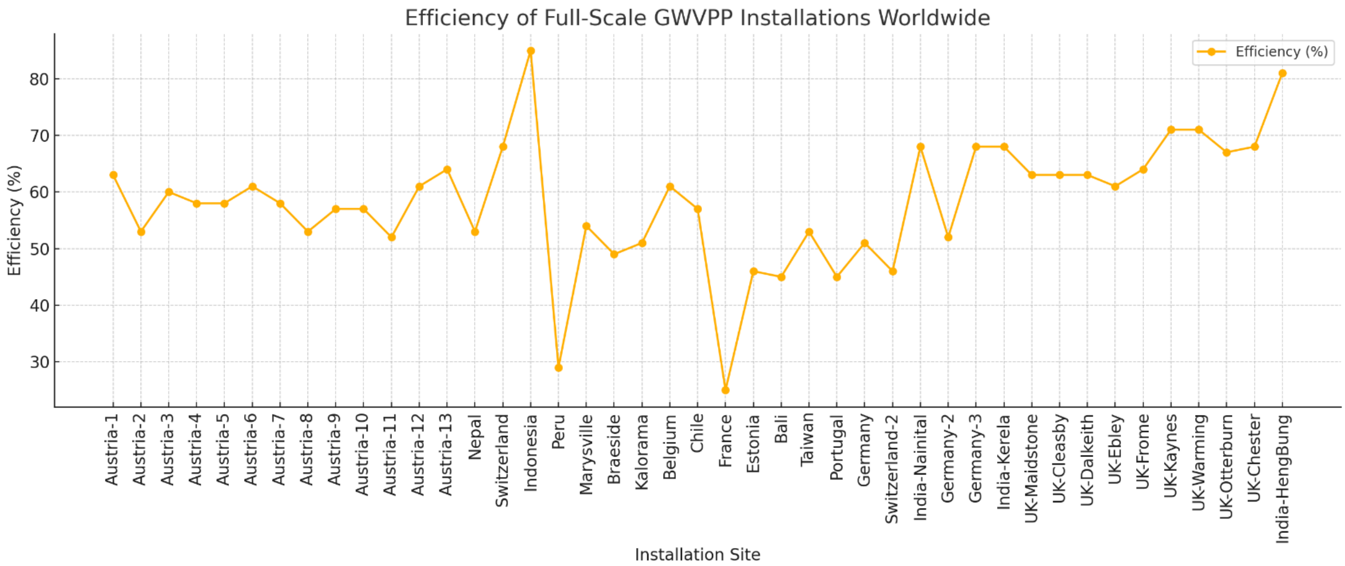
In this study author has conducted an installation survey of full-scale gravitational power plants installed worldwide. This survey includes investigating through articles and reaching out to a few organizations in order to know the location of the site, flow rate, hydraulic head, and power output, so that efficiency and power density may be determined. In the table below is a list of full-scale surveyed installations throughout the world to date.

Table 4.1 Summary of full-scale installation survey

Sr. No.	nization	Site Location	r. Head (m)	Flow Rate (m^3/s)	Output Power (KW)	ciency (%)	Power Density
1	Zotloterer	Austria	1.5	0.9	8.3	63	9.22
2	Zotloterer	Austria	0.9	0.7	3.3	53	4.71
3	Zotloterer	Austria	1.5	0.5	4.4	60	8.80
4	Zotloterer	Austria	1.4	0.5	4.0	58	8.00
5	Zotloterer	Austria	1.4	0.5	4.0	58	8.00
6	Zotloterer	Austria	1.4	0.6	5.0	61	8.33
7	Zotloterer	Austria	1.5	1	8.5	58	8.50
8	Zotloterer	Austria	1.2	1.2	7.5	53	6.25
9	Zotloterer	Austria	1.8	1	10	57	10.0
10	Zotloterer	Austria	1.6	2	18	57	9.00
11	Zotloterer	Austria	1.0	0.9	4.6	52	5.11
12	Zotloterer	Austria	1.5	1.0	9.0	61	9.00
13	Zotloterer	Austria	1.8	0.8	9.0	64	11.25

14	Vortex Energy Solution	Nepal	1.5	0.2	1.6	53	8.00
15	GWWK Schweiz	Switzerland	1.5	1	10	68	10.0
16	Green School	Indonesia	1.5	1.2	15	85	12.5
17	Khadagya	Peru	1.2	1.02	3.5	29	3.43
18	KCT	Marysville	0.6	0.1	0.3	54	3.1
19	KCT	Braeside, Australia	0.8	0.05	0.18	49	3.6
20	KCT	Kalorama, Australia	1.0	0.1	0.5	51	5
21	Turbulent	Belgium	2.0	0.25	3.0	61	12
22	Turbulent	Chilie	1.5	1.8	15	57	8.3
23	Turbulent	ersailles, France	3.2	0.7	5.5	25	7.85
24	Turbulent	Otepää, Estonia	1.6	0.75	5.5	46	7.33
25	Turbulent	Bali, Indonesia	1.85	1.57	13	45	8.28
26	Turbulent	Ylang, Taiwan (In progress)	3.3	5.8	100	53	17.24
27	Turbulent	Mindanao, Philippines (In progress)	Under process	Under process	120-150	Under process	Under process
28	Turbulent	Pichorro, Portugal (In progress)	1.5	0.75	5	45	6.66
29	Turbulent	Suriname (In progress)	Under process	Under process	15	Under process	Under process

30	Aquazoom	Wesenitz, Germany	1.2	1.5	6	51	4.0
31	Aquazoom	Suhre, Switzerland	1.5	2.2	15	46	6.8
32	Aquazoom	ainital, India	2.0	1.5	20	68	13.3
33	Aquazoom	ermany	1.2	0.5	3	52	6.0
34	Aquazoom	resden, Germany	1.0	0.75	5	68	6.66
35	Aquazoom	erela, India	1.5	1.0	10	68	10.0
36	Aquazoom	aidstone, UK Jpcoming)	2.0	2.0	25	63	12.5
37	Aquazoom	leasby, UK Jpcoming)	2.0	4.0	2*25	63	12.5
38	Aquazoom	alkeith, UK Jpcoming)	2.0	2.0	25	63	12.5
39	Aquazoom	oley, UK Jpcoming)	1.5	2.0	18	61	9.0
40	Aquazoom	ome, UK Jpcoming)	1.5	3.0	2*14	64	9.33
41	Aquazoom	aynes, UK Jpcoming)	1.2	1.2	10	71	8.33
42	Aquazoom	'armingham JK Jpcoming)	1.9	0.9	12	71	13.3
43	Aquazoom	tterburn- UK Jpcoming)	1.9	2.0	25	67	12.5
44	Aquazoom	hester-UK Jpcoming)	1.5	1.0	10	68	10
45	Aquazoom	engBung, India (Upcoming)	1.5	1	12	81	12
						Average Efficiency = 58.16	Average density = 8.79



This plot shows the efficiencies of installed full-scale GWVPP worldwide.

Technical analysis of gravitational water vortex power plant:

The table above shows the full-scale installed GWVPPs and upcoming power plants in the near future throughout the world. Based on the experimental study and technical data obtained from 45 different installations all around the globe. This section of the study attempts to analyze the technical parameters of GWVPP to suggest the most effective technical plan for the installation of GWVPP in rural areas. Most of the data are collected from the published research papers and the publications of the researchers. Also, data from some location sites is collected from manufacturers' websites and by personal enquiries from installers.

In order to describe the performance characteristics of a micro power plant, efficiency is the dominant parameter to evaluate its performance, but for ultra-low sites, since the head nearly becomes zero for these sites, therefore, power density becomes a more important parameter than efficiency. Power density is basically the power generated by a passing water through a turbine per unit volume. It can be seen from the 45 installation plants that most of the plants are below 10kW capacity. We can see from the table that mostly those installations that have higher installation capacity, i.e., above 10kW, have higher power densities and efficiencies. The average efficiency of all the installation plants is recorded to be approximately 58%. However, Zotloterer claims to have approximately 83% efficiency for GWVPP. It can also be noted that results of all the academic research (that was carried out on small scales, i.e., < 1 kW) show 20–30% of efficiencies for the system [Wanchat et al.2013]; However, those plants that have capacities more than 10kW are mostly recorded to have average efficiencies of approximately 65%.

4.1. Economic analysis and environmental impact of gravitational water vortex power plant:

An economic analysis is conveyed by Zotloterer for the first 10-kW GWVPP located in Obergrafendorf, Austria (working since 2006). This contextual investigation presents functional expenses, capital expenses, and produced income for GWVPP to observe the amortization as contrasted to a traditional hydropower framework. The analysis is outlined below:

The expenditure for the development of a 10-kW GWVPP was 60,000 US dollars.

- The expense of maintenance and operation was around 1000 US dollars per annum.
- The mean power yield was fifty-five thousand kW for each annum. The association structure uses the power expenditure, with an expense of 0.2 dollars/kWh for energy use, which adds up to 11 US dollars/annum. Project was tracked down to have a rate of return of 7 years.

However, a conventional hydropower system of the same capacity has a return of 15 years because of the high initial cost. The higher capital expense of customary power plants was expressed because of the need of fish pass, cleaning framework and fine screen, turbine arrangement and generator lodging that are asserted not be needed in gravitational vortex power plant.
Thus, the return on investment of 7 years is more favorable.

The cost breaks down resulted from the economic case study of Zotloterer's installation, the cost of civil works is highest amongst all other linked cost which makes it the costliest installation among all other installation. In comparison to the latest implementations from Aqua zoom and Turbulent, the Zotloterer's installation comprised of cylindrical basin two-three times bigger in size which makes the cost higher in civil works. Later Turbulent and Aqua zoom adapted a smaller size cylindrical basin for minimizing the civil works which in turn minimize the total cost and % of civil works cost in the total project cost.
Besides, they additionally pick destinations having existing water framework like irrigation canal, weir structure and reservoir, etc. in which minimum civil work is needed to divert the water flow towards basin. Unlike other, Kouris power accumulated a system having less civil construction among all other installers. According to their economic study of 10-kW installation, he spends only 12 % on civil works out of the total cost of 45,000 euro. It can be seen from the study that progress has been made to minimize the civil cost work from the early patent of Zotloterer to the last patent of Kouris.
Dhakal. al [2015] suggested a conical-shaped basin, which reduces the civil work cost very much (which is considered one of the prominent costs in the overall construction of GWVPP), and also determined that the efficiency of a conical basin is higher than that of a cylindrical basin.

4.2. Environmental Impact:

The advantages of the vortex turbine, in contrast to other micro hydro turbines (with the exception of the screw Archimedes turbines), it is that the pressure differences are small since it works with free surface flow and a small height difference. Moreover, the big clearance between blades helps to make this turbine fish-friendly.
It works at much lower rpm and doesn't upset the normal stream of water; subsequently, it doesn't hurt the marine and aquatic organisms [15].
This system enhances the space of the water surface and, in this manner, builds the course of air circulation normally because of the great speed of development on the water surface region to support the self-purification of water with water plants and microorganisms. So, it enhances the dissolved oxygen concentration, hence it is useful for the aquatic and marine life as compared to other micro hydro power plants [16].
It increases the head of evaporation to reduce the temperature of water by itself at rising temperatures in the summer. [16].
According to Zotloterer's statement, fish can migrate the GWVPP in both directions, downstream and upstream.

Conclusion & Research Recommendations

Conclusion:

GWVPP is found to be an efficient source of electricity generation, especially in rural areas where it can be installed along the run of rivers, by using very low head and low flow rates.
Because of its low ultra head requirements, the vortex plant doesn't operate on the difference of pressure but on the force of the dynamic produced by the vortex in the basin. Therefore, hydropower producing costs are much lower compared to other micro hydropower plants.
Pakistan has a strong potential for producing power from run-of-river projects. The huge capacity of 39717MW of the determined assets can be delivered from the water of the Indus River, followed by the Jhelum River, 5624MW. Right around 40 % of present hydropower assets are accessible in KPK, and 36% of the perceived assets are accessible in Gilgit Baltistan. Subsequently, the need emerges to deliver electrical energy from these distinguished sources.
As this technology is new and developing very quickly, experimental validation for its theoretical findings is the utmost requirement. Studies have shown that most past work (both experimental & theoretical) has been done on the optimization of the runner, but very few studies have been found on the optimization of the basin, which is one of

the reasons efficiencies have not been obtained to date, as claimed by Zotloterer (83%).

A survey showed that almost 40 GWVPP are in operation worldwide; a few are in progress and are likely to be completed soon. The average efficiency of all the installation plants is recorded to be approximately 58%. However, those plants, having capacities more than 10kW, have recorded the average efficiency of approximately 65%.

Technical, economic, and ecological parameters of GWVPP are compared to other micro hydro power plants, and it is concluded that GWVPP is the most efficient of all these, having low cost, being environmentally friendly, and most useful for aquatic life.

Research Recommendations:

A set of research recommendations is determined from this work, which is presented here to support the present research.

- Optimization of the basin using an experimental approach to cover the gap between the claimed and achieved efficiencies.
- The inflow channel is one of the most important parameters that needs to be considered in future research work, as it directs water for effective vortex generation. The ratio of inlet width to height of the inflow channel can be optimized by undertaking extensive research on it to increase the vortex strength in the basin.
- A comprehensive and defining cost-benefit analysis of GWVPP compared to other micro hydro power plants would also be a productive study to summarize the quantitative monetary analysis.
- As seen from this study, GWVP plants having higher capacities achieve higher efficiencies, so GWVP plants should be tested for higher capacities.

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