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Using Barrages on the Euphrates River in Iraq to Generate Clean Electrical Power

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Abstract: In the present study, the Archimedes turbine is employed at low heads at Barrages and regulators in Anbar Province, Iraq. It is a small hydropower station that is suitable for application because it does not require high storage water (high head) in a Barrage. The 3D numerical model (ANSYS) has been employed for simulating and determining the power produced from the turbine in the Barrages. The physical model is applied to determine the optimal inclination angles of the shaft turbine (α) with a suitable water flow rate. This physical model was applied after conducting a set of tests that included different inclination angles of the shaft turbine (30°, 35°, 40°, 45°) and different discharges also reached the highest efficiency of 89.4% for the optimal angle of the model 35°. The results show Ramadi and Fallujah Barrages are the best investments in generating power because the discharges of these barrages continue throughout the year. Using Archimedes screw turbine as clean energy technology is an effective method and can be used to generate clean power without the need for large storage water because it appropriates the hydrologic conditions of the Euphrates River in Iraq. This study supports renewable energy, improves energy access, and contributes to energy efficiency and energy security for local communities.

Keywords: Clean electrical power; Euphrates River barrages; Archimedes screw turbine; Green electrical power; Small hydropower station; Low-Head Hydropower; Small-Scale Hydropower; Green Technology; Eco-Friendly Energy; Sustainable Development Goals

1 Introduction

The increasing energy demand caused the demand to become incompatible with production. Furthermore, the environmental repercussions associated with fuel and gas power generation have heightened the necessity to explore alternative energy sources. Renewable energy is one of the most important sources for future needs that can reduce the demand for fossil fuels [1]. The global theoretical potential for hydropower is approximately 14,000 terawatt-hours of electricity annually, comparable to current global electric energy production [2]. Although most hydropower energy will not be exploited because of economic and environmental reasons but it will develop continuously. It is a significant source of renewable energy due to its cleanliness, relative affordability, and production efficiency of approximately 100% [3]. Large-scale hydropower technologies require huge budgets and must maintain the living standards of citizens, which is so difficult in developing countries due to the high costs, including infrastructure costs and electricity transmission to population areas. Due to climate change in recent years and dam projects in Syria and Turkey, Iraq has experienced diminished river levels in the Euphrates and Tigris rivers, projected to decline by 50% and 25%, respectively, by 2025 [4–6]. The energy sector in Iraq faces significant challenges with power production because of low water in dam reservoirs such as the Haditha dam in Anbar province when the energy production reduced by nearly 50% [3]. The production capacity of Iraqi Dams was decreased from 2,500 MW to 1,300 MW, because of the lowering water level in the dam reservoirs [7]. Following the completion of the Haditha Dam in 1989, the average discharge of the Euphrates River became directly contingent upon the releases from the Haditha Dam [8]. Figure 1 shows the rate of water flows entering the Haditha Dam reservoir and released from it to the Euphrates River (2018–2022). These are the clearest years in demonstrating the impact of climate change on Iraq particularly in the Euphrates River Basin. It can be observed that the rate of water entering the dam reservoir decreases, and sometimes it reaches less than the demand requirements for use in the areas downstream of the dam.

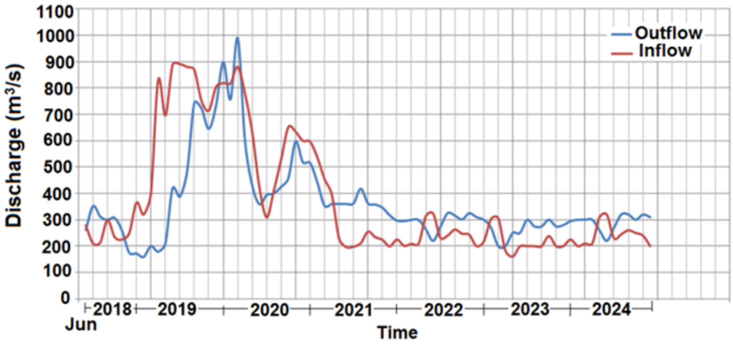

Figure 1. Inflow and release discharge (outflow) of Hadith reservoir

Figure 2 also shows the rate of flows in the Euphrates River in the Zawiya area (30 km) from the Ramadi Dam, which is based on releases from the Haditha Dam. It indicates a clear decline in their rates from 21 BCM during (1989–2000) to 16 BCM during (2011–2020) due to the reasons mentioned previously.

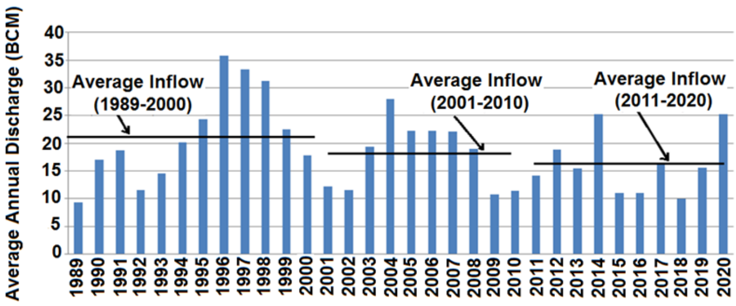

Figure 2. Euphrates inflow at Zwaia (30 km upstream of Ramadi Barrage 1989–2020)

Low Euphrates River water levels disrupt the thermal and gas power plants of (Zwiah) in Anbar province which require high flows to operate their cooling systems. The growing energy demand resulted from population growth in addition to the high demand for cooling systems in the hot summer months when the temperature can reach (50 °C). Gas-fired power plants currently constitute the backbone of electricity generation, as the scarcity of water supplies has impacted the construction of large hydroelectric power plants, which require large amounts of water and storage capacity that are currently unavailable. The weak production of petroleum derivatives to supply gas-fired power plants has also significantly impacted the production of these plants. Hence, the importance of this study in demonstrating the potential benefits of small-scale power plants that can be built on river regulators. These stations are characterized by the possibility of operating without the need for a large amount of water storage. They also enable the generation of a relatively high level difference as a result of the operation of the Barrages, which is essentially raising the water level in the Barrages upstream.

Small hydropower sources can provide power without negative effects anywhere where resources are available for generation. Those resources can be invested depending on various technologies that are available for hydropower working with low head and no need for high storage. Small Hydropower is suitable for the hydraulic conditions of the site and can be used with existing barrages or any hydraulic structures. The cost of construction works forms more than 40% of the total cost of the small hydropower stations, the setting of the turbine and generator is 30%, control equipment is about 22%, and management costs about 8% [9]. The Regulators and Barrages that were founded in Anbar province are a good opportunity to invest in small hydroelectric power stations. These structures are already constructed and form a part of the water resources management system that can reduce the costs by about 30%. Figure 3 shows the Regulators and Barrages in Anbar province that is selected as case study. It is expected that the energy generated by these Barrages will be substantial, sometimes reaching approximately 15% or more of Anbar Governorate's electricity needs. The present study seeks to ascertain the potential energy that small hydroelectric power stations can generate and utilize for the development of a water resource management system that encompasses both energy and water harvesting. The objective of the current study is to quantify the discharges of the Barrages and Regulators, as well as to ascertain the river levels both upstream and downstream of these structures, contingent upon the hydrological conditions of the river. The power generated can be assessed based on the discharge and the available head between the upstream and downstream of the structure, as well as the efficiency of the Archimedes screw turbine.

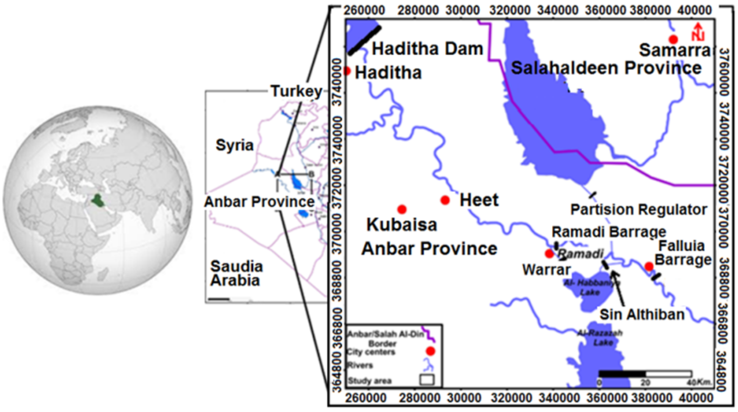

Figure 3. Regulators and Barrages in Anbar Province

Various types of hydro turbines are utilized to generate hydropower, contingent upon the head and water flow rates. The most renowned turbine utilized globally is the Pelton turbine, designed for high-head applications. The Francis turbine is employed for medium head applications, whereas the Kaplan and Archimedes turbines are utilized for low head scenarios [10]. Hydropower methods can be categorized based on variations in head and flow. Figure 4 shows the head (m) and flow rate (m^3/s) for each type [11].

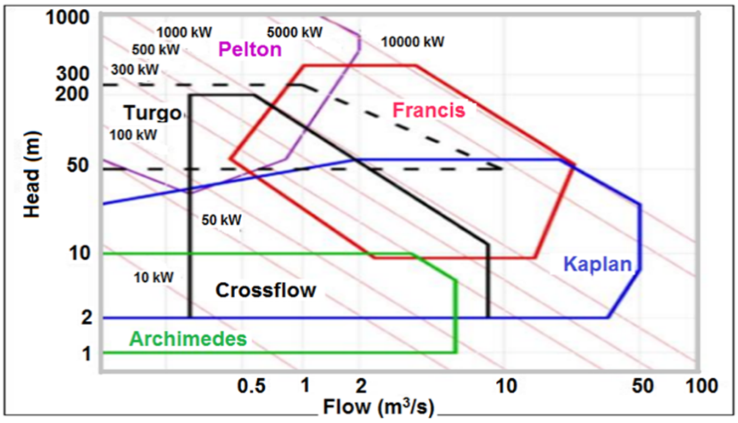

Figure 4. Classification of Hydropower techniques for head and flow rate [12]

Archimedes screw turbine technology is adopted in the present study as the best choice for a low head which is suitable for low water conditions in the Euphrates River. Also, there are five barrages along the river in Anbar province including gates with water heads (1 to 5) m between its upstream and downstream which means suitable for low-head turbines at low cost because the structures already exist (no need for construction cost).

Figure 5 shows barrages in Iraq and Stockport Hydro, Cheshire in the UK that use the Archimedes screw turbine.

Archimedes screw turbine can be installed on existing Barrages and Regulators which makes it low-cost. Furthermore, there is no requirement for extensive storage, and a reservoir will not be created that could alter the river system and displace the population [13]. This indicates that there are no expenses for civil works, which constitute a significant portion of the total cost. The design of it is simple and maintenance is very low which makes it low costs in comparison to other types of turbines. An additional feature is highly efficient at the beginning of operation compared with other hydroelectric generators, as shown in Figure 6 [14].

The limitation of the present study considered the hydraulic characteristics of the flow, represented by the discharge, available head, inclination angle, and effects of these parameters on the generation efficiency and the amount of power generated. It did not take into consideration the manufacturing characteristics and mechanical performance of the turbine.

Figure 5. Setting of Archimedes screw on Barrages

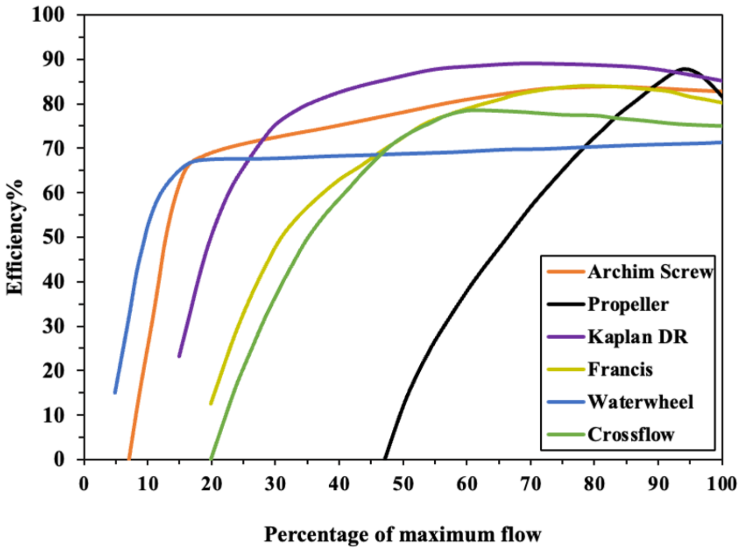

Figure 6. Efficiency of hydroelectric generators [14]

It is essential to conduct an environmental impact study (EIA) for the installation of this type of turbine on dams or barrages. The EIA includes determining the impact of turbine installation on the water level in the dam and the discharge rate, which can be controlled by controlling the openings of the dam's gates. The EIA also determines the impact of these turbines on aquatic life and fish, and the possibility of reducing this impact by designing fish passages within the regulators. With the worsening electricity problem in Iraq and the increase in pollution and emissions resulting from the use of fossil fuels, these clean energy projects could be well-received and welcomed by the local community. Especially when energy production could be incidental as a result of the operation of the Barrage, which requires the release of water discharges to areas downstream of the Barrage.

In Iraq, the energy supplied by small local plants that use fossil fuels is measured in Amperes. The cost of one Ampere from these small local power plants is 10,000 Iraqi dinars, or approximately \$8. The cost of one Ampere produced by small power plants on the Euphrates River barrages can be estimated at between 4,000 and 4,250 Iraqi dinars or 2.75–3.00\$, which encourages the successful exploitation of this energy.

2 Methodology

Figure 7 represents the methodology used in the current study. A model of the Archimedes screw turbine was designed to determine the turbine installation angle that gives the best operating efficiency. Also, to study the discharge relationship with the available head between the upstream and downstream of the turbine at the installation angle, the efficiency, and the generated power. The numerical model Computational Fluid Dynamics (CFD) aims to test several operating scenarios based on the available data for the observed elevations and discharges of the Barrages and regulators under study. The numerical model was also used to determine the effect of the turbine shaft length and diameter.

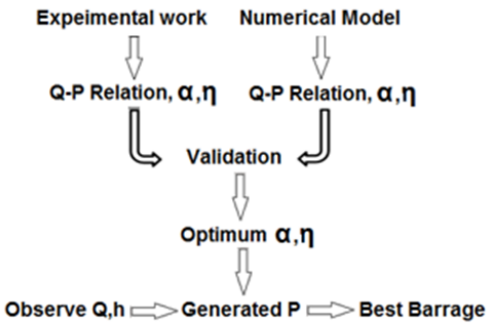

Figure 7. Methodology of the present study

2.1 Experimental Work

To minimize the cost of the experimental work, the Archimedes screw turbine model is manufactured from available materials. The model shown in Figure 8 consists of 12 helices welded on a hollow shaft (both are made from stainless steel). A small galvanized iron tube is used as a cover for the screw and the top of which has been cut to work as a trough (Figure 8). Table 1 shows the dimensions of Archimedes' screw turbine model.

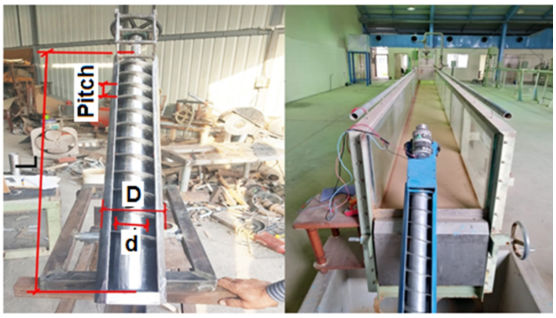

Figure 8. Trough of screw turbine

Table 1. The dimensions of Archimedes' screw turbine model

Parameters	Variable	Value
Screw length	L	1000 mm
Outer diameter	Do	130 mm
Inlet diameter	Di	70 mm
Number of helices	m	12
Pitch	P	70 mm
Slope (inclination)	α	30°, 35°

The turbine is supplied with water by the laboratory open channel device shown in Figure 8. The channel is supplied with water by a 10 hp pump and has a lock for controlling the entering flows to the channel. The power generated by turbine can be calculated using Eq. (1) [5, 14]:

$$\mathrm{P} = \gamma \mathrm{QH} \tag{1}$$

where, P = Hydraulic power in the site, γ = water density (N/m^3), Q = flow rate (m^3/s), H = head (m)

The Mechanical power of turbine is given by Eq. (2):

$$P_m = T.\omega \tag{2}$$

where, T is a torque of a screw (Nm), and ω is screw angular velocity in (rad/s) that can be estimated by the following Eq. (3):

$$\omega = \frac{2\pi * n}{60} \tag{3}$$

where, n is rotation (rpm).

The rotation (n) of screw in Eq. (3), is calculated by Eq. (4) [15],

$$n = \frac{50}{D^{2/3}} \tag{4}$$

where, D is external diameter of the Archimedes screw.

The efficiency of turbine (η) is calculated by Eq. (5):

$$\eta = \frac{P_{mec}}{P_{Hyd}} \tag{5}$$

2.2 Numerical Modelling

Fluid dynamics is a discipline within mechanical engineering that concerns the behavior of fluid flow. Fluid motion can be examined through various methodologies, including experimental studies, theoretical analyses, and numerical methods. The numerical methodology is predicated on Computational Fluid Dynamics (CFD). Numerical simulation is a computational code employed to execute simulations of fluid flow scenarios. This code elucidates various fluid flow phenomena, including fluid motion, heat transfer, thermal performance in numerous engineering scenarios, and chemical reactions involving base fluid flow [16]. The utilization of the CFD code is substantiated by its numerous advantages. This entails minimizing the duration required for constructing experimental devices and the expenses associated with physical model-based work. Furthermore, numerous details that cannot be quantified or visualized through experimentation can be effectively predicted via simulation. It has demonstrated multiple benefits regarding troubleshooting and redesign methodologies [17].

Any CFD-based model analysis includes the following steps.

The geometric construction of specific problems can be accomplished using any CAD software. In this phase, specifications must be established without any gaps, as the CFD code employs the finite volume method. Mesh is created to depict the solution domain using specialized software designed to produce either structured or unstructured mesh.

The model is prepared for resolution by a defined numerical methodology and specified boundary conditions. The numerical model analysis results are presented through streamlines, contours, and plots in the final step. Extract quantities for analysis, including velocity profile, pressure distribution, force distribution, moment distribution, etc. [18].

The governing equations of the present study can be represented by the continuity equation and Navier-Stokes equations in three dimensional, as follows:

Continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho \boldsymbol{u})}{\partial x} + \frac{\partial (\rho \boldsymbol{v})}{\partial y} + \frac{\partial (\rho \boldsymbol{w})}{\partial z} = 0 \tag{6}$$

In this context, ρ represents the fluid density; t denotes time, and u signifies the velocity vectors corresponding to the u, v, and w components in the x, y, and z directions, respectively. In this scenario, as previously stated, the problem is addressed using a pressure-based solver for incompressible fluid, resulting in a density of zero.

The Navier–Stokes equations are crucial in CFD as they depict the viscous stress term in the momentum balance. The equation provided pertains to the x-momentum and can be reformulated for the y and z directions [19]. Below is a link equation relating viscous stress to fluid pressure.

x- Momentum

$$\frac{\partial (\rho u)}{\partial t} + \frac{\partial \left(\rho u^2\right)}{\partial x} + \frac{\partial (\rho u v)}{\partial y} + \frac{\partial (\rho u w)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right] \tag{7}$$

y- Momentum

$$\frac{\partial (\rho v)}{\partial t} + \frac{\partial (\rho u v)}{\partial x} + \frac{\partial \left(\rho v^2\right)}{\partial y} + \frac{\partial (\rho v w)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right] \tag{8}$$

z- Momentum

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho u w)}{\partial x}+\frac{\partial(\rho v w)}{\partial y}+\frac{\partial\left(\rho w^{2}\right)}{\partial z}=-\frac{\partial p}{\partial y}+\frac{1}{\operatorname{Re}}\left[\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}\right] \tag{9}$$

Let p represent the pressure, Re denote the Reynolds number, and τ signify the stress. An additional equation was employed in the simulation, incorporating the turbulence model, based on a straightforward calculation derived from the Reynolds number; it was determined that this simulation case falls within the turbulence range.

A turbulence model is a computational procedure extensively employed to elucidate the significance and impact of fluid turbulence behavior in the calculation of mean flow. Numerous turbulence models are incorporated in CFD code to address and streamline the computational domain; among the most significant are the k-epsilon models, which include three renowned sub-models: standard, RNG and realizable [20]. The k - ε model delineates the correlation between kinetic energy and the dissipation rate in fluid flow issues. This model demonstrates the capacity to connect the mechanistic effect of the two-term k (kinetic energy) and the dissipation rate of this energy (ε) [21, 22]. In this simulation, it is advised that the standard base model is the optimal choice for accurately depicting the actual flow behavior, as the flow exhibits separation with swirl; utilizing this model facilitates effective convergence criteria. This study employs the k-ε model to evaluate the feasibility of utilizing an Archimedes screw turbine for power generation, based on empirical data from existing barrages and regulators under actual operating conditions. This is the inaugural comprehensive study focused on investing in Barrages on the Euphrates River to produce electricity and address its deficiency.

3 Results and Discussion

3.1 Effect of Archimedes Screw Turbine Inclination Angle (α)

The inclination angle of the Archimedes screw turbine is a crucial parameter determined by the turbine length, available head, efficiency, and power output. Müller and Signor [23] find out that the Archimedes screw turbine efficiency increases with the low inclination angle for the screw. The turbine's efficiency in relation to its inclination can be analyzed based on the results presented in Figure 9. Figure 9 illustrates that a reduced water discharge results in diminished turbine efficiency as the inclination of the turbine shaft increases. Furthermore, at elevated discharge levels, the efficiency rises with shaft inclinations of 30 to 35 or 45 degrees, subsequently declining thereafter. The optimal inclination angle of the turbine is between 35 and 40 degrees, particularly under moderate discharge conditions. The maximum efficiency was at 35°, reaching 91% then it began to decrease at the 40 angle of inclination. The efficiency decreases at a 35° inclination under high flow rates (Figure 9) because of the overflow losses will increase due to increase flow velocity in addition to inadequate design to satisfy these flow rates. Also, losses will increase when flow velocity and friction with surfaces increased. In general, the optimal angle that gives maximum power with maximum efficiency is the angle that balances friction, leakage losses, and overtaking losses.

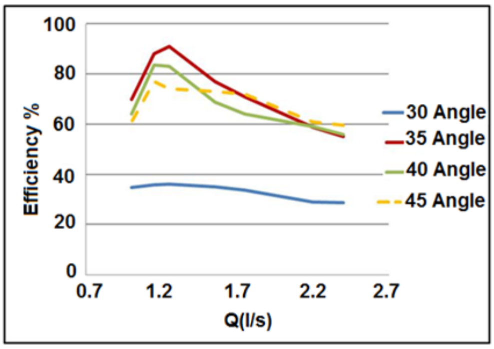

Figure 9. The relation between flow rate and efficiency

Figure 10 displays the mechanical power values derived from both the simulation (numerical model) and experimental data, based on the flow rate at shaft inclination angles of 30° and 35°. Figure 11 ustrates the anticipated correlation whereby mechanical power escalates with an increase in flow rate, and a commendable concordance between simulated and experimental power values is observed.

The numerical model was established using identical geometry and engineering parameters as the physical model, maintaining the same boundary conditions. The screw geometry is the same for each angle of inclination used which means the operated head for the power increases when the angle of inclination increases. From a theoretical view, the highest inclination angle for the screw will generate the maximum power in the experiments. The inclination angle (35°) generates power more than the inclination angle (30°). This means the losses associated with the screw are not considered when changing the inclination angle to more or less the optimum angle (35°). For the angles with a slope lower than the optimum angle, the minor losses in the screw will play the most role cause total losses. However, in angles with a steep optimal slope, the losses due to gaps and overflow will be more significant. When high flow rates occur, there's a high overflow reducing efficiency.

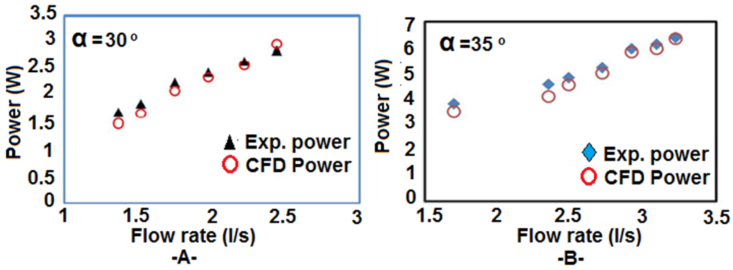

Figure 10. Experimental and numerical power at the angle of inclination: (A) α = 30°; (B) α = 35°

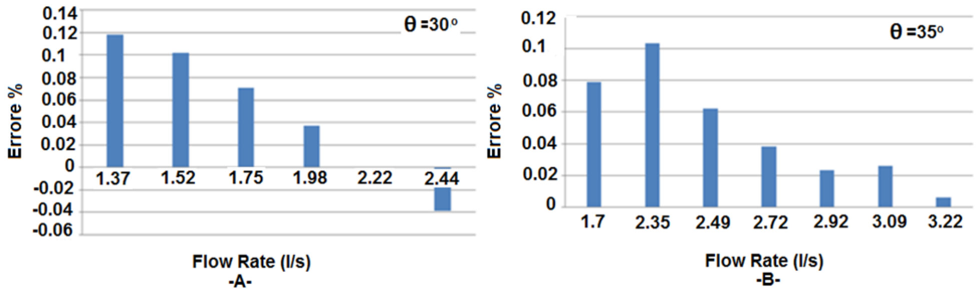

Figure 11. REP values for both numerical models with experimental data: (A) θ = 30°; (B) θ = 35°

For accuracy, error analysis of experimental and simulation results in predict behavior (correlation between power and flow rate) is used by the relative error percent ($REP\%$) with Eq. (10) [24].

$$REP\% = \frac{100}{N} * \sum_{1}^{N} \left| \frac{P_m - P_s}{P_m} \right| \tag{10}$$

where, Pm and Ps are the power of the experiment and simulation results. Based on Figure 11, the numerical models give good results compared to experimental data. Notwithstanding, these discrepancies are minimal, and the outcomes are remarkably similar.

Figure 12 illustrates the assessment of screw efficiency at various flow rates for 30° and 35°. The efficiency diminishes at elevated flow rates due to leakage around the screw core. The efficiency may diminish due to gap leakage, which is deemed more significant from this perspective. A close correlation between numerical and experimental efficiency values may be attributed to an underestimation of gap leakage, highlighting the necessity of refining the mesh between blades and troughs.

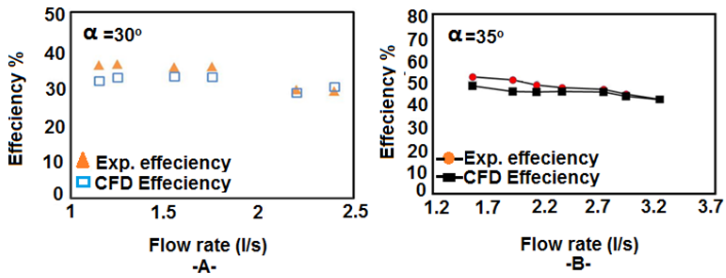

Figure 12. Experimental and numerical efficiency at the angle of inclination: (A) α = 30°; (B) α = 35°

3.2 Effect of Water Flow Rate

Archimedes screw turbine with two diameters (2500 mm and 4000 mm) is applied in the numerical model to evaluate the generated potential power from Ramadi Barrage. The discharge range is determined based on historical data of the Euphrates River, specifically the minimum and maximum discharge values recorded from 1932 to 1997, which provides a more precise estimation due to its extensive and continuous nature, particularly as the minimum discharge in the river is influenced by actual inflow to Iraq. The current study utilized a discharge range of 90 m^3/s to 360 m^3/s to evaluate the potential energy generated under various operational conditions at the Ramadi Barrage. The barrage features 24 gated openings, resulting in an average discharge range of 3.75 m^3/s to 15 m^3/s for each opening.

Table 2 and Table 3 show the results of the numerical model application at three different angles based on the observed discharge from one gate and the observed available head (2–3.5 m). Table 2 represents the results of the low discharge held on a (2500 mm) Archimedes screw turbine, while Table 3 represents the results of the high discharge held on a (4000 mm diameter) Archimedes screw turbine. The results in Table 2 show the maximum power is 280,800 watts at a 35° inclination which was obtained from a 2500mm diameter at a maximum discharge. It can be concluded that as the inclination angle becomes smaller the power production decreases. Also, the maximum efficiency attained at 35° inclination angle which consistent with the result of [25, 26], which pointed out 35° as the optimal angle of the Archimedes screw turbine. For the (4000 mm diameter) turbine, the results showed as the diameter of the screw increases the power production with discharge increases but decreases the efficiency. The maximum efficiency of the 4000 mm diameter was 88% obtained at a 30° inclination angle while 89.4% efficiency was achieved for 2500 mm at an inclination angle of 35°. The inclination angle can affect the flow inside Archimedes screw turbine that can cause changes in flow velocity and head (Table 2 and Table 3).

Table 2. Power production and efficiency for 2500 mm diameter

Flow Rate (m^3/s)	Head (m)	Angle of Inclination (°)	Power (W)	Efficiency (%)
		18	60504	70
4	2.2	23	69410	80.4
		35	70804	82
		18	130506	78.7
6.5	2.6	23	138351	83
		35	143000	86
		18	237900	75.7
10	3.2	23	265150	84.4
		35	280800	89.4

Table 3. Power production and efficiency for 4000 mm diameter

Flow Rate (m^3/s)	Head (m)	Angle of Inclination (°)	Power (W)	Efficiency (%)
		18	98800	50
10	2.0	23	120250	61
		30	160000	81.5
		18	178400	60.6
12	2.5	23	213504	72.5
		30	259700	88
		18	311453	66
15	3.2	23	357600	75.9
		30	400000	84.9

In recent years, Iraq has suffered from climate change, which has led to a significant decrease in the discharge of the Euphrates River. The average discharge in the river does not exceed, at best, 360 cubic meters per second. Figure 13 represents the potential power generated at Ramadi Barrage based on measured data for the discharge rate in the year 2022 and the numerical model results at an angle of inclination 35 and an efficiency rate of 80%. This figure represents the power that can be generated from the Fallujah, Sin Al-Dhuban, and Al-Warar regulators during 2020-2022, considered among the driest years in the Euphrates River Basin.

The results in Figure 13 and Table 4 indicate that the Ramadi and Fallujah Barrages are the best for investment in the use of small generating hydropower stations. These Barrages are located on the main stream of the Euphrates River, which ensures the continuation of the discharge water throughout the year, unlike the Al-Warar and SinThuban regulators, which depend on the water flow situation and are located on channels that are not on the mainstream of the river. In recent years, especially since the end of 2022, the gates of both Sin SinThuban and Al-Warar have been closed due to the sharp decrease in imports from the Euphrates River. The Fallujah Barrage is the best in terms of the power that can be generated due to the high discharges of the Euphrates River as a result of feeding the river from Lake Tharthar so that the river's discharge sometimes reaches double the river's discharge at the Ramadi Barrage.

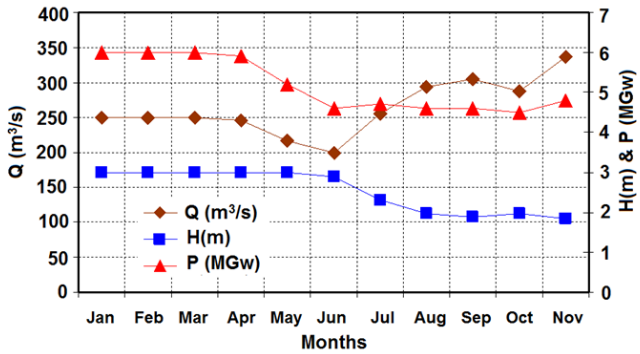

Figure 13. The potential power generated at Ramadi Barrage

Table 4. The potential power generated at Falluja Barrage, SinThuban and Warrar Regulators

Month	Barrage	2020			2021			2022		
		Q (m^3/s)	H (m)	P (MW)	Q (m^3/s)	H (m)	P (MW)	Q (m^3/s)	H (m)	P (MW)
Jan	Falluja	484.7	3.71	13.5	400.5	3.55	11.2	340.9	4	10.7
	SinThu.	175.1	6.49	8.6	145.8	6.12	7.0	7.7	4.23	0.3
	Warrar	281.3	0.3	0.67	117.7	0.65	0.6	36	2.3	0.65
Feb	Falluja	386	3.71	11.4	354.5	3.77	10.5	370	3.58	10.4
	SinThu.	121.4	6.79	6.3	113.6	7.45	6.6	59.5	4.15	1.8
	Warrar	110.7	0.35	0.3	191	0.31	0.25	35	2.2	0.61
Mar	Falluja	404.7	3.95	10.6	470.6	3.45	12.7	374.8	3.66	10.8
	SinThu.	162.3	6.31	7.8	85.8	6.43	4.5	109.4	3.41	2.8
	Warrar	348.1	0.3	0.58	51.6	0.6	0.25	50	2.72	1.07
Apr	Falluja	361	3.67	11.2	365	3.96	11.3	324.1	3.85	9.8
	SinThu.	119.1	5.81	5.1	60	6.05	2.9	C	C	C
	Warrar	178.7	0.47	0.68	73	0.7	0.4	C	C	C
May	Falluja	432.4	3	12.3	381.4	3.61	10.8	307.5	3.82	9.2
	SinThu.	13.9	6.1	0.7	60	5.9	2.8	C	C	C
	Warrar	65.2	0.72	0.38	78.5	0.3	0.18	C	C	C
Jun	Falluja	681.5	1.93	14.1	613	2.63	12.7	334.9	3.44	9.0
	SinThu.	46.7	5.46	2.0	43.7	5.07	1.8	111.2	2.42	2.0
	Warrar	55	0.5	0.2	65.5	0.4	0.2	C	C	C
Jul	Falluja	744.8	1.96	13.4	661	2.3	11.9	356.5	3.36	9.4
	SinThu.	58.9	5.54	2.6	119.7	4.7	4.4	136.3	0.61	0.7
	Warrar	69	0.35	0.19	64.5	0.6	0.25	C	C	C
Aug	Falluja	675.7	2.43	13.8	628.7	2.61	12.9	341.8	3.16	8.5
	SinThu.	70	5.72	3.2	226.5	4.32	7.6	C	C	C
	Warrar	108	0.35	0.28	146	0.9	0.8	-	-	-
Sep	Falluja	632.2	2.48	12.2	598	2.46	11.5	342.3	2.98	8.0
	SinThu.	70	5.80	3.2	260	3.53	7.2	C	C	C
	Warrar	102.5	0.5	0.4	70.2	1.8	1.0	-	-	-
Oct	Falluja	543.4	3.2	13.7	475	3.21	12.0	-	-	-
	SinThu.	70	5.91	3.2	157.3	3.29	4.0	-	-	-
	Warrar	103	0.6	0.45	70.6	2.45	1.37	-	-	-
Nov	Falluja	350	4.48	9.9	410.2	3.59	11.6	-	-	-
	SinThu.	165.3	6.1	7.9	45.3	3.85	1.4	-	-	-
	Warrar	179	0.42	0.6	80	2.34	1.5	-	-	-
Dec	Falluja	363.6	4.12	10.9	379.7	3.82	11.4	-	-	-
	SinThu.	69.7	6.3	3.4	14.2	3.92	0.45	-	-	-
	Warrar	83.5	0.48	0.35	57	2.34	1.02	-	-	-

Finally, to reduce the technical challenge, such as turbine efficiency and discharge variations in these projects, the designer must consider optimizing turbine design to match the specific site conditions, including discharges and head resulting from differences in water level upstream and downstream barrage gate. Also, variable speed operation can be achieved to optimize turbine efficiency across a range of discharges. Designers can implement flow rate forecasting systems to predict changes in discharge and optimize operation conditions with advanced control systems to adjust turbine operation in real-time to match changing discharges. The monitoring and control system is necessary to track turbine performance and discharges, and make adjustments as needed.

4 Conclusion

The present study demonstrates the great potential of investing in hydraulic structures (Barrages and Regulators) located in Anbar Governorate in Iraq. These structures provide cheap, clean, and environmentally friendly electrical power, which can contribute to meeting part of the large energy need in the governorate and reduce harmful emissions that can reduce the impact of clear climate changes in Iraq. Thus, the main conclusions are explained as follows:

•The highest efficiency of nearly 89.4% was achieved for the optimal angle of model 35°.

•The Ramadi and Fallujah Barrages are the best investments in generating electrical energy because the discharges of these barrages continue throughout the year.

•The small hydropower stations (with Archimedes screw turbine) are an effective method because they are appropriate to the hydrologic conditions of the Euphrates River in Iraq.

•Based on these hydrologic conditions such as discharge, and available head, Archimedes screw turbine can be used to generate power without the need for large storage water.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Nomenclature

CFD	Computation fluid dynamics
D_i	Inlet diameter (mm)
D_o	Outer diameter (mm)
G	Gravitational Acceleration (m/s^2)
H	Head (m)
L	Screw length (mm)
m	Number of helices (-)
n	Rotation (rpm)
P	Pitch (mm)
p	Pressure (Pa)
P_{Hyd}	Power generated (W)
P_{mec}	Mechanical power (W)
Q	Flow rate (m^3/s)
Re	Reynolds number
RNG	Reynolds Normalisation Group
T	Torque of a screw (Nm)
u, v	Velocity components in the x and y directions, respectively

Greek symbols

α	Slope (inclination) ($^\circ$)
η	Efficiency of the screw turbine (%)
ρ	Water density (kg/m^3)
τ	Stress (Pa)
ω	Angular velocity of screw (rad/s)