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Optimum control and design of a small hydro power plant for agriculture investment in Iraqi desert

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ABSTRACT

The aim of this paper is to conduct a mathematical and physical analysis to get a systematic treatment of design parameters and thus optimize water wheels. By today's standards, one finds empirical formulas instead, which take into account the practical experience of previous constructions, estimates of particular wheelbase shapes and sizes. So, based on the basic design and optimization standards for water wheels implementation, this paper attempts to design a water wheel power source in desert areas. Since the water wheels mainly use the gravitational force of water, there is only a slight hydrodynamic power loss. In addition to the high torque due to the large inertia of the water wheel. The obtained results indicate that the optimum operating range of the trailing water wheels is at a diameter of (2-7 m) and the Q water flow of about (0.1 m^3/s). So, it can conclude that the implementing design has good efficiency and offer an economic benefit when use for the agriculture investment in desert areas.

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1. INTRODUCTION

There are a large desert areas in Iraq inhabited by many people as well as contain large quantities of inventory groundwater are available and easy to extract. The energy was generated by hydropower relies on the water cycle, which is extracted from the Artesian wells, making it a source of renewable energy, more reliable and affordable source in comparison with rapidly depleting fossil fuels. For electricity generation in the desert, water wheels are still a viable option for energy conversion. We can still find many of the possibilities of such use of hydropower [1]-[4].

Against this background, the question arises as to the design criteria of water wheels from today's perspective. The available literature about water wheels is very few. In depth analytical considerations, both hydraulic and constructive, in today's standards are hard to find it. For decentralized use of hydropower in the lower power range, the potential for use of overshot water wheels have economically feasible capacity is approximately 10-15 kW is sufficient [5]-[9]. Instead of systematic representations, one finds rather empirical formulas, which consider practical experiences constructions, and estimates for special water wheel forms and sizes. So, the proposed small hydro power plant aims to perform a physical-mathematical analysis, in order for developing a practical constructive instructions of water wheels [10]-[17].

In this paper the overshot water wheel is designed to measure the quantity of well water and has been studied on converting energy at low altitudes here. From above, the water enters the wheel. This kind of wheel was used to account for head variations of 4 to 8 m and flow rates of 0.2 to 0.3 m^3/s per m width. A physical model is prepared for testing in the lab environment, assisted by digital modeling using the computer method [5]. The physical model tests show that the wheel speed at fixed fallen water levels has a linear relationship with torque as well as the flow rate. The ratio of the wheel to the head height, the blade numbers, the channel transmission forms, and the bottom clearance gap have been tested experimentally for the wheel's performance. In order to achieve the ambitious goals of environmental protection, renewable energies were supported. The focus will also be on converting energy through small hydropower, which will be tested in this work on the overshot water wheel [15]-[20].

The majority of water wheels, commonly referred to as just "water wheels," are wheels that are positioned upright and revolve around a horizontal axle. These water wheels are categorized based on how the water is directed to the wheel in relation to the axle [18]-[21]. As one might anticipate, water wheels are rather huge devices that rotate at moderate rotational speeds and have little efficiency because of frictional losses and buckets that are not entirely full [22]. The torque on the axle is created by the water driving upon the buckets or propellers on the wheel, but the wheel's speed as well as effectiveness can be increased by redirecting the water at these buckets and propellers from various locations on the wheel. The two most prevalent configurations for water wheels are the water wheel that is undershot and the water wheel with overshot [23]. This paper presents a proposed type of "overshot water wheel", according to the system requirements in the crash structure, an overshot water wheel was selected for using the energy of the fall water in the present paper.

The earlier model of the overshot water wheel consists of twelve triangular buckets fastened to the rim of the optimized wheel design and control [24]. Moving freely along the horizontal axis is what each bucket does. Water is poured into buckets and then dropped vertically into the canal. The water wheel rotates because of the bucket being full of water. The buckets drip water when the spillage angle is small ($\varphi 1$), close to the wheel's rim; contrary, no water is poured. It was believed that the wheel rotates a millstone and has no friction. A perfect water wheel is not a reality, which is where physical reality and mathematical modeling deviate from the practical water wheels. First, swivel buckets were not a feature of actual water wheels. In order to prevent water from leaking out when the wheel rotated, the above layout was used. The water spilled out increases as the spill angle (φ) increases because the wheel's rim is divided into sectors that rotate with the wheel [16]. Water falls from the top buckets to the lower buckets and spills over the sides into the buckets as the wheel rotates.

Denny performed some adjustments to the overshot water wheel design in order to make it more accurate. First of all, swivel buckets are not a feature of actual water wheels. Rather, as illustrated in Figure 1, the wheel's edge is divided into parts. As φ grows, more water flows out because it revolves with the wheel. Additionally, as the water rushes into the buckets, it overflows over the edges. Denny's overshot water wheel model's efficiency is displayed in (1) $\eta = \{1+\sin(\varphi)\} / \{2 + v2 / (2 g R)\}$ [24].

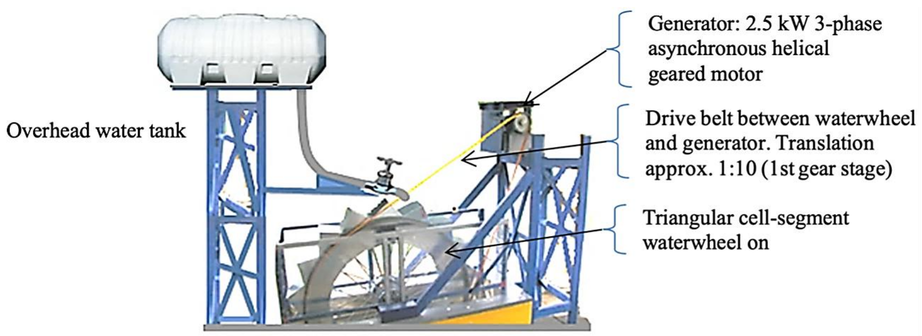


Figure 1. Laboratory model, prototype of a fully functional hydroelectric power station with energy converter

2. METHODOLOGY

2.1. Design of overshot water wheels

For energy generation from hydropower, the hydro mechanical energy of the water can be converted into electricity. This is done using a water power machine and a generator. The most popular kind of water wheel construction is the overshot type. Because it uses buckets or tiny compartments that capture and keep water, the overshot water wheel is more intricately designed and constructed than the earlier undershot water wheel. Water enters these buckets from the top of the wheel. As the empty buckets on the opposite side of the wheel get more lightweight, the wheel rotates around the central axis due to the water's gravity weight in the completely filled buckets.

Since nearly all of the water and its entire weight is employed to generate electrical power, overshot water wheels are far more efficient than undershot designs. This form of water wheel uses gravity to increase output in addition to the water itself. But just like previously, the water's energy is only used once to turn the wheel before dissipating along with the remaining water. Usually constructed on the slopes of hills, overshot water wheels remain suspended over a river or stream and feed water from above with a small head (the upward distance among the water at the very top and the stream or river that flows below) of five to twenty meters. Although the water's amount, not its rate of flow, is what contributes spin the wheel, a tiny reservoir or dam can be built to channel and accelerate the water to the top of the wheel, giving it additional energy.

Overshot water wheels are often constructed as big as feasible to provide the maximum head height necessary for the water's gravity mass to spin the wheel. Nevertheless, because of the immense weight of the wheel and water, building an enormous diameter water wheel is more difficult and costly [13]. The wheel spins in the course of the water flow once everyone buckets get full with water due to the water's gravity mass. The water in the bucket flows into the river or stream below as the angle of rotation approaches the bottom of the wheel, but the wheel maintains its rotational speed due to the weight of the buckets spinning behind it [14]. The cycle restarts as the unfilled bucket keeps going about the revolving wheel until it reaches its peak once more, waiting to be filled up with new water. The fact that the water can only be utilized only after as it passes over the wheel is one drawback of an overshot water wheel construction [15]. The block diagram of the proposed hydro power plant is shown in Figure 2 and the technical data of the overshot water wheel is illustrated in Table 1. With the overshot water wheel, water flows from above into the blades of the wheel, allowing for an efficiency of up to 80%. It features a horizontal axle on a vertical wheel, where the water strikes in front of the axle and close to the peak of the wheel. The wheel uses steering surfaces called buckets to capture the water effectively. This type of wheel operates best when using a small volume of water with an enormous head. The proficiency of this system can reach between 80% and 90%.

The overshot water wheel only uses the water's gravity. The sole basis for converting the position's potential energy into the movement's kinetic energy is the (Galilean) free fall law. If a mass travels against the gravitational pull in a unit of time, a power P is released. This power which is measured in (kg m/s), is transferred to the wheel axis by the torque.

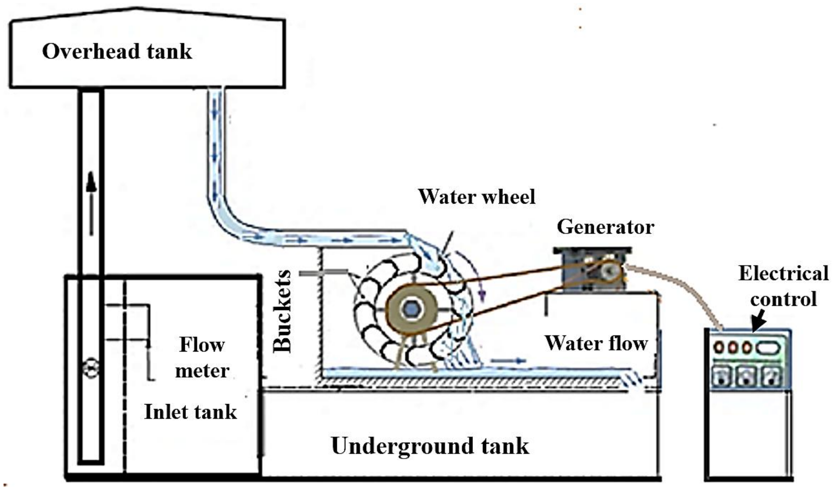


Figure 2. Block diagram of the proposed hydro power plant

Table 1. Technical data of the overshot water wheel [25]

Technical data	Unit
Diameter	3 m
Number of blades (iron sheet)	30
Theoretical capacity per blade	65 liters
Capacity in operation, per bucket	12 liters ca.
Usable width	0.55 m
Wheel segments	10
number of revolutions	15-20 revolutions/minute
Medium power	5-6 PS = ca 3,5-4,5 kW
Water requirement at medium power	ca. 3.5 m^3/minute = ca. 60 liters/second

This efficiency is reduced by the mechanical friction losses of all rotating parts, the reduced filling of the panniers in the upper apex and the beginning emptying before the lower apex. Because of the layout, the overshot water wheel already achieves its highest level of effectiveness with a 20% loading and maintains this nearly lossless up to the highest volume transfer that was recorded. Thus, the future hydropower is at its best. used over a wide area. At low pressures, the water wheel has the best efficiency of all hydropower machines. Table 2 presents the achievable performance per m of drop height as how the water volume flow Q and efficiency η interact.

Table 2 can be used in order to assess possibilities for effectiveness. For instance, using the volume of water in the drop Q = 0.1 [m³/s] and an efficiency η = 0.781, a power potential of 0.801 [kW/m] results. Based on a fall height of h = 4 [m] is the attainable power P = 4 × 0.80 = 3.2 [kW]. Whereas energy can be measured over a particular length of time, such as a second, an hour, or a year, power can be recorded at any moment. Typical units of assessment for electrical power include watts (W), kilowatts (kW), and megawatts (MW). For a particular duration, such as an hour, the energy is expressed in kilowatt hours (kWh). Energy per unit of time is called power.

The rate of water flow Q, header H, and overall water wheel generator system effectiveness η determine the power P produced by the generator or water wheel. This power may be computed using the equation outlined below [26].

$$P = \frac{\rho . Q . H . g . \eta}{1000} \text{ [kW]} \tag{1}$$

From this, the performances shown in Table 1 can be calculated depending on the case water volume flow Q and the efficiency η. The characteristic values for a water wheel are given by the volume of water Q, the head H, and the wheel diameter D. For additional design of an operational water wheel, the diameter D is evaluated first. For overshot water wheels, 9-12% of the height of fall H, subtracted to get an initial diameter value, increases its accuracy by using (2).

$$D = \left[H - \frac{4v^2}{2g} \right] \tag{2}$$

Where the optimal peripheral speed, v[m/s], is 1.3 m/s or marginally above amounts. The wheel diameter should be selected as large as possible with a view to optimal use of the potential, as the water is both in the inlet and outlet in terms of flow.

Table 2. How the water volume flow Q and efficiency η interact

Drop water volume	Power P per m height of fall [kW/m]							
Q [m³/s]	η = 0.3	η = 0.4	η = 0.5	η = 0.6	η = 0.7	η = 0.8	η = 0.9	η = 1.0
0.10	0.289	0.391	0.489	0.592	0.689	0.781	0.882	0.978
0.20	0.589	0.782	0.981	1.183	1.372	1.571	1.772	1.961
0.40	1.18	1.57	1.96	2.35	2.75	3.14	3.53	3.92
0.60	1.77	2.35	2.94	3.53	4.12	4.71	5.30	5.89
0.80	2.35	3.14	3.92	4.71	5.49	6.28	7.06	7.85
1.00	2.94	3.92	4.91	5.89	6.87	7.85	8.83	9.81

2.2. Feasibility considerations

In order to implement a small hydro power plant using overshot water wheel, the basics of feasibility must be ascertained and a feasibility assessment made. Feasibility assessment is based on available energy potential and structural development potential. To determine the energy potential, local conditions such as the amount of water and the usable drop height must be recorded in order to be able to measure the system dimensions and identify the different parts of the system. In order to record the amount of water available, a hydrograph is usually prepared in a hydroelectric plant construction. The discharge duration curve has the same volume and corresponds to the volumes of water depleted in the observation period.

A radius with respect to the vertical axis defines the proposed overshot waterwheel. All values of alpha (α) can be measured and compared using Figure 3. So, the entry into the waterwheel and due to the shovel profiling could then result in any alpha = α_{max}. Because some $\alpha = \alpha_{max}$ sees that it is not quite accurate here in the time, but the water is expected to leave the shovels gradually, but for the simple calculation of this water wheel, the calculation based on electrical or electromagnetic induction is not considered in this study. Then the torque of the turbine is given according to the definition of the torque as 2 radius (R2). The radius of the water must be determined, along with the force, which is also relatively simple.

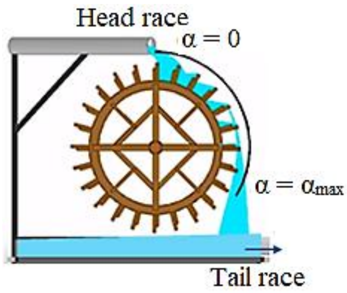


Figure 3. Energy hydraulic works: the overshot water wheel

So, the force of weight ($m . g \sin \alpha$) is considered in the direction of the radius, and at this point, the angle ($\sin \alpha$) applies throughout until it becomes evident that this holds true at this position. In the zero state, there will be no torque on the wheel shaft. When the water starts flowing onto the wheel blades, a torque is exerted on the shaft as the weight is pulled straight down. Therefore, the torque of the turbine can be calculated at any angle alpha, only that this angle is distributed between $\alpha = 0$ and $\alpha = \alpha_{max}$. There is not just one angle, but also a whole range of angles from 0 to α_{max}, which must be taken into account as follows.

2.3. The torque

From Figure 1, it can be seen that the mass difference appears slightly in the area of the angle α, as if this angle in radians were always equal to the radius. Multiply the angle segment is the arc length, so here alpha is actually the arc length.

$$dM = \rho . A . Rd\alpha \tag{3}$$

So, if multiply the cross-sectional area of these blades, that is length times area arc length times the cross-sectional area of the water wheel. The volume stored water volume and which takes the density times is the pass that lies in an angle piece $d\alpha$. First, the moment has to be calculated, which is mass or weight times radius, and upon it, α_{max} filters have to integrate the angle range between 0 and α_{max}.

$$\mathrm{MT} = M . g . R = \int_0^{\alpha max} \rho . g . R^2 . A(sin\alpha) d\alpha \tag{4}$$

$$MT = \rho . g . R^2 . A \, (1 - cos\alpha) \tag{5}$$

This must be integrated over the angle range between 0 and α, so R2 that is the mass of R2 through the calculation of the torque in 1, i.e., (R2 sinα) integrated between 0 and αmax, that is (1 – cosα) for α = 0, in (2) and (3). If sinα is integral cosα and compared to the integration value 0, there is cos1, which means (1 – cosα_{max}).

3. RESULTS AND DISCUSSION

The result is the flow that is always cross-section times speed by resolution. The speed here is the orbital speed of this outer area, as in (6).

$$P_T = M_T . \omega_{stat} = \rho . g . Q . R(1 - \cos\alpha) \tag{6}$$

Whereas the stationary operating case (ω_{stat}), is given by (7).

$$\omega_{stat} = \rho . g . R \frac{Q}{M_F} (1 - \mathrm{os}\alpha) \tag{7}$$

The cross-sectional flow of individual compartments multiplied by the angular velocity multiplied by the radius, the filling of the individual parts of a given flow can be calculated. Finally, about the efficiency that will be the power of the turbine, about the current power efficiency of such a turbine that after making an attempt to skip the rise times in the raw flow times, the flow times head times, and by configuring the entire turbine system to operate with a large delta H. After that, the height of the fall from the overall efficiency of the turbine can be calculated. Take advantage of the turbine power and the current impact force of the gain flow, and then take out from here P_T.

$$P_F = \rho . g . Q . \Delta H \quad (8)$$

$$\Delta H = R(1 - cos\alpha) \quad (9)$$

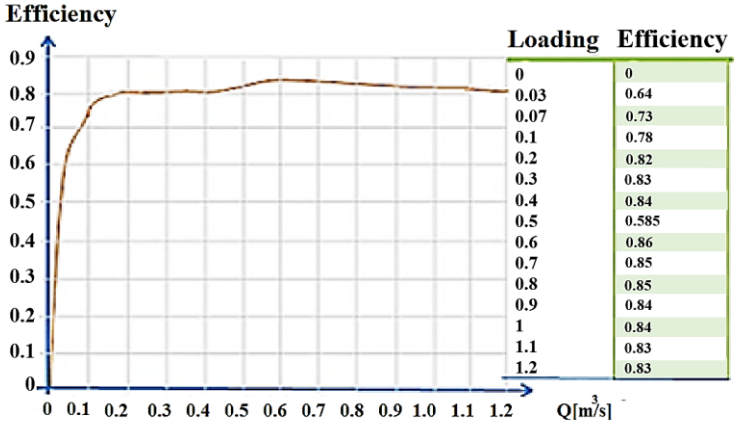
Thus, arriving at the fall height, which is no more than using the delta falling height/current falling height.

$$\eta = \frac{P_T}{P_F} = \frac{\Delta H}{\Delta h} \quad (10)$$

Where P_T is the total power and flow power P_F

Such a turbine can have a relatively high degree of efficiency with optimum control and design of overshot water wheels, such things are still built today because they have a very high degree of efficiency that depends on the total head we can use for the water. Figure 4 shows the achievable performance per m of drop height depending on efficiency η and water volume flow Q. For testing the water wheel in the laboratory, a test stream was built and the physical model and measuring instruments installed. The physical model, measuring equipment, calculation and analysis methods, improvement steps, and analysis method are described as in the model shown in Figure 5. The test device consists of a water pump, an overhead tank, pipelines, a flow meter, and a ground tank. The ground tank, 3 meters in length, 1 meter in width, and 1 meter in depth, includes a model of the water wheel, the shaft, the torque transducer, the velocity sensor, the water pipe, the inlet tank at the upstream, and the control dam at the downstream. The side walls of the duct consist of a wall and the bottom is a concrete floor.

Channel slope is adjustable and in all tests conducted in this research, the slope is maintained at 0°. The maximum flow rate that the test setup can handle safely is around 35 L/s. Water was provided by a pump with a maximum capacity of 50 L/s. The general shape of the test device is shown in Figure 4 and the physical model is shown in Figure 5. The wheel consists of a hub, blades, and side caps. The wheel hub is made of solid iron tubes, which have a diameter of 100 cm and a width of 30 cm. 12 steel V-shaped blades of 2 mm thick fixed along the perimeter of the axle. The blades are 10 cm long and are V-curved to obtain an angle of 127 degrees. The blades are coated to reduce surface roughness and prevent corrosion. A stainless steel shaft with a diameter of 20 mm was used.



Loading	Efficiency
0	0
0.03	0.64
0.07	0.73
0.1	0.78
0.2	0.82
0.3	0.83
0.4	0.84
0.5	0.585
0.6	0.86
0.7	0.85
0.8	0.85
0.9	0.84
1	0.84
1.1	0.83
1.2	0.83

Figure 4. The water capacity flow Q and the effectiveness η

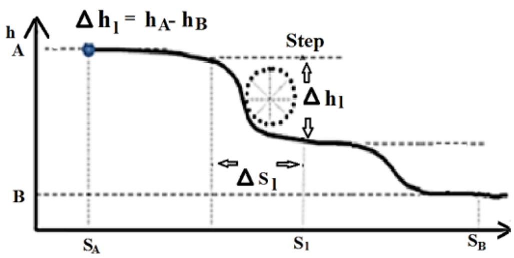


Figure 5. Height profile pattern for overshot water wheels

3.1. Overshot water wheel- lots of power with little water

A suitable terrain for overshot water wheels is shown in Figure 2 with a step-shaped course. At the same time, the body of water experiences its respective increase in velocity, essentially during the step passage. As a result, not too much kinetic energy must be destroyed (braked) when entering via a contactor to the water wheel. With the results from Figure 5, the velocity v_i before the step should optimally satisfy the following relationship.

$$v_I \leq v_{max} = f.\sqrt{2\,.\,g\,.\,hs}\ \text{[m/s], (Frictional losses } f\text{)} \tag{11}$$

The speed of the inlet is less than that of the maximum contactor outflow. With the available quantity of water Q, for the geometry of the water wheel: L*B ≈ Q/v_i [m^2]. This must be matched with the technically realizable speed using the formula n = $\frac{60.L.B}{z.\varepsilon.Vz}.v_I$ [min^{-1}] is the number of cells with the respective max. Filling volume Vz and the degree of filling 0 ≤ ε ≤ 1. The maximum possible diameter D of the water wheel is given by the available step height Δh_i, so D = 2R≤ Δh_i. For the steepness of the natural step, one could set 0 ≤ Δs_i ≤ (2…3)*D, considering the required earthworks.

The height differential between the headrace and tailrace water surfaces is known as the pressure header (hp). The water's velocity in the headrace, where the pressure head is measured, is used to compute the head velocity ($h\boldsymbol{v}$). The jolly sticks technique, which involves time an item that floats over a specified distance, can be used to determine the velocity (speed) $\boldsymbol{v}$. An adjustment factor needs to be used, as shown in the calculation below, because water at its surface travels more quickly than water closer to the bottom and sides.

The volume flow rate can be determined in a variety of means. The cross-sectional footprint and velocity are two of the most basic. The measurements need to be taken at the same location, which could be any part of either the head or tailraces. The volume flow rate can occasionally be measured using the bucket and stopwatch approach; it must have the same quantity of water passing through it as the wheel.

4. CONCLUSION

According to the results achieved, the water wheel's real amount of water is approximately 5.36 times that of the blade. Considering that the rate of water flow remains constant, the water wheel's size can be expanded proportionally to raise its water capacity. The nozzle's length influences the water wheel's spinning; having a shorter nozzle results in a greater RPM. This demonstrates how the RPM is impacted by the nozzle's coefficient. Additionally, the results demonstrated that the greatest RPM measurement was attained at 56.25° (68.3) nozzle angle. Because the volume of water maintained in a triangular blade is more than that of a propeller blade, water wheels with triangular blades generate greater rotations per minute than water wheels with propeller-type blades. The water wheel's mass created moment inertia and subsequently increased angular velocity, which accelerated the water wheel's rotation. For the water wheel propeller and triangle, the ideal nozzle angle is 20° to achieve maximum efficiency. The ideal axis angle was discovered for the propeller 10° and 20° triangles, respectively. Similar RPM will be delivered with an axis angle of 15°.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Zubaidah Ghaze Abdulkareem	✓	✓	✓		✓	✓			✓					
Ghanim Thiab Hasan	✓	✓		✓	✓	✓			✓	✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

We have no conflict of interest to report.

DATA AVAILABILITY

Some information was obtained from the Mosul Dam Hydropower Company in Iraq.

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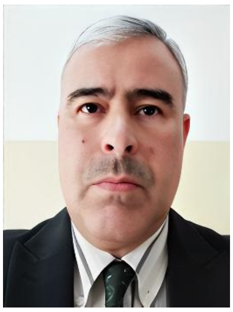

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