



Experimental Investigation of Sharp-Crested Weirs for Enhancing Water Quality in a Laboratory Flume

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ABSTRACT

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Sustainable water quality is a substantial challenge for both ecological health and human consumption. Weirs are hydraulic structures widely used to regulate discharge and water levels in rivers, with their turbulence-generating capacity providing a promising method for enhancing water quality. This study aims to quantify changes in DO, TUR, TDS, pH, and EC after passage over a sharp-crested weir at different flow rates under laboratory conditions. To achieve this study, a laboratory flume with dimensions of 12 m length, 0.30 m width, and 0.46 m depth was used. The weir model dimensions were 0.25 m height, 0.29 m width, and a crest thickness of 10 mm. Measurements were taken at two points of upstream and downstream weir at a distance of 1 m under range discharges from 0.003 to 0.009 m³/s. The tested parameters included dissolved oxygen (DO), total dissolved solids (TDS), turbidity (TUR), electrical conductivity (EC), and pH. Results showed that DO has been measured at low discharge of 6.9 to 7.3 mg/L at the upstream and downstream, respectively. At high discharge, DO was measured from 7.2 to 7.85 mg/L at the upstream and downstream, respectively. The maximum improvement was 14.7%. TDS values were slightly increased in both upstream and downstream. The maximum aeration efficiency was 15% for $Q = 0.009$ m³/s. Similarly, turbidity declined from 9.47 to 8.5 NTU at low discharge and from 9.50 to 7.9 NTU at higher discharge, with a maximum reduction of 17.2%. In contrast, pH and EC values exhibited minimal variation, remaining within stable ranges. These findings demonstrate that sharp-crested weirs can significantly enhance water quality through increased aeration and mixing, highlighting their potential as sustainable tools for ecological preservation and hydraulic management.

1. INTRODUCTION

Rivers are considered an essential source of water, which is directly related to human life. Climate change plays a worthy role in the planning and management of water resources. It is also used to evaluate the impacts of the environment. However, due to a lack of sustainable policies, several environmental problems occur in water resources, such as rivers, lakes, canals, and reservoirs [1]. Weirs are hydraulic structures that are used to control water discharge in rivers. Sufficient weir capacity is necessary to warrant the secure release of flood and surplus water. Weirs in rivers commonly impact both flow and water quality in aquatic schemes [2]. Weirs are integrated into river engineering, not only for flow regulation and discharge measurement but also for their role in enhancing aeration and mixing processes. Water flow over a weir produces turbulence and air entrainment. This phenomenon creates favorable conditions for oxygen transfer from the atmosphere to the water column [3]. Dissolved oxygen (DO) is one of the most crucial indicators of surface water quality in systems such as rivers, lakes, and reservoirs. Increasing the amount of dissolved oxygen concentration and decreasing the diffusion

of toxic materials into aquatic environments, turbulent phenomena cause a water mixing process in downstream weirs. The mixing process of water accelerates the diffusion of oxygen and the transfer of pollutants. Dissolved oxygen also enhances water quality because it is essential for microbial activity, which encourages the biodegradation of organic pollutants. Dissolved oxygen is a significant factor in improving water quality in rivers. Therefore, using sharp-crested weirs in river engineering is a practical way to enhance ecological quality and hydraulic efficiency [4]. Water quality is largely determined by its concentration, which is one of the most crucial indicators for aquatic ecosystem survival and human consumption. The natural flow of oxygen from the atmosphere into the water, known as aeration, is necessary to maintain DO levels. Sharp-crested weirs are commonly used in river systems to increase oxygenation.

Numerous investigations have confirmed that aeration efficiency is influenced by the geometric properties of weirs, including crest sharpness, height, and flow regime [5]. Emiroglu and Baylar [6] confirmed that the flow regime changes from subcritical to supercritical, turbulence is created, which encourages the formation of air bubbles and makes

oxygen transfer easier. The water and structure only interact for a short time, but this process is essential for raising DO levels. Fesal and Binti [7] presented that creating turbulent mixing through the free fall of water jets and their collision with the downstream channel, weirs enhance ventilation by drawing air into the body of water. Baylar et al. [8] showed that the air entrainment rate and aeration efficiency are enhanced by this interaction. Puri et al. [9] studied the ability of numerous hydraulic structures to raise DO levels. They found that the sharp-crested weir's geometry has a main effect on the efficiency of oxygen transfer and air entrainment. Gulliver et al. [10] demonstrated that the development of intelligent modelling tools has enabled more precise predictions in complex systems, especially in environmental processes and hydrodynamics. Kim et al. [11] investigated the environmental effects of weirs on water quality in the South Han River. They found significant variations in water quality by measuring many points. The objective of the present study was to investigate the impact of sharp-crested weirs on water quality in rivers. Begum et al. [12] utilised statistical methods and the water quality index (WQI) to assess a standard watershed. They suggested a series of methods to supply the essential data required for watershed management. Ervine [13] showed that sharp-crested weirs were distinguished to generate nappe flow and turbulent jets, which enhance air–water contact and accelerate oxygen diffusion. These processes contribute not only to oxygenation but also to improved water clarity and reduced pollutant impact downstream. Tiwari et al. [14] investigated the concentration of dissolved oxygen at both upstream and downstream for various weir shapes. They illustrated that the efficiency of aeration for the triangular weir was twice as large as that of the rectangular weir. Küçükali [15] investigated the aeration performance of the weirs experimentally. The results showed that the efficiency of aeration was proportional to the $1/3$ power of the unit discharge and the $3/4$ power of the drop height.

Jaiswal et al. [16] investigated the efficiency of aeration using weirs. They applied statistical methods and machine learning techniques to predict aeration efficiency. The results demonstrated that combining mathematical modeling with laboratory experiments reduced the error percentage in estimating oxygen transfer efficiency. The results also confirmed that weir geometric properties, such as height and ridge shape, were critical factors for dissolved oxygen. Jaiswal and Goel [17] carried out laboratory experiments using ten modified steep weir configurations. They applied machine learning techniques to predict aeration performance under different conditions. They also focused on visualizing the nappe flow, such as the shape and behavior of the flow falling over the weir and relating it to the weir's air admittance. The outcomes presented that changing the geometry of the edge or cross-section of the weir increased aeration efficiency. They provided that intelligent model as an accurate tool for predicting DO enhancement in riverine environments. Mondal et al. [18] investigated the effect of the hydraulic jump generated below steep-edge weirs on improving dissolved oxygen levels. The results showed that strong vortices were created due to the accelerated flow over the dam. They showed that the vortices increase the water-air contact surface and enhance oxygen input. They also demonstrated that the relationship between turbulence and flow intensity is directly related to the enhancement of downstream DO concentration. Sohrabzadeh Anzani et al. [19] estimated the energy

dissipation downstream of a rectangular steep-edge weir. The findings showed that the degree of turbulence and air bubble formation had a strong impact on the energy loss rate and enhanced natural aeration. They recommended that the downstream energy loss analysis is an indirect indicator for predicting aeration efficiency. Idrees and Al-Ameri [20] investigated experimentally the aeration efficiency of the labyrinth weir using an artificial aeration approach. The results showed that the weir's performance for reaeration in the downstream was improved. The aeration was increased with high discharge due to the availability of turbulent phenomena and mixing of water with atmospheric air, which was provided by artificial tools.

Despite extensive research on aeration mechanisms, many previous studies have focused primarily on theoretical models or field-scale structures, with limited emphasis on controlled laboratory-scale experimentation under systematically varied discharges. Furthermore, while turbulence is often highlighted as a key factor, quantitative correlations between flow parameters (e.g., discharge, Froude number) are not discussed. However, water quality improvements remain insufficiently clarified.

This gap underscores the need for experimental investigations that directly measure DO, TDS, and turbidity responses to sharp-crested weirs under laboratory conditions.

Accordingly, the present study aims to experimentally quantify the effect of a sharp-crested weir on water quality parameters, including DO, TDS, turbidity, pH, and EC, under a range of discharges in a laboratory flume. Specifically, it seeks to determine (i) the extent of improvement in DO, TDS, and turbidity downstream of the weir, (ii) the relationship of these improvements with hydraulic parameters such as the Froude number, and (iii) the practical implications of these findings for sustainable water quality management in the river system.

2. MATERIALS AND METHODS

The experimental work was conducted in the Fluid Mechanics Laboratory at the Civil Engineering Department, University of Babylon. A rectangular flume with glass sidewalls was employed for testing, as shown in Figure 1. The flume measured 12 m in length, 0.30 m in width, and 0.46 m in depth, and was mounted on an iron base coated with moisture-resistant paint. Water circulation was maintained using a closed-loop system with a 5 kW centrifugal pump. Flow rates were regulated by a control valve and monitored using an ultrasonic flow and temperature meter, while water levels were continuously recorded with a non-contact ultrasonic level sensor with a measuring range of 40 m and a digital display output of 4–20 mA. The sharp-crested weir model used in this study had a width of 0.29 m, a height of 0.25 m, and a crest thickness of 1 cm, ensuring that the edge qualified as a sharp crest, see Figure 2.

The weir was installed 3.27 m upstream of the spillway gate. Measuring points were located 1 m upstream and 1 m downstream of the weir. The pond depth upstream was maintained at an optimal level to ensure that the bubble penetration depth was less than the pond depth, thereby minimising the influence of depth variations on aeration efficiency [21]. Seven discharges (0.003, .004, 0.005, 0.006, 0.007, 0.008, and 0.009 m³/s) were tested.

At each flow condition, water quality parameters were

measured after the flow stabilised for 2 minutes, with three consecutive readings taken and averaged for accuracy. The investigated parameters included dissolved oxygen (DO), total

dissolved solids (TDS), turbidity (TUR), pH, and electrical conductivity (EC).

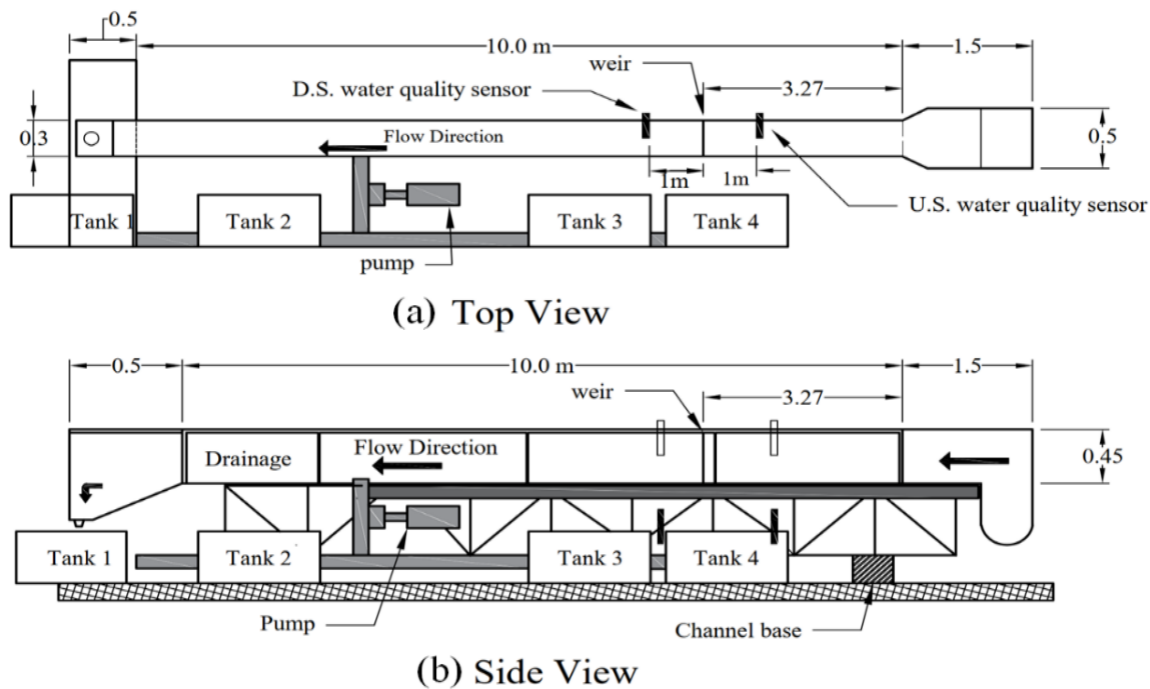


Figure 1. The schematic diagram of the experimental setup (a) Top view, (b) Side view

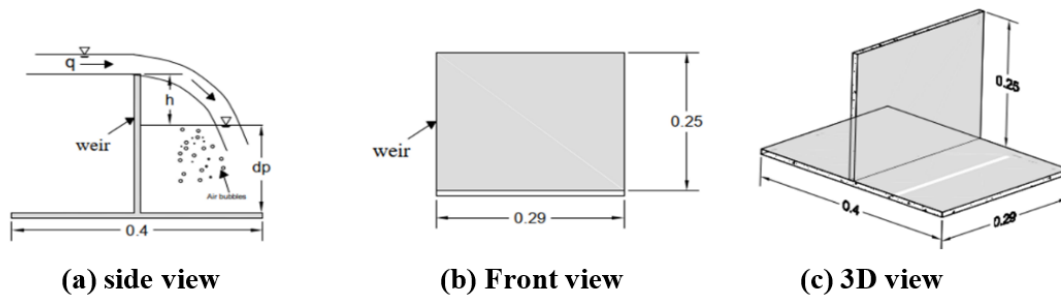


Figure 2. The cross-section of a sharp crest weir: (a) side view, (b) Front view, and (c) 3D view

Table 1. The Specifications of the sensors used for measuring water quality parameters

Device Type	Specifications
1. Dissolved Oxygen (DO)	Smart dissolved oxygen meter (pen-style) equipped with an Aurora sensor and Bluetooth technology. Measurement range: (0.0–30.0) mg/L, with a digital backlit display for clear readings.
2. pH Measurement	A high-precision pH sensor for hydrogen ion concentration. Specifications: • Operating voltage (5.00 V) • Measurement range (0–14) pH • Temperature range (0–60)°C
3. Total Dissolved Solids (TDS)	A high-accuracy pen-type TDS m, compatible with Arduino. Features: • Input voltage (3.3–5.5) V • Analogue output (0–2.3) V
4. Temperature Sensor (Tem)	A waterproof DS18B20 sensor (with heat-shrink tubing). Features: • Operating range: up to 125°C. • Compatible with (3.0–5.0) V systems and Arduino.
5. Turbidity Sensor (TUR)	A turbidity sensor with an electronic monitoring module for Arduino. Features: • Operating voltage (0–4.5) V. • Cable length (20 cm). Provides digital/analogue output signals.
6. Electrical Conductivity (EC)	It has been calculated that electrical conductivity is based on TDS values: $EC = (TDS/K)$ and $K=0.64$ [22].

Table 1 summarises the specifications of the sensors employed. The DO sensor was a pen-style digital meter

equipped with an Aurora probe and Bluetooth connectivity (range: 0-30 mg/L). pH was measured using a high-precision probe with a range of 0–14, while TDS and turbidity were measured using Arduino-compatible probes. Temperature was monitored using a waterproof DS18B20 sensor. Electrical conductivity was derived from TDS values using the empirical relation $EC = TDS / 0.64$, a conversion widely applied in freshwater studies [22].

All instruments were factory-calibrated by the manufacturer. To further ensure reliability, calibration was verified before experimentation by testing both drinking water and tap water samples. The measured values were then compared with Iraqi water quality standards, and the results confirmed the accuracy of the sensors within acceptable tolerances.

The aeration process replaces the oxygen deficiency in water by absorbing oxygen from the atmosphere. Aeration efficiency at any weir is the amount of oxygen being infused in the water while it flows through the weir. The efficiency of aeration is an important criterion for determining the ability of the weir to improve water quality. The efficiency of aeration is estimated by Eq. (1), which was defined by [23]:

$$\eta = \frac{\Delta DO}{D_{up}} = \frac{DO_{down} - DO_{up}}{DO_{sat} - D_{up}} \times 100 \quad (1)$$

where, DO_{up} is upstream dissolved oxygen ($mg \cdot L^{-1}$), DO_{down} is downstream dissolved oxygen ($mg \cdot L^{-1}$), and DO_{sat} is oxygen saturation concentration ($mg \cdot L^{-1}$) at temperature (T).

3. RESULTS AND DISCUSSIONS

3.1 The impact of a sharp crested weir on Froude number

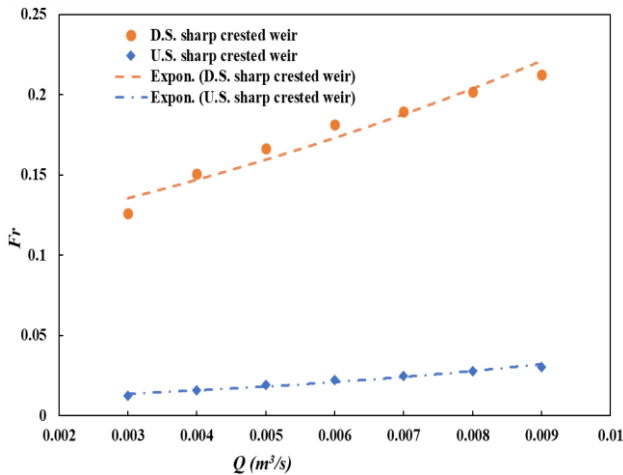


Figure 3. Relationship between Fr and Q (m^3/s) at upstream and downstream sharp crested weir

Figure 3 illustrates the variation of the Froude number (Fr) with discharge (Q) at the upstream and downstream sections of the sharp-crested weir. The results show a clear increase in Fr with increasing discharge, particularly downstream. At higher flows, the transition from subcritical to supercritical regimes becomes evident, producing stronger turbulence and greater energy dissipation. This turbulence promotes mixing and air–water interaction, confirming the role of the sharp-crested weir in intensifying aeration processes. Although Fr provides a useful hydraulic indicator, it should be noted that more advanced turbulence indices (e.g., turbulent kinetic

energy, energy dissipation rate) or oxygen transfer metrics such as the Standard Oxygen Transfer Efficiency (SOTE) would provide a more comprehensive assessment of aeration performance.

3.2 The impact of a sharp crested weir on dissolved oxygen

Figure 4 shows the relationship between discharge and DO concentrations upstream and downstream of the weir. Dissolved oxygen levels consistently increased downstream, with improvements ranging from $6.9 \rightarrow 7.3$ mg/L at the lowest flow ($Q = 0.003$ m^3/s) to $7.2 \rightarrow 7.85$ mg/L at higher discharges ($Q = 0.007$ m^3/s). This corresponds to a maximum enhancement of 14.7%.

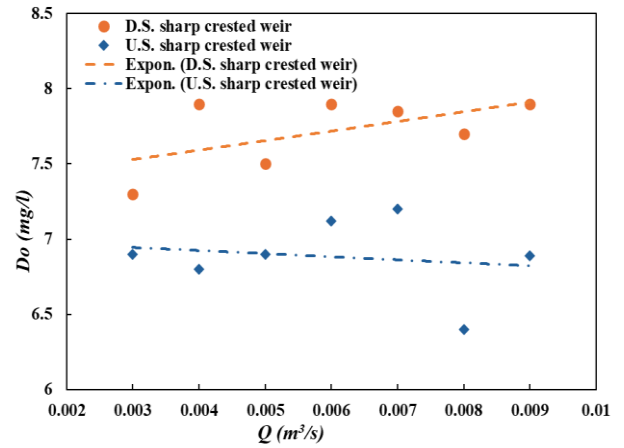


Figure 4. Sharp crested weir's upstream and downstream relationships between DO (mg/L) and Q (m^3/s)

The increase is attributed to air entrainment and self-aeration caused by the nappe flow, bubble formation, and subsequent oxygen transfer. These findings align with previous studies that reported similar DO gains across sharp-crested and triangular weirs [15].

Oxygen transfer and air entrainment depend on nappe morphology, such as free, partially submerged, or fully submerged. Free nappes occur due to separate flow lines from the weir crest and then raise air entrainment underneath the falling sheet. This process causes the development of an air cavity in the downstream face of a sharp crested weir. The air cavities act as a transient air reservoir, while bubbles and vortices replace air with the bulk. The air cavities increase air exchange by increasing the stay time and the mixing region of air bubbles. In contrast, submerged nappes decrease air cavities by reducing turbulence-driven entrainment and thus aeration capacity. The nappe flow may change from free to partially submerged when increasing discharge; formation of air cavities is controlled by the downstream tailwater, falling jet energy, and flow depth, as shown in Figure 5.

Figure 6 shows the relationship between aeration efficiency and discharge. Aeration efficiency increases with increasing discharge. This is attributed to the amount of turbulence that is generated at the downstream of the weir. Turbulence increases as the velocity of the drop increases downstream of the weir. The maximum efficiency of aeration was 15% for $Q = 0.009$ m^3/s . The efficiency of the weir for aeration is an important criterion to consider when designing weirs. Eq. (2) shows the best-fit curve with a regression coefficient of 0.96.

$$\eta = 3.9987 e^{151.36 Q} \quad (2)$$

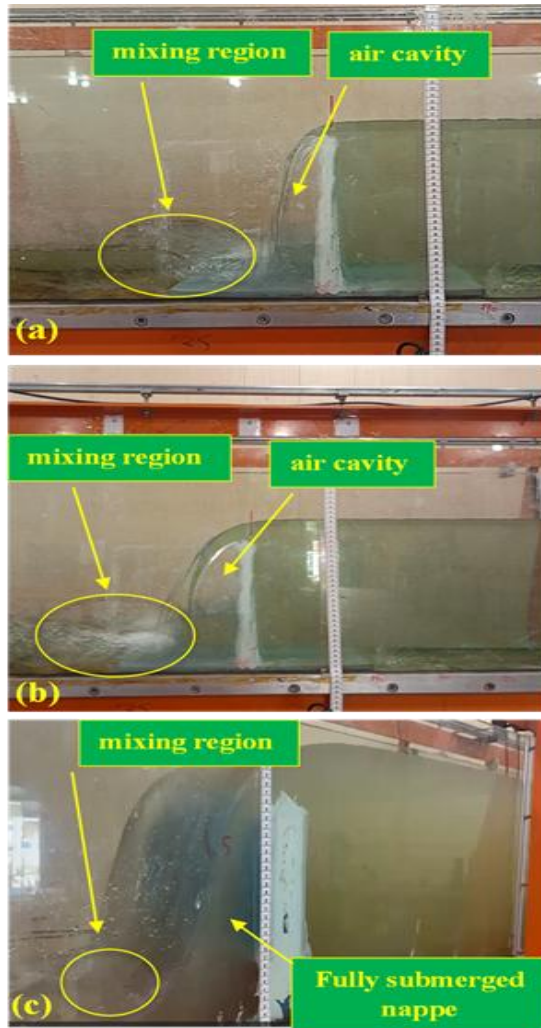


Figure 5. Nappe flow conditions (a) aerated, $Q = 0.003 \text{ m}^3/\text{s}$, (b) partially aerated, $Q = 0.005 \text{ m}^3/\text{s}$, and (c) fully submerged, $Q = 0.009$

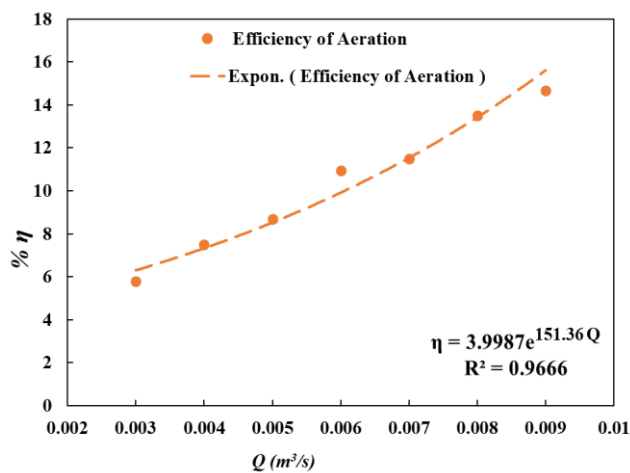


Figure 6. The aeration efficiency using a sharp-crested weir

3.3 The effect on TDS of a sharp-crowned weir

Figure 7 presents the effect of discharge on TDS upstream and downstream. The results showed that TDS values were slightly increased in both upstream and downstream because strong turbulence downstream may cause contact with the bed

of flume material, dissolving salts, or releasing adsorbed ions. Also, the results demonstrated that TDS values in the downstream were slightly higher than upstream of a sharp-crested weir. It may be attributed to the high DO environment, which promotes the degradation of some soluble organic matter by aerobic microorganisms.

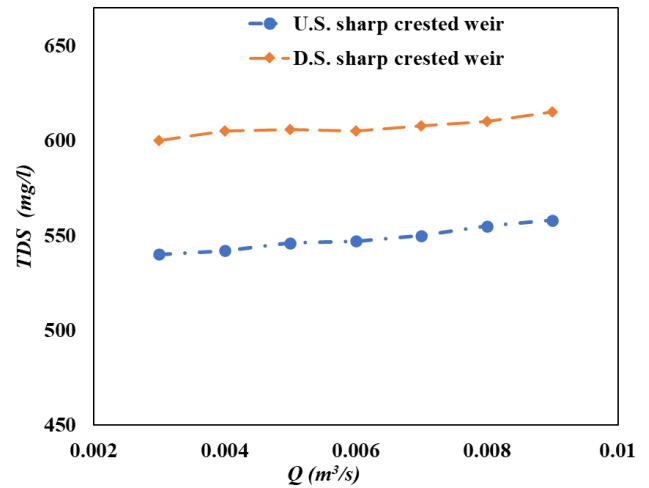


Figure 7. Sharp-crested weirs upstream and downstream exhibit a relationship between TDS (mg/L) and $Q \text{ (m}^3/\text{s)}$

3.4 The impact of a sharp-crowned weir on turbidity

Figure 8 illustrates turbidity variations across the weir. Results show a consistent decrease downstream, from $9.47 \rightarrow 6.5$ NTU and upstream from $9.50 \rightarrow 7.0$ NTU, representing up to 17.2% reduction. The reduction in turbidity can be explained by particle flocculation and settling, aided by turbulence-induced collisions, as well as the growth of aerobic microorganisms supported by higher oxygen levels. Reduced turbidity improves light penetration, which is beneficial for aquatic photosynthesis and ecosystem balance.

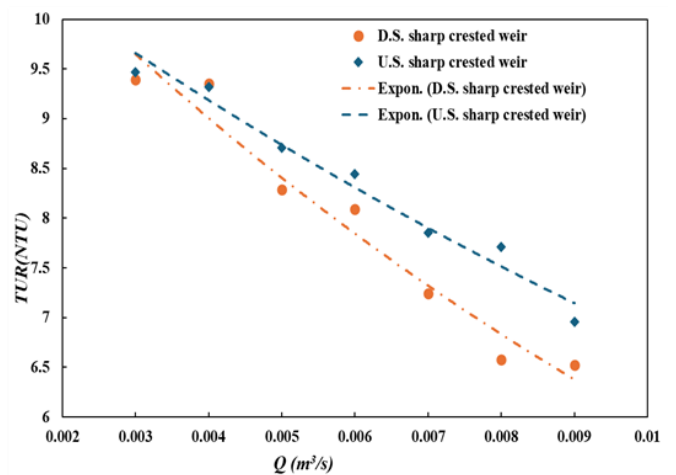


Figure 8. Relationship between TUR (NTU) and $Q \text{ (m}^3/\text{s)}$ at upstream and downstream sharp crested weir

3.5 The impact of a sharp crested weir on pH

Figure 9 shows the relationship between various flow rates (Q) and the pH in the upstream and downstream sharp-crested weir. The results showed that pH values remain relatively stable, with minimal variation upstream and downstream. This

indicates that the weir does not significantly alter the chemical balance but maintains it within an acceptable ecological range. The slight variation in pH values implies minimal chemical reactivity during passage over the weir. However, minor increases at higher discharges may result from degassing of CO₂ due to turbulence, which slightly raises pH levels. Overall, the weir maintains water chemistry stability, which is crucial for the health of aquatic species.

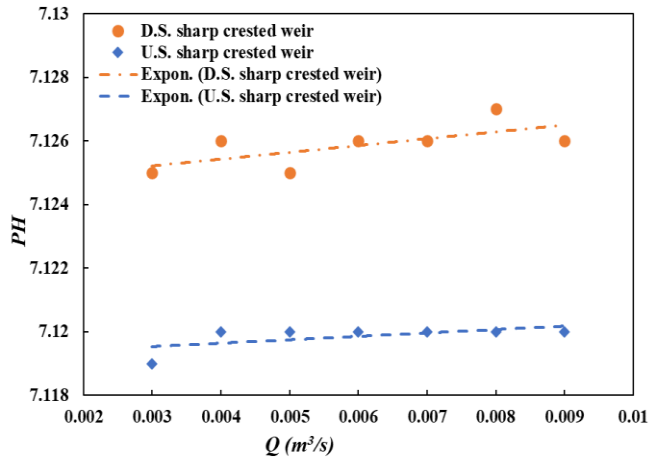


Figure 9. Relationship between pH and Q (m³/s) at upstream and downstream sharp-crested weir

3.6 The impact of a sharp crested weir on electrical conductivity (EC)

Figure 10 shows that EC exhibited only marginal changes between upstream and downstream sections, consistent with its dependence on ionic concentrations rather than DO levels. While turbulence and reoxygenation may influence ion distribution, the results suggest that EC remained largely stable. The observed minor variations are closely aligned with TDS trends, as EC is directly derived from TDS through the empirical relationship $EC = TDS / 0.64$ [17]. Thus, rather than indicating detoxification or ionic disruption, the results demonstrate that EC stability reflects the minimal impact of the weir on ion concentrations.

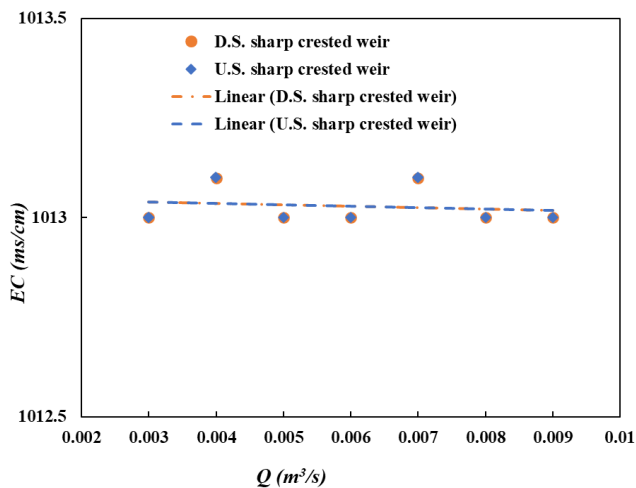


Figure 10. Relationship between EC and Q (m³/s) at upstream and downstream sharp crested weir

Overall, the experimental results confirm that sharp-crested weirs contribute positively to water quality by:

- Enhancing DO concentrations through turbulence-driven aeration.
- Reducing TDS and turbidity via mixing, dilution, and particle flocculation.
- Maintaining pH and EC within stable ecological ranges.

The improvements were more pronounced at higher discharges, where hydraulic energy and turbulence intensity were maximised. These outcomes highlight the potential of sharp-crested weirs as sustainable tools for ecological restoration and engineered water management.

3.7 Comparison of aeration efficiency with the literature

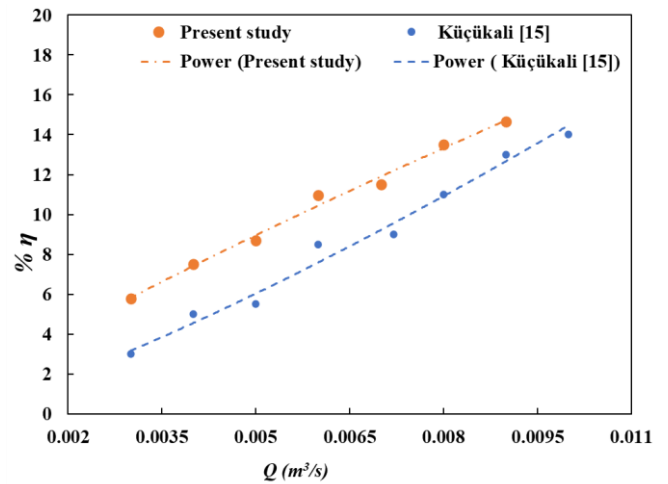


Figure 11. The comparison of aeration efficiency for the present study and the literature

Figure 11 shows the relationship between aeration efficiency ($\% \eta$) and discharge (Q). Aeration efficiency in both the present study and Küçükali [15] showed a positive correlation between discharge and aeration efficiency. The present study showed that the aeration efficiency increases as discharge also increases. This is expected, since higher discharge increases turbulence and mixing, which improves oxygen transfer at the air – water interface. As shown in Figure 11, the present study demonstrated that the efficiency of aeration was consistently higher than that described by Küçükali [15] for the same values of discharges. At $Q \approx 0.003$ m³/s, $\eta \approx 3\%$ in the Küçükali [15], compared to $\approx 6\%$ in the present study. At $Q \approx 0.009$ m³/s, $\eta \approx 13\%$ in Küçükali [15], compared to $\approx 15\%$ in the present study. Küçükali [15] showed a similar increasing trend, but with lower values compared to the present study. The results indicated that aeration efficiency increases with discharge, but less significantly than in the present study. Aeration efficiency enhancement in the present study, compared to Küçükali [15], is attributed to enhanced oxygen transfer. The main reasons were differences in weir geometry, tailwater depth, nappe trajectory, or downstream conditions, which may have promoted stronger air entrainment and turbulence in the present study. Also, the difference in scale effect between the Lab-scale and field-scale caused differences in turbulence intensity and bubble breakup, thus changing aeration enactment. Moreover, Variances in the concentration of initial dissolved oxygen, water temperature, and water quality parameters could have influenced differences in measured efficiency. The nappe flow condition in the present study was more aerated (e.g., free-falling nappe

with significant cavity formation), which would improve oxygen transfer compared to a more attached or submerged nappe observed in Küçükali [15].

4. CONCLUSIONS

The present study experimentally assessed the impact of a sharp-crested weir on key water quality parameters under controlled laboratory conditions. The outcomes showed that sharp-crested weirs improve ecological sustainability based on the weir's ability to increase turbulence and air–water interaction. The main findings can be summarized as follows:

- 1) Dissolved oxygen increased significantly downstream of the weir, with enhancements of up to 14.7% (from 7.2 to 7.85 mg/L at higher flow). Dissolved oxygen demonstrated the efficiency of sharp-crested weirs in promoting aeration by nappe flow and bubble entrainment. The maximum efficiency of aeration was 15% for $Q = 0.009 \text{ m}^3/\text{s}$.
- 2) Turbidity reduced downstream, with decreases of 17.2%, respectively. These changes are attributed to improved mixing, dilution, and flocculation rather than sedimentation, leading to enhanced clarity and decreased pollutant concentrations.
- 3) TDS values were slightly increased in both upstream and downstream. Also, the results demonstrated that TDS values in the downstream were slightly higher than upstream of a sharp-crested weir.
- 4) Electrical conductivity and pH showed only slight variations, staying within stable ranges of ecological conditions. This indicates that the weir does not disturb the chemical balance of the water while supporting physical improvements in quality.

From a practical perspective, sharp-crested weirs can serve as effective, low-cost, and sustainable hydraulic structures to improve water quality in engineered channels and river systems. By simultaneously enhancing oxygen levels and reducing pollutant loads, they can reduce the burden on downstream treatment facilities and support ecological restoration efforts. However, it is important to note that the present research was conducted in a laboratory flume under controlled conditions. Natural rivers are far more complex, influenced by factors such as sediment transport, aquatic organisms, seasonal variability, and pollutant diversity. Therefore, field studies are necessary to validate the long-term ecological performance of sharp-crested weirs in real river environments. Future research should extend this work by:

- Investigating different weir geometries and multi-barrier configurations.
- Incorporating advanced turbulence indicators (e.g., turbulent kinetic energy, energy dissipation rate) and oxygen transfer metrics (e.g., SOTE).
- Examining pollutant-specific responses (nutrients, heavy metals, organic contaminants) to better assess practical applications in water quality management.

In conclusion, sharp-crested weirs demonstrate considerable promise as multifunctional hydraulic structures that combine flow regulation with ecological benefits, contributing to sustainable water management strategies in both urban and rural contexts.

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