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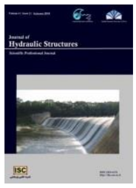

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Modeling of discharge Coefficient of nonlinear weirs with QNET and SVM methods

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Abstract

In this study, we investigate the discharge coefficient prediction of arched labyrinth weirs with a cycle angle of 6 degrees, employing 243 data series. Labyrinth weirs, aside from their economic advantages, exhibit superior flow-passing capabilities compared to linear weirs. Notably, increasing the length of the crest within a specified width enhances discharge efficiency with less upstream height. Machine learning algorithms, namely QNET and SVM, play a pivotal role due to their proficiency in uncovering intricate relationships between independent and dependent parameters, leading to significant time and cost savings. Our results using QNET and SVM indicate that the combination of (Cd, $\frac{H_T}{p}$, θ, $\frac{L_C}{W}$) yields optimal accuracy, with QNET achieving (R^2=0.9850), (RMSE=0.0259), and (DC=0.9892) in the training phase, and (R^2=0.9824), (RMSE=0.0292), and (DC=0.9788) in the test phase. For SVM, the training phase results are (R^2=0.9889), (RMSE=0.0189), and (DC=0.9870), and in the test phase (R^2=0.9881), (RMSE=0.0199), and (DC=0.9853). Sensitivity analysis shows the significant role of the total water load ratio parameter ($\frac{H_T}{p}$) in determining the discharge coefficient of arched labyrinth weirs. This research contributes to the understanding of non-linear arched weir discharge predictions and highlights the efficacy of QNET and SVM algorithms in this domain.

Keywords: Sensitivity Analysis, Non-Linear Weirs, Evaluation Indicators, Discharge Coefficient.

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1. Introduction

One of the important topics during the development of civilization is the management and transfer of human water. Various hydraulic structures have been designed and built to meet the needs. One of the common structures in many dams and water transfer channels are weirs, which are used for the purpose of draining, measuring and controlling the water level. Given the potential for maximum rainfall and the constant need for dam safety, most of the existing weirs are small and correction. The volume of flow passing through the weir depends on the length and shape of the weir crest. Numerous studies have been conducted on the impact of hydraulic and geometrical parameters on the flow discharge coefficient and the amount of flow passing through the weirs. An effective approach to increase the length of a flow weir within a specific width is the use of weirs with a non-linear plan, such as triangular, trapezoidal, circular, parabolic, etc., commonly referred to as multi-faceted, labyrinth or zigzag weirs These multi-faceted weirs are typically constructed in a single cycle or through multiple cycles. The emergence of labyrinth weirs in recent years has enhanced weir performanceby replacing linear weirs with non-linear labyrinth weirs. One of the main characteristics of labyrinth weirs is their capacity to increase the overall length within a channel with limited width. Arched labyrinth weirs show their highest level of efficiency in the damn reservoirs. According to the hydraulic performance and geometric diversity, arched labyrinth weirs are built as a water head control structure, energy consumption, flow aeration and flow measurement in the direction of channel, river, lake, and reservoirs. A labyrinth weir is a folded linear weir in plan. Increasing the crest length in a limited width of the channel is possible and can be designed for labyrinth weirs. A labyrinth weir can pass more flow at relatively low heads compared to linear weirs with the same channel width. A labyrinth weir has a crest length that extends beyond the width of the channel, which is a developed characteristic compared to linear weirs located in the same channel. In other words, for the given discharge, the head for the labyrinth weir is less than the linear weir. This condition is widely used when the maximum height of the flow is limited. The aeration efficiency of the labyrinth weirs is better than the linear weirs of the same length and this increasement in efficiency is effective in reducing the higher discharges. Figure 1 illustrates the plan of different labyrinth weirs.

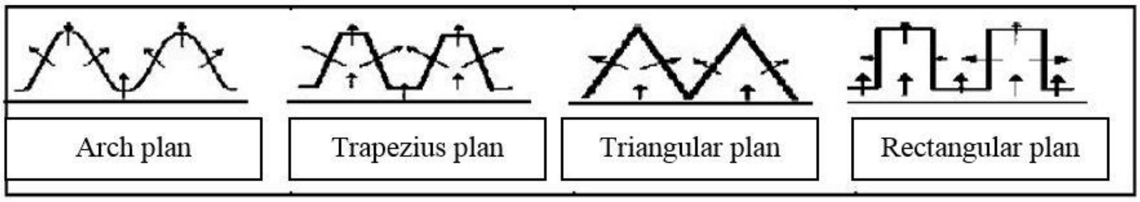

Figure 1: Plan of different types of labyrinth weirs

The hydraulics of labyrinth weirs was investigated for the first time by Gentilini in 1940 [1]. Kozak and Swab in 1961 examined eleven labyrinth weirs with different trapezoidal plans. They came to the conclusion that the volume of flow passing through the labyrinth weirs for a specific head in the upstream is significantly more than the linear weirs. Also, they came to the conclusion that for an equivalent length, the number of small cycles is more efficient than large cycles [2]. Tison and Fransen (1963) researched labyrinth weirs [3]. Taylor (1968) also studied the performance of triangular, trapezoidal and rectangular weirs with sharp edges and different number of cycles [4]. Also, Hay and Taylor (1970) were the first people who conducted the most comprehensive study on triangular and trapezoidal labyrinth weirs (with a sharp edge crest shape) and achieved practical results in this field. They used the ratio of labyrinth weirs flow to linear weirs flow to show the performance of labyrinth weirs. In the design curves presented by them, the hydrostatic height of the flow was included as an effective load on the weir [5]. Darvas (1971) presented the results of his research based on the physical models of Verona and Avon dams, this researcher also presented a curve handle for the design of trapezoidal weirs with a quarter circle crest and an experimental relationship [6]. Indlekofer and Rouve (1975) studied the flow interference zone at the vertices of sharp edge triangular weirs and defined a length for the flow interference zones [7]. Cassidy et al. (1985) showed that for high heads, the discharge coefficient of labyrinth weirs is significantly lower than other weirs [8]. Tacail et al. (1990) showed that in similar widths, two-cycle labyrinth weirs perform better than three-cycle labyrinth weirs [9]. Tullis et al. (1995) worked trapezoidal labyrinth weirs with 4 cycles and 5 different crest shapes and they found that the capacity of trapezoidal labyrinth weir is a function of total hydraulic load, medical crest length and coefficient the water is passable. The water passage coefficient is a function of the height of the weir, the total hydraulic load, the thickness of the weir wall, the shape of the crest, the shape of the top, and the angle of the lateral walls of the weir. By examining the effect of these parameters on the performance of labyrinth weirs, they presented new diagrams and found that the throughput efficiency of labyrinth weirs increases three to four times compared to linear weirs for the same upstream load [10]. Wormleaton and Soufiani (1998) stated that the aeration coefficient of triangular labyrinth weirs compared to linear weirs depends on the apex angle and the length of the weirs crest [11]. Wormleaton and Tsang (2000) conducted their studies on the aeration of labyrinth weirs and concluded that the rectangular labyrinth weirs have a higher efficiency for flow aeration compared to the triangular shape and compared to the linear weirs. These researchers also announced that with the increase in discharge, the superiority of the rectangular shape over the triangular shape increases, which is due to the increase in the interference of the falling layers of the flow in the triangular weirs [12]. Ghodsian (2007) conducted laboratory studies on a triangular labyrinth weir with different crest shapes and first extracted the relevant parameters in a dimensionless way by dimensional analysis, and then with the laboratory data, a regular and consistent relationship for the discharge coefficient and introduced Head-Debbie [13]. According to the findings of the experimental research conducted by Zerihun and Fenton (2007) and Kabiri and Samani et al. found [14] and [15]. Carollo et al. (2012) worked on a dimensionless head-discharge relationship for triangular labyrinth weirs with a change in the flow direction of the vertices of the triangles [16]. Crookston et al. (2013) analyzed the analysis and optimal design of labyrinth weirs for flow aeration, estimation of the head-discharge relation, stabilization of the water blade on the weirs, and by cutting parts of the wall and nose of the weirs, as well as by creating appendages. Crookston et al. (2013) analyzed the analysis and optimal design of labyrinth weirs for aeration flow, estimation of the head-discharge relationship, stabilization on the weir blade, and by cutting parts of the wall and nose of the weir, as well as by creating appendages. On the walls and nose of weirs, they improve the main factors [17]. The research results of Dabling (2014) showed that with the increase of the ($\frac{H_o}{P}$) ratio in modified and unmodified weirs, the absorption ratio increases [18]. The results of the experimental research carried out by Seo et al. (2016) showed that the flow rate through a labyrinth weir is about 70% higher than the flow rate through a direct sharp edge weirs under free flow conditions. They stated that with the increase of the degree of absorption of the weirs, the permeability efficiency of the weirs decreases, and its value is proportional to the ratio ($\frac{h_d}{h^*}$) [19]. Christiansen (2015) while investigating the inflow field to labyrinth weirs, investigated the effect of the number of cycles on the performance of this type of weirs and concluded that with the increase in the number of cycles, the water passage coefficient decreases [20]. In recent years, following experimental and laboratory studies, a lot of research has been done to improve and advance experimental methods for calculating the discharge coefficient, choosing the optimal geometry and efficiency of labyrinth weirs, among which we can soft computing methods that are data oriented. Cimen (2008), Kakai Lafdani et al. (2012) used the SVM model to predict the monthly volume of suspended sediment in the Dorij River located in Ilam province [21] and [22]. Govan et al. (2009) and Azmatullah et al. (2010) and Goyal et al. (2011) using the method (SVM, GEP and ANN and artificial neural network) scouring around hydraulic structures and the scouring depth of the bridge base in a The laboratory model predicted and showed that the above methods provide more accurate predictions than experimental methods [23], [24] and [25]. Azhdari Moghadam et al. (2009) optimized the geometry of the triangular labyrinth weirs using neural fuzzy model and genetic algorithm (case study of Hyrum Dam in the state of Utah, USA) and compared the results of this method with the available values from The weight of concrete used in the current situation shows a 12.35 percent reduction in weirs costs, which indicates the better results of this method [26]. Abbaspour and Arvanaghi (2011) used GEP model to estimate flow rate on triangular-rectangular composite weirs and investigated and compared the effect of geometric and hydraulic parameters on flow rate. The results showed that there is a good match between the observed and predicted values of the genetic programming model [27]. The use of artificial intelligence models such as GEP, SVM, ANFIS, etc. have found a lot of use in the simulation of complex hydraulic, hydrological and water resources phenomena in recent years, Farrokhy et al [28] (2009). The use of soft computing methods such as support vector machine can be considered as an alternative method for empirical equations and models, and in recent decades, they have brought about a huge evolution in engineering problems. These methods have shown good ability in modeling and predicting complex phenomena and optimizing engineering problems. The main reason for using smart models is the cost estimation and time-consuming normal methods compared to smart models. Karami et al. (2016) used artificial intelligence algorithms to accurately predict the water flow coefficient of labyrinth weirs [29]. Roushangar et al. (2016) predicted the flow rate coefficient for lateral weirs by using intelligent learnable algorithms [30]. Parsaie, Haghiabi et al. (2017) used neural network and adaptive neural fuzzy inference system to estimate the permeability coefficient of oblique lateral weirs. They used the SVM algorithm to model the discharge coefficient of a sharp edge weirs with a W-shaped plan [31]. Majedi and Fuladi Panah (2017) have recommended the use of SVM algorithm for use in simulations where the laboratory variable is a function of several independent variables [32]. Majedi et al. (2018) investigated the use of evolutionary systems in determining the discharge coefficient of triangular labyrinth weirs and stated that the support vector machine method has a very good performance in predicting the discharge coefficient of sharp edge labyrinth weirs and can He used this method in similar cases [33]. Roushangar et al. (2018) determined the discharge coefficient of labyrinth weirs and labyrinth arch by the support vector regression method and by comparing the experimental and predicted data, they found the SVM model as the appropriate model for determining the discharge coefficient. Labyrinth weirs recommended [34]. Mehri et al. (2018) used the SVM model to estimate the flow coefficient of piano key weirs in irrigation and drainage networks. The result of their research confirmed the appropriate flexibility of the SVM model compared to nonlinear regression and the high accuracy of the SVM model [35]. In the research conducted by Parsaie et al. (2019), the use of intelligent mathematical models GEP, GMDH and MARS modeled the discharge coefficient of non-linear weirs [36]. Kumar et al. (2020) simulated the flow coefficient of piano key weirs in a laboratory and machine learning algorithm, the result of their research indicated the very appropriate accuracy of machine learning algorithms [37]. Fuladi Panah et al. (2020) investigated the use of intelligent algorithms for modeling the discharge-Eschol relationship in the conditions of congestive and linear weirs [38]. Majedi et al. (2021) conducted a study using data mining methods to improve the prediction of the discharge coefficient in the weirs of piano keys and labyrinth [39]. Roushangar et al. (2021) in laboratory studies as well as modeling based on artificial intelligence investigated the discharge coefficient of converging peak weirs [40]. Omidpour Alavian et al modeled and evaluated the discharge coefficient of arched labyrinth weirs [41]. Omidpour Alavian et al. compared the hydraulic efficiency of labyrinth weirs with quarter-circle and semi-circle crest shapes [42]. Majedi et al investigated the hydraulic efficiency of labyrinth weirs with quarter-circle and semi-circle crest shape [43]. Majedi et al. compared the hydraulic efficiency of labyrinth weirs with artificial intelligence methods [44]. Labyrinth weirs are among the weirs that have been researched from various hydraulic and geometrical aspects. The review of previous sources and researches shows that there is less study and research regarding the comparison of laboratory results and the prediction of the flow rate coefficient of the arched labyrinth weir using QNET and SVM smart algorithms combined with the application of the effect Various hydraulic and geometrical parameters have been determined, which is the novel and innovative aspect of the current research.

In this regard, with the help of laboratory results data and using QNET and SVM machine learning algorithms, the effect of geometric and hydraulic parameters including total water load ratio ($\frac{H_T}{p}$), magnification factor ($\frac{L_C}{W}$), cycle wall angle (α), the angle of the arc cycle (θ) has been investigated on the discharge coefficient of the arched concourse overflow. The purpose of this research is to compare the discharge coefficient of the arched labyrinth weir (Cd) obtained in Crookston's (2010) research with those derived from machine learning analyses, QNET and SVM, applied to the arched labyrinth weirs.

2. Materials and Methods

The aim of this research is to compare laboratory data results with those obtained from machine learning algorithms, namely QNET and SVM, for determining the flow rate coefficient in arched labyrinth weirs. Additionally, the study aims to accurately evaluate machine learning algorithms using statistical parameters and compare their outcomes with the laboratory data results. In this article utilizes the research data of Brian Mark Crookston’s work conducted in 2010 at the Utah Water Research Laboratory. An illustration of the rectangular channel and the test facility of the tank is shown in Figure 2. Crookston's research employed two facilities for physical modeling: a rectangular flume designed for channelization applications, and a large head box intended for reservoir applications, as depicted in Figure 2.

2.1. Rectangular channel Installations

The rectangular laboratory channel with specifications (1.2 m wide, 14.6 m long and 1 m deep) consists of a steel frame and acrylic glass for the walls and floor. The slope of the channel is adjusted by four large mechanical jacks. For this study, the longitudinal slope of the channel bed, S_{bed} was set to zero. After installation, the platform was adjusted to the horizontal level (±0.4 mm). A 2.44-meter-long ramp, with a slope of 7 degrees, was installed upstream of the platform to ensure a smooth transition between the floor of the flume and the platform. Two supply lines deliver water to a steel head box that has a baffle structure to maintain smooth flows and uniform approach conditions to the channel.

Figure 2: Pictures of the channel and reservoir and laboratory facilities. (Crookston [2], 2010)

The one-dimensional equation of the flow on the labyrinth weirs is expressed as a function of the total water load (H_T) in meters, the length of the weir crest (L) in meters and the dimensionless weir flow coefficient (Cd), obtained from equation (1) in the work of Henderson [45] (1966). The effective parameters on the discharge coefficient in the weirs of the labyrinth can be expressed in the form of functional relationship, as given in equation (2).

$$Q = \frac{2}{3} Cd\sqrt{2g}\, LH_T^{\frac{3}{2}} \quad (1)$$

$$Cd = f\,(B, L, H_T, Hd, P, R, CR, Na, N) \quad (2)$$

In the equation (2), B is width of the channel where the weirs is installed; L is length of weirs crest; H_T is the head of the total flow upstream of the weirs, which is equal to ($\frac{h+v^2}{2g}$); Hd is head of the entire flow downstream of the weirs; P is weirs height; R is the radius of curvature of semicircular cycles; CR is the parameter representing the shape of the weir's crest, which can be edged, smooth, quarter circle with small to large rays, semicircular and pointed; Na represents the shape of the flow blade in the weirs of the labyrinth, which can be free fall, mixed fall, aerated, incomplete or complete aeration, and N is the number of cycles. In this research parameters are (Cd, $\frac{H_T}{p}$, α, Ɵ, $\frac{L_C}{W}$) and the number of data is 243. to the investigation of the changes in the discharge coefficient of the labyrinth weir has been done using QNET and SVM methods.

Table 1. Different input combinations related to QNET and SVM models

Effective Parameters	Combination
$\frac{H_T}{p}$	Combination 1
$Cd, \frac{H_T}{p}, \Theta, \frac{L_C}{W}$	Combination 2
$Cd, \frac{H_T}{p}, \frac{L_C}{W}$	Combination3
$Cd, \Theta, \frac{H_T}{p}$	Combination 4
$Cd, \frac{L_C}{W}$	Combination 5
$Cd, \Theta, \frac{L_C}{W}$	Combination 6
Cd, Θ	Combination 7

2.2. QNET

Currently, there is significant attention given to neural network modeling systems and their effectiveness in addressing data modeling problems. The QNET 2000 implements a neural network algorithm and features powerful software for creating and training backpropagation neural networks, effectively addressing various everyday problems. The above software is a post-error propagation neural modeling system, which is designed to increase the power of personal computers. The problems that can be solved with this software are unlimited. This software provides an advanced network design structure for generating complex networks, which uses the optimal training algorithm after error propagation. The advantages of this neural network include high speed, multiple training methods, a software help section for all models, fast and straightforward network design, easy data commonality and set of automatic tests for analysis. Additional model and training, complete cross-analysis of the learning process using network graphs and its powerful self-magnification structure, advanced network analysis tools, the ability to automatically save the network model during training, learning speed control side to automate network training, algorithms Numerous trainings, verification method with complete structure, the ability of integration of neural network models to everyday work space and example problems were pointed out. All these characteristics have made QNET 2000 the most powerful and convenient neural network software to use.

2.3. SVM

The Support Vector Machine (SVM) is an algorithm used for classification or pattern recognition, initially introduced by Vapnik in 1995. In recent years, SVM has been used as a new method in solving water engineering problems and hydraulic structures. The clear example supporting this statement is the current popularity of SVM compared to the past preference of neural network. Presently, most researchers tend to use SVM in their research work. In fact, the main reason is the usability of this method in solving various hydraulic problems. The theoretical foundation of the SVM classifier rests on the principle of linear classification. This involves dividing the data into two classes using a straight line (hyperplane in higher dimensions). SVM seek to find a hyperplane with the maximum margin, maximizing the distance between the closest data points of each class, as this leads to the most confident separation of the classes. In this scenario, we encounter solving a type of constrained optimization problem that can be solved by the Quadratic Programming method. Assuming linear separability of classes, hyperplanes with the maximum margin are obtained that separate the classes. When the data is not linearly separable, it is mapped to a higher-dimensional space to enable linear separation in this new space [46].

2.4. Performance evaluation indicators

In this research, the efficiency of the models is evaluated based on the following criteria:

1- The root mean square of errors (RMSE) is calculated using Equation 3.
2- Coefficient of determination (DC), or linear correlation between the observed and predicted values, indicates the strength of the correlation. A value closer to one suggests a better correlation of the data. The DC is calculated using the Equation 4.
3- The values for the square of the correlation coefficient (R^2), which is calculated using the Equations 5.

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{(Cdo - Cdp)^2}{N}} \tag{3}$$

$$DC = 1 - \frac{\sum_{i=1}^{N}(Cd_i^o - Cd_i^p)^2}{\sum_{i=1}^{N}(Cd_i^o - \overline{CDp})^2} \tag{4}$$

$$R^2 = \left(\frac{\sum_{i=1}^{N}(Cd_i^o - \overline{Cd^o})(Cd_i^p - \overline{Cd^p})}{\sqrt{\sum_{i=1}^{N}\left(Cd_i^o - \overline{Cd^o}\right)^2 \sum_{i=1}^{N}(Cd_i^p - \overline{Cd^p})^2}}\right)^2 \tag{5}$$

In the above equations, the parameters Cdp, Cdo and N are the predicted discharge coefficient, the observations of weirs, and the number of data, respectively. The above statistical criteria are calculated for the training and test stages.

3. Results and Discussion

As mentioned earlier, the purpose of this research is to compare the flow coefficient obtained from laboratory data with the predicted flow coefficient of QNET and SVM algorithms. The flow passing over the labyrinth weirs has a three-dimensional and complex structure; thus, it is not possible to solve it explicitly. Therefore, to calculate of the discharge coefficient relies on the general equation of weirs according to Equation 2.

3.1. Results of the QNET method

In this research, in order to achieve better and more accurate results, training and test data were evaluated using different percentages (60-40, 70-30, 80-20) and with node transfer functions in seven different combinations. Finally, the best combination according to the optimal levels of the evaluation indices was determined that the pattern (40-60) and with the hyperbolic secant transfer function (sech(x)) and one intermediate layers for most of the investigated parameters. In all the models of the current research, 60% of the data was used for training the network, while the remaining 40% were used for testing. The results for the combination are given in table (2) and the desired combination is number 2. This combination with inputs ($\frac{H_T}{p}$, Θ, $\frac{L_C}{W}$) has the lowest error (RMSE=0.0259) and the highest correlation coefficient (R^2=0.9850) and coefficient of determination (DC=0.9892) in the training phase. Also, this combination has showed the lowest error (RMSE=0.0292) and the highest correlation coefficient (R^2=0.9824) and explanation coefficient (DC=0.9788) in the test phase. Thus, it is selected as the best model for predicting the discharge coefficient of arched non-linear weirs.

Table 2. Evaluation criteria of different input combinations to determine the discharge coefficient for the QNET model

Train			Test			
R^2	RMSE	DC	R^2	RMSE	DC	Name of the combinations
0.8902	0.0366	0.89005	0.9345	0.03555	0.9033	$\frac{H_T}{p}$
0.9850	0.0259	0.9892	0.9824	0.0292	0.9788	$\frac{H_T}{p}, \Theta, \frac{L_C}{W}$
0.8907	0.0366	0.8907	0.9352	0.0355	0.9034	$\frac{H_T}{p}, \frac{L_C}{W}$
0.7811	0.0189	0.8809	0.9241	0.0191	0.8938	$\frac{H_T}{p}, \Theta$
0.000	0.164308	0.0002	0.0001	0.1667	-0.000735	$\frac{L_C}{W}$
0.2178	0.1598	0.21782	0.01121	0.1607	-0.1385	$\frac{L_C}{W}, \Theta$
0.0263	0.1787	0.0269	0.1825	0.1753	0.0787	Θ

Figure 3 illustrates the graphs depicting the distribution of experimental and predicted data for the best combination (second combination) during both the training and test phases. The values of R^2 indicate a linear relationship with a very favorable accuracy between the two values of the experimental and predicted data. The values of R^2 for the distribution diagram of the training phase are 0.9850 and in the test phase it is equal to 0.9824. The results in both stages of training and testing in the maximum and minimum points of the predicted points are almost more estimated than the experimental points.

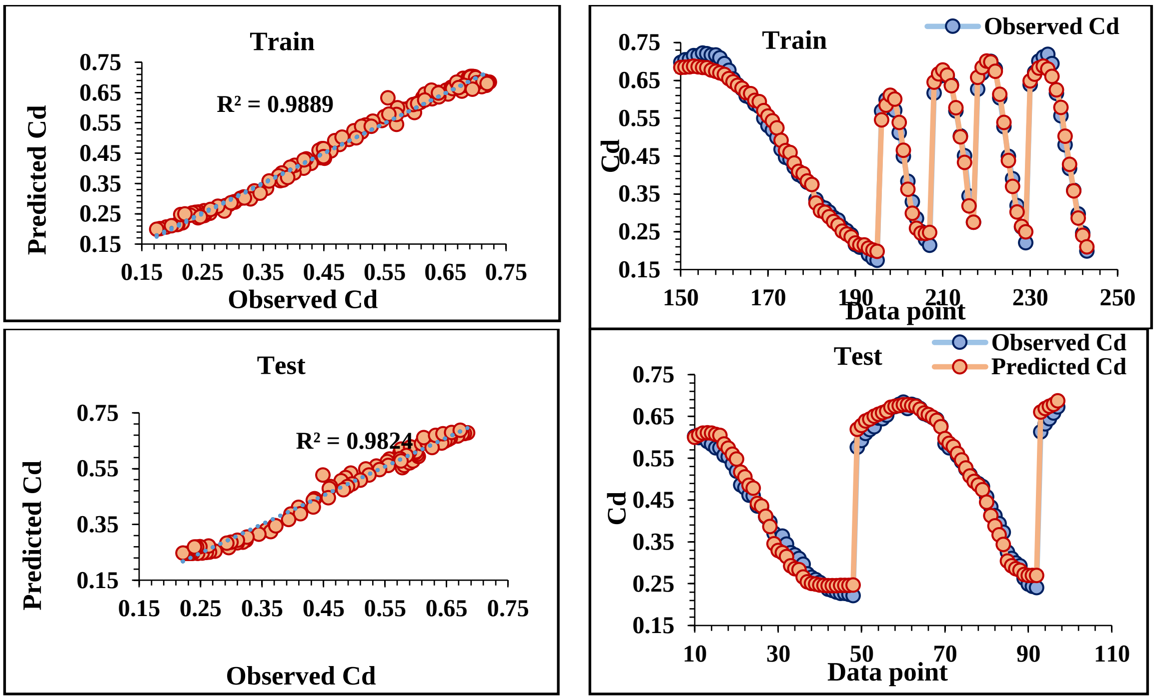

Figure 3. Data Distribution of experimental and predicted data during the training and test phases

Table (3) shows the statistical parameters of the sensitivity analysis related to the arched labyrinth weir. According to the relevant table, by removing the ($\frac{H_T}{p}$, Ɵ, $\frac{L_C}{W}$) parameters, RMSE and R^2 parameters have been calculated for both training and test phases. Notably, when ($\frac{H_T}{p}$) was removed, the resulting values indicated poorer performance compared to the removal of other parameters. This observation suggests that the most important parameter in determining the discharge coefficient of the arched labyrinth weirs is the total water load ratio parameter ($\frac{H_T}{p}$).

Table 3. Sensitivity analysis related to the QNET method

Train			Test			Remove the parameter	Combination
$\boldsymbol{R^2}$	*RMSE*	*DC*	R^2	*RMSE*	DC		
0.9850	0.0259	0.9892	0.9824	0.0292	0.9788	-	$\frac{H_T}{P}$, Ɵ, $\frac{L_C}{W}$
0.8907	0.0366	0.8907	0.9352	0.0355	0.9034	Ɵ	$\frac{H_T}{P}$, $\frac{L_C}{W}$
0.7811	0.0189	0.8809	0.9241	0.0191	0.8938	$\frac{L_C}{W}$	$\frac{H_T}{P}$, Ɵ
0.2178	0.1598	0.21782	0.01121	0.1607	-0.1385	$\frac{H_T}{P}$	$\frac{L_C}{W}$, Ɵ

3.2. Results of the SVM method

In this research, in order to achieve better and more accurate results, training and test data with different percentages (40-60, 30-70, 20-80) and with appropriate gamma value and with RBF radial function in seven combinations was evaluated. Finally, the best combination for the optimal levels of the evaluation indices was determined that the 40-60 pattern with a gamma value of 10 leading to the best results for most of the investigated parameters. Currently, 60% of the data were used for training the model, while the remaining 40% were used for testing.

The results for all combinations are presented in Table (4) and the most desirable combination is the combination number 2. This combination with inputs ($\frac{H_T}{P}$, Ɵ, $\frac{L_C}{W}$) has the lowest error (RMSE=0.0199) and the highest correlation coefficient (R^2=0.9881) and coefficient of determination (DC=0.9853) in the test phase. As a result, it is chosen as the best model for predicting the discharge coefficient of arched labyrinth weirs.

Table 4. Evaluation criteria of different input combinations to determine the discharge coefficient for the SVM model

Train			Test			
R^2	RMSE	DC	R^2	RMSE	DC	Name of the combination
0.9512	0.03651	0.9518	0.9534	0.0356	0.9533	$\frac{H_T}{p}$
0.9889	0.0189	0.9870	0.9881	0.0199	0.9853	$\frac{H_T}{p}, \Theta, \frac{L_C}{W}$
0.9512	0.0367	0.9512	0.9534	0.0357	0.9529	$\frac{H_T}{p}, \frac{L_C}{W}$
0.9888	0.0184	0.9512	0.9882	0.0199	0.9853	$\frac{H_T}{p}, \Theta$
0.0000	0.1644	0.0238	0.000	0.1667	-0.027	$\frac{L_C}{W}$
0.0571	0.0256	0.0758	0.0668	0.1607	0.0446	$\frac{L_C}{W}, \Theta$
0.0527	0.1688	-0.0292	0.0502	0.1653	-0.010	Θ

Figure 4 shows the graphs related to the distribution of experimental and predicted data for the best combination (second combination) in the training and test phase. The values (R^2) show a linear relationship with a very favorable accuracy between the two values of the experimental and predicted data. The values of (R^2) for the distribution diagram in the training phase are (0.9881) and in the test phase it is equal to (0.9889). The relevant results in both stages of training and test have estimated the predicted points at the maximum points almost more than the experimental points and at the minimum points almost less.

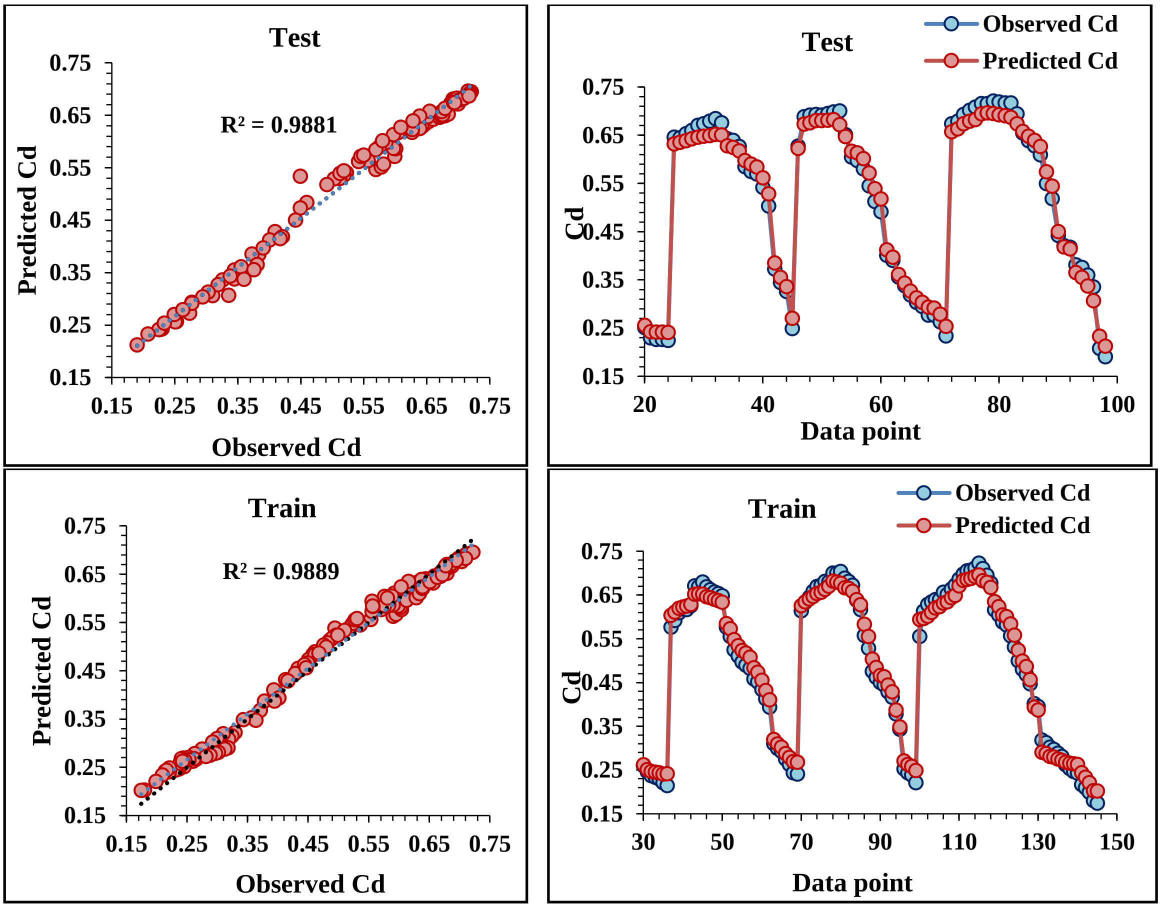

Figure 4. Data Distribution of experimental and predicted data in the training and test phases

Table (5) shows the statistical parameters of the sensitivity analysis of arched labyrinth weir. According to the presented table, by removing the ($\frac{H_T}{p}$, Θ, $\frac{L_C}{W}$) parameters, RMSE and R2 parameters have been calculated for both training and test phases. Notably, when ($\frac{H_T}{p}$) was removed, the resulting values indicated poorer performance compared to removal of other parameters. This observation suggests that the most important parameter in determining the discharge coefficient of the arched labyrinth weir is the total water load ratio parameter ($\frac{H_T}{p}$).

Table 5. Sensitivity analysis of the SVM model

Train			Test			Remove the parameter	Combination
R^2	RMSE	DC	R^2	RMSE	DC		
0.9889	0.0189	0.9870	0.9881	0.0199	0.9853	-	$\frac{H_T}{P}$, Θ, $\frac{L_C}{W}$
0.9512	0.0367	0.9512	0.9534	0.0357	0.9529	Θ	$\frac{H_T}{P}$, $\frac{L_C}{W}$
0.9888	0.0184	0.9512	0.9882	0.0199	0.9853	$\frac{L_C}{W}$	$\frac{H_T}{P}$, Θ
0.0571	0.0256	0.0758	0.0668	0.1607	0.0446	$\frac{H_T}{P}$	$\frac{L_C}{W}$, Θ

4. Comparing the results of two investigated models (QNET-SVM)

Figure 5 illustrates a bar chart of experimental and predicted data for the arched labyrinth weir with cycle wall angle of α = 6° related to the best combination, which includes the parameters ($\frac{H_T}{p}$, Θ, $\frac{L_C}{W}$) for both QNET and SVM models in the test phase. Figure 5 shows that the SVM model exhibit a superior performance compared to the QNET model.

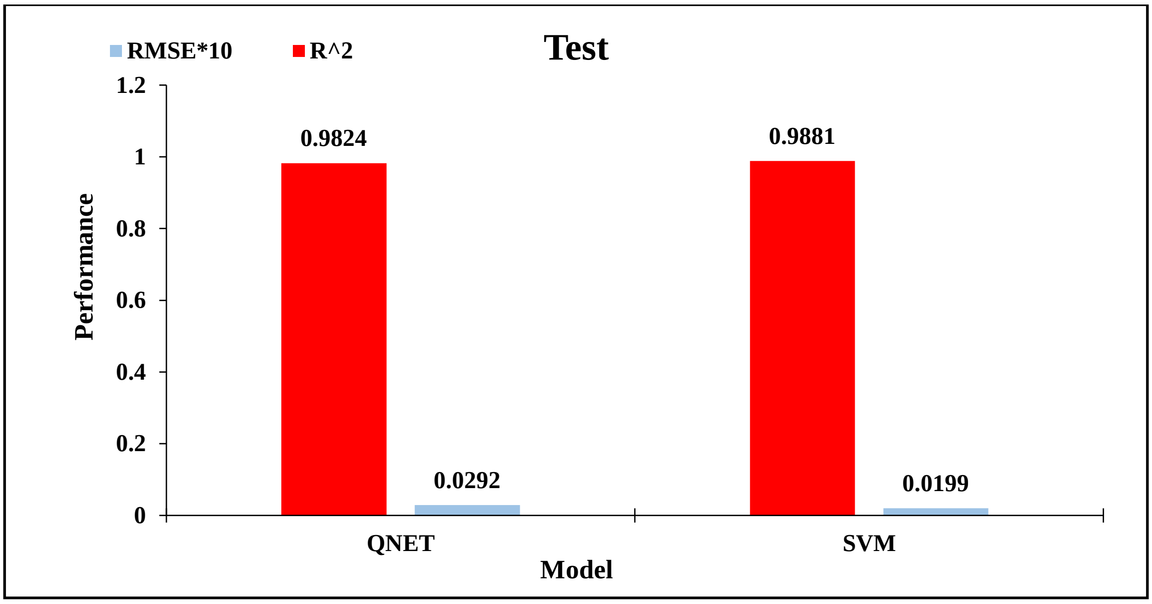

Figure 5. Comparing the results of QNET and SVM models in the test phase

5. Conclusion

In this research, the QNET and SVM algorithms were employed using the laboratory data of Crookston's research (2010) to predict the discharge coefficient of the labyrinth weir. The study is focused on the evaluating the performance of QNET and SVM algorithms in predicting the discharge coefficient of arched labyrinth weirswith a cycle angle of 6 degrees, utilizing 243 data series. The results of the sensitivity analysis showed that the total water load ratio ($\frac{H_T}{p}$) is an effective parameter in determining the discharge coefficient (Cd) of the arched labyrinth weird. According to the results of this study, the second combination with parameters (Cd, $\frac{H_T}{p}$, Θ, $\frac{L_C}{W}$) outperforms the other combinations.

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