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Use Artificial Neural Networks to Predict Seepage in the Hilla Canal Regulator

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ABSTRACT

The variation in the seepage under hydraulic structures significantly impacts their stability and effective water management, especially considering recent water scarcity challenges. This paper aims to calculate seepage and investigate the hydraulic performance of the Al-Hilla canal regulator's foundation. The methodology involves constructing a model (SEEP/W) and comparing its results with one-site piezometer readings. Using a mixed-methods approach, this study integrates software modelling and statistical analysis techniques. This study integrates software modelling and statistical analysis techniques. The Geo-studio program facilities modelling of seepage flow, while JASP software is used for statistical analysis and predictive equation development**.** The methodology consists of data collection, Geo-Studio modelling, JASP analysis, and validation of equation accuracy. After verifying the models' efficiency, the data for the seepage equation was established under various upstream and downstream conditions, incorporating artificial intelligence algorithms. This data was analyzed to drive a predictive equation for seepage with a high coefficient of determination (R2) OF 97%. Additionally, another equation was formulated to determine the total water pressure head, achieving an R2 value of 95 %. These equations are invaluable tools for predicting the total water pressure head and seepage and enhancing the management of hydraulic structure.

Keywords: Seepage, Artificial Neural Network, Hilla canal, Piezometer, Factors of safety.

1. INTRODUCTION

AL-Hilla Canal's vital hydraulic structure faces persistent challenges with the seepage phenomenon, where water infiltrates the underlying soil structure, significantly threatening the canal's stability, longevity, and efficient water management. Previous research has explored various methodologies for predicting **(El Bilali et al., 2022; Ren et al., 2023)**.

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These methodologies can be broadly categorized into physics-based approaches and data-driven techniques, physics -based approaches leverage fundamental principles of mechanics and physics, often employing concepts like Darcy's Law **(Ren et al., 2021, Zhang et al., 2020)**. Seepage and hydrodynamic pressure generate downward forces on the upstream slope, adversely affecting its stability and creating a critical condition for the slope's structural integrity **(Fattah et al., 2017)**. These methods aim to simulate seepage flow and understand pressure distribution. While they can yield promising prediction outcomes, they rely heavily on extensive field data and assumptions, particularly for dams lacking historical data **(Ren et al., 2023).** Additionally, these methods can be time-consuming and computationally demanding. The rapid advancement of intelligent monitoring technology has led to an exponential increase in driver datasets. This issue has stimulated researchers to delve into the basis governing these datasets and their importance. Machine learning (ML) models **(Salazar et al., 2015)** have appeared as powerful analytical tools, especially adept at uncovering hidden causal relationships within many datasets. As a consequence, they enable exact estimate and scientific prediction using complex models like neural networks **(Zhang et al., 2020)** successfully employed neural networks to predict seepage, and effectually catch the non-linear relationships between Canal seepage and influential factors, thereby increasing the model's non-linear mapping ability. climate variations can change groundwater mount, soil moisture content, and hydraulic pressure, in Hilla Canal foundation. Building upon the work of **(Mahdi and Al-Hadidi, 2023)** who studied the Hilla regulator and the factors that affect seepage calculations, the previous studies recommend in the case of changing water levels that discharge can be mitigated through several methods: utilizing low-permeability soils, implementing cut-offs in foundation, and extending the seepage path by deploying upstream blankets **(Fattah et al., 2014)**.
This paper investigates the application of artificial intelligence techniques for predicting seepage for the Hilla Canal Foundation. By harnessing the capabilities of AI, particularly its ability to analyze complex datasets and patterns. This research focuses on developing a robust AI-powered methodology for achieving accurate seepage prediction for the Hilla Canal, leveraging the strengths of AI, especially its proficiency in analyzing complex datasets and uncovering patterns. The study will take on a multifaceted approach which includes evaluating the effectiveness of various AI techniques for seepage prediction constructing and executing an AI-based model for accurate prediction and investigating the influence of various factors on seepage patterns within the canal foundation.

1.1 Study Region

Hilla Canal, located in Iraq, plays a vital role as a conduit for diverting water from the Euphrates River to both the city of AL-Hilla and surrounding agricultural areas in Babylon governorate, situated in the southern region. This canal is essential for managing water flow and ensuring equitable distribution among its various users. Measuring approximately 120 kilometres in length (equivalent to roughly 75 miles), the canal's hydraulic system is crucial for its operation. **Fig. 1** illustrates the Canal layout, marking the location of piezometers. The X-axis measures from point (A), starting from the face of the cutoff to piezometer No.27 in the upstream direction. The vertical axis at point A extends from the starting point to where piezometer 18.5 emerges in the soil. A similar methodology applies to a point that is positioned in the downstream direction. **Fig. 2** provides a detailed depiction of piezometer No.27 and 28, offering a visual representation of their precise location within the Canal system **(Ministry of Water Resources, 2022; Al-Sultani and Al-Hadidi, 2023).**

Figure 1. Hilla Canal Main Regulator **(Google Earth)**.

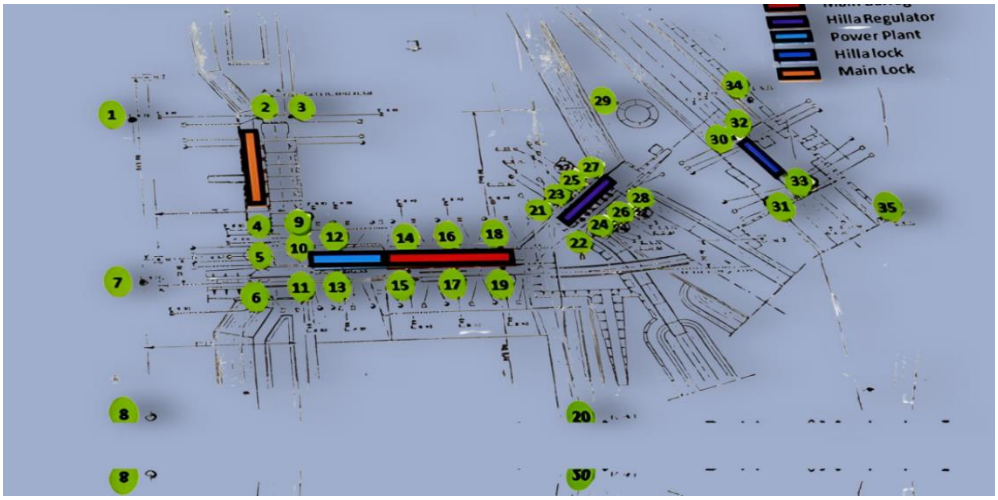

Figure 2. The locations of the 27 and 28 Piezometers **(Ministry of Water Resources, 2022).**

1.2 Numerical Modeling of Seepage in the Al-Hilla Canal Foundation

Darcy's law is a basic principle in fluid mechanics that describes the flow of water or any fluid through a porous medium, such as rock or soil. This law is often employed in the study of seepage and water flow in structures like embankments, dams, tunnels, and other engineering construction.

This law mathematically expresses the relationship between the rate of flow (Q) of the water through the porous medium, the pressure gradient (Δh), the permeability coefficient (K) of the soil, the length (L) over which the flow takes place, and the cross-sectional area (A) through which the flow occurs, is represented by the following equation:

$$Q = \frac{K \times A \times \Delta h}{L} \qquad (1)$$

In Geo-studio, the finite elements equation used for groundwater flow and seepage analysis is based on (Darcy's law) and the continuity equation. The equation specifically depends on the module within Geo-studio being utilized (such as SEEP/W), as well as the problem setup defined by the user. However, the general form of the finite element equation for groundwater flow can be described as follows:

$$KH = Q + F \quad (2)$$

Where the connectivity matrix represents the hydraulic connectivity properties of the porous medium, H is the head vector representing the hydraulic head at each node in the finite element mesh, Q source /sink vector represents any additional water inputs with drawls from the system, F is the vector of nodal flow rates, often associated with boundary conditions. This equation is derived from discretizing Darcy's law and the continuity equation over the finite elements mesh. The connectivity matrix (K) is typically assembled based on the material properties and geometry of the problem domain. The head vector (H) represents the unknown groundwater head at each node, which is solved iteratively using numerical methods. The source/sink vector (Q) incorporates any external water sources or sinks, while the nodal flow rates (F) are determined by the boundary conditions specified by the users. Numerical modeling in Geo-studio relies heavily on Darcy’s Law. This fundamental principle in fluid mechanics governs the flow of fluids through porous media like soil, which forms the foundation of the Canal. Darcy’s Law mathematically relates the flow rate of the fluid (water in this case) to the hydraulic conductivity of the soil, the pressure gradient within the soil, and the flow path characteristics.

The specific implementation of Darcy’s Law within Geo-studio is integrated into its finite element method. This method involves discretizing the problem domain (the Canal foundation) into a mesh of small elements. By applying Darcy’s Law and continuity equation (which ensures mass conservation) to each element, a system of equations is formed. Solving this system numerically allows us to estimate the hydraulic head (water pressure) at various points. There is another method of analyzing seepage problems which involves constructing a network of flow lines (representing water flow paths) and potential lines (representing lines of constant water pressure). While flow net analysis can be a quick and visual method for simple geometries, it has limitations. The accuracy of analysis relies heavily on the engineer's experience and judgment in constructing the flow net. Additionally, flow nets become cumbersome and less reliable complex geometrics, such as the case of AL-Hilla Canal foundation.

In this case, the complex geometry of the Canal foundation and the need for more accurate seepage estimates make numerical modeling with Geo-studio a preferable choice. This method allows us to incorporate various material properties and boundary conditions, leading to a more realistic representation of the seepage phenomenon.

2. MATERIALS AND METHOD

This research proposes using AI for seepage prediction in Al-Hilla Canal. It will include field data (piezometer reading, historical seepage data), soil property data (hydraulic conductivity, porosity, unit weight from the provided table), and chosen AI software. Methods will involve data pre-processing, selection, and training of an AI model (e.g., neural network) using the prepared data, and evaluation of model performance.

2.1 Modeling Seepage Flow Through Dams Using Geo-Studio

Set up the steady state analysis. Locate the placements of the piezometers positioned both upstream and downstream. Sketch the regulator. As shown in Fig. 3, Specify the hydraulic conductivity of the soil layers in the foundation as **Table 1**.

Table 1. Characteristics of building materials employed in the construction of the Hilla Canal. **(Ministry of Water Resources, 2020)**

Material Description	γ (kN/m^3)	Ø	k m/s	C (kPa)	Color code
Fine- to Medium Silty sand	19.7	40	0.1	0	
Plio -Pleistocene deposits	20.0	33	0.001	10	
Very weak calcareous sandstone	20.0	40	$1*10^{-5}$	0	
clay _ mud /siliceous carbonite silt	18.5	33	0.001	0	
Transition and Filter layer	200.0	40	----	0	
Concrete Protection Slab	25.0	----	----	----	

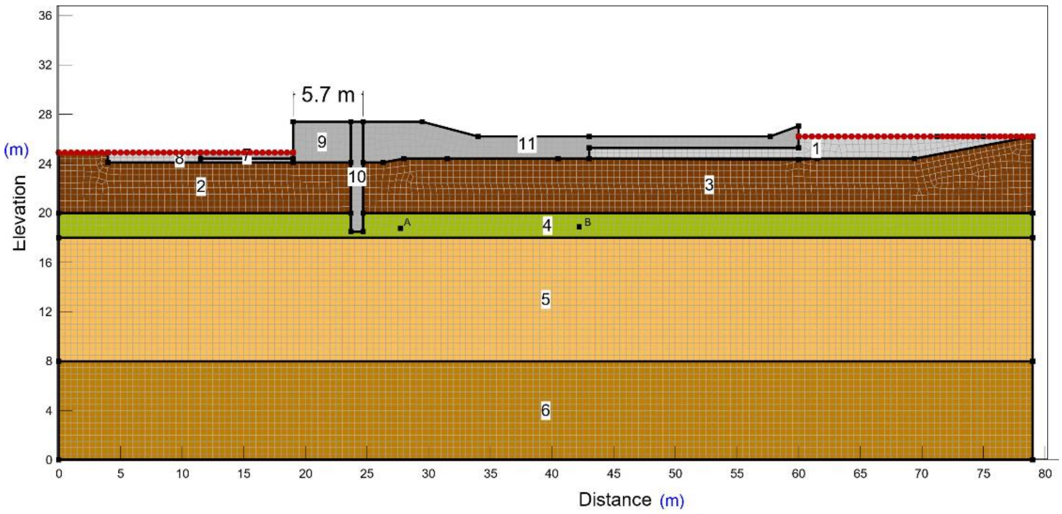

Figure 3. Al-Hilla Canal regulator with soil layer, 1-rip rap, 2-2,3-soil/fine to medium Silty sand, 4-soil/Plio -Pleistocene deposits, 5-soil/very weak calcareous sandstone, 6-soil/clay - carbonate Mud/Siliceous Carbonite silt,7,8,910,11 concrete for Canal.

2.2 Statistical Comparisons between Observed and Simulated Pressure Head Data

The hydraulic pressure head denotes the water height in a hydraulic system from a point. It is pivotal for calculating hydraulic pressure and fluid flow within subsurface or groundwater systems. The observed hydraulic pressure head is the measured value from (Al-Hilla Canal project- Ministry of Water Resources), while the simulated hydraulic head is calculated via computer models. Simulating hydraulic heads entails mathematical models and stats to address intricate water-subsurface interactions. for model validation via comparing simulated results with observed data as in **Table 2.**

Table 2. The relationship between the observed and the simulated hydraulic head

Upstream (m)	Downstream (m)	From field (m)	Result (m)	Hoi (m)	His (m)	Error	Hsi -Hoi
31.90	30.5	31.13	30.839	31.13	30.839	0.936	-0.291
31.65	29.5	30.29	29.966	30.29	29.966	1.069	-0.324
31.95	30.7	31.02	30.971	31.02	30.971	0.158	-0.049
31.80	30.1	30.67	30.469	30.67	30.469	0.657	-0.202
31.65	29.5	30.45	30.020	30.45	30.020	1.412	-0.430
31.75	30.4	30.90	30.727	30.90	30.727	0.561	-0.174
31.95	30.7	31.15	31.002	31.15	31.002	0.474	-0.147
31.80	30.1	30.82	30.511	30.82	30.511	1.002	-0.309
31.75	30.4	30.77	30.693	30.77	30.693	0.252	-0.077
31.90	30.5	31.01	30.804	31.01	30.804	0.666	-0.207

*(His)is the value of the simulated head, (Hoi) is the value of the observed head

2.3 Verifying the Performance of the Program/ Model

To ensure the model's applicability and accuracy, statistical analysis employs parameters like RMSE, ME, and Maximum Relative Error, as in **Table 3.** Notably, the model efficiency (EF) registers an impressive value of 99.159, signifying the model's high accuracy in prediction. After confirming the model's efficiency, data is generated by altering the upstream and downstream parameters to compute the seepage values. Additionally, coordinates for 365 points are identified to represent specific locations within the artificially intelligent system.

Table 3. Overview of the statistical parameter of the model for the canal.

Statistical indicators	Value
Maximum Relative Error	1.412
mean Error (ME)	-0.221
Root mean square Error (RMSE)	0.248
Model Efficiency (EF)	99.159

2.4 JASP Program

JASP Software is a popular open-source statistical analysis program that provides users with a wide range of statistical analyses and data visualization tools. JASP's versatility encompasses a comprehensive range of statistical techniques, spanning from fundamental t-tests and ANOVAs to intricate regression models and factor analyses. Its intuitive graphical interface streamlines the analysis process, allowing researchers to navigate analyses efficiently and interpret results with clarity **(Wagenmakers, 2023)**.

2.4.1 Quantifying Total Head with JASP

Upon confirming the Geo-Studio software's functionality, an extensive analysis was undertaken on the head pressure readings. This thorough investigation considered various factors including upstream and downstream influences, as well as the readings from piezometers. Consequently, from this analysis an equation representing the hydraulic head. In addition, leveraging artificial intelligence algorithms post-validation of the Geo-Studio software, the equation was extracted to elucidate the hydraulic water pressure as presented below:

$$\text{total head} = -9.855 + (0.861 \times \text{UP}) + (0.438 \times \text{DS}) \quad (3)$$

where:
Up: refers to Upstream, in the direction towards the source of river or stream, opposite to the flow of water taken in meters (m).
Ds: refers to Downstream, in the direction that the current of a river or stream flows, away from the source taken in meters (m).
Comparison results between the water pressure from the JASP program and the actual field measurements to prove the accuracy of the equation are listed in **Table 4.** The statistical analysis employing parameters like RMSE, ME, and Maximum Relative Error are shown in **Table 5.** After confirming the accuracy of the equation, the equation for seepage can be identified.

Table 4. The comparison was made between the water pressure data obtained from the JASP program and the actual field measurements.

Up stream (m)	Down stream (m)	From site H0 (m)	Total head = (-9.855+ (0.861*up +0.438*ds)) (m)	Relative error (%) =(Ho-Hs)/Ho	Hsi - Hoi	(Hsi-Hoi)^2	(Hoi-Hoa)^2
31.65	29.5	30.29	30.31	0.00	0.02	0.00	0.2333889
31.9	29.3	30.37	30.44	0.00	0.07	0.00	0.162492
31.65	29.7	30.46	30.40	0.00	-0.06	0.00	0.0980337
31.7	30	30.52	30.57	0.00	0.05	0.00	0.0640613
31.8	29.6	30.52	30.48	0.00	-0.04	0.00	0.0640613
31.70	30	30.59	30.57	0.00	-0.02	0.00	0.0335268
31.80	29.6	30.61	30.48	0.00	-0.13	0.02	0.0266027
31.8	30.1	30.67	30.70	0.00	0.03	0.00	0.0106303
31.85	30	30.73	30.70	0.00	-0.03	0.00	0.0018579
31.75	30.4	30.77	30.79	0.00	0.02	0.00	9.631E-06
31.75	30.15	30.78	30.68	0.00	-0.10	0.01	4.756E-05
31.90	30.16	30.81	30.75	0.00	-0.06	0.00	0.001361
31.75	30.4	30.9	30.79	0.00	-0.11	0.01	0.0161027
31.9	30.5	31.01	30.96	0.00	-0.05	0.00	0.0561199
31.90	30.5	31.13	30.96	0.01	-0.17	0.03	0.1273751
31.95	30.7	31.15	31.09	0.00	-0.06	0.00	0.1420510
31.4	30	30.32	30.31	0.00	-0.01	0.00	0.2053027
31.9	29.3	30.37	30.40	0.00	0.03	0.00	0.162492
31.85	29.55	30.45	30.50	0.00	0.05	0.00	0.1043958
31.75	30.2	30.77	30.70	0.00	-0.07	0.00	9.631E-06
31.82	30.6	30.97	30.94	0.00	-0.03	0.00	0.0387682
31.7	30.6	30.98	30.84	0.00	-0.14	0.02	0.0428061
31.83	30.52	30.99	30.91	0.00	-0.08	0.01	0.0470441
31.75	30.8	31.04	30.97	0.00	-0.07	0.01	0.0712337
31.75	30.8	31.06	30.97	0.00	-0.09	0.01	0.0823096
31.75	30.8	31.11	30.97	0.00	-0.14	0.02	0.1134992
31.8	30.95	31.12	30.97	0.00	-0.15	0.02	0.1203372
31.75	30.8	31.12	31.07	0.00	-0.05	0.00	0.1203372

Table 5. The statistical analysis of the water pressure from JASP program and the actual field measurements.

Parameters	Value
ME	-0.02
Maximum Relative Error	0.01
RMSE	0.06

2.4.2 Mathematical Analysis of Seepage

Seepage in a Canal refers to water leakage through its foundation. Failure in managing this seepage might jeopardize the Canal's safety. Ensuring Canal's safety involves evaluating seepage rates to prevent excessive erosion and potential structural weaknesses that could lead to failure. This evaluation includes monitoring seepage levels, reinforcing weak points, and implementing safety measures to maintain Canal's structural integrity and prevent any catastrophic failures by analysis of seepage using JASP artificial intelligence. The variations in the seepage magnitude were investigated concerning the sheet pile, attributed to the presence of factors such as upstream and downstream flow, as well as the specific coordinates (X, Y) at the site. This equation can be applied at any point within the location to assess the seepage behavior comprehensively, through this analysis, the equation governing seepage was derived as follows:

$$\text{Seepage } (m^3/\text{month}) = 0.343 + (0.478 \times \text{US}) - (0.484 \times \text{DS}) - 0.009 \times \text{X} - (4.070 \times 10^{-4} \times \text{y}) \quad (4)$$

A comparison was made between the seepage results obtained from Geo Studio and those derived from JASP. This comparison revealed an R-squared value of 97%.

2.4.3 Software Model Building

To conduct a seepage analysis, preparing the necessary data is vital. Field data is collected through piezometer reading, providing vital information about groundwater levels and hydraulic heads. Soil properties, such as hydraulic conductivity, porosity, and unit weight are obtained from **Table 1**, ensuring accurate input data and using the Geo-studio SEEP/W module to create a cross-sectional drawing of the Hilla canal, incorporating the various soil layers and their respective properties. This detailed representation is crucial for simulating seepage behavior accurately.

The next step involves refining the model by calibrating it against observed data. This process enhances the accuracy of the program by aligning simulated results with field measurements. Once the model is verified, seepage is analyzed by varying upstream and downstream conditions at 365 different coordinate points. These variations help in understanding the canals' response to different hydraulic conditions.

The calculated seepage values, along with their corresponding upstream and downstream coordinates, are important for the JASP software to drive the equation (refer to as Eq. (4)) that describes the relationship between seepage and varying conditions. This equation is shown in **Table 6.**

Table 6. Drive Equation for Seepage From JASP

Model		Unstandardized	Standard Error	Standardized	t	p
H0	(Intercept)	0.567	0.013		44.257	< .001
H1	(Intercept)	0.343	0.553		0.620	0.536
	Upstream	0.478	0.017	0.656	28.618	< .001
	downstream	-0.484	0.014	-0.879	-35.654	< .001
	x	-0.009	0.001	-0.169	-7.517	< .001
	y	-4.070×10^{-4}	2.843×10^{-4}	-0.033	-1.432	0.153

This research aims to compare the obtained results with research conducted by **(Tang et al., 2020),** seeking to identify similarities, differences, and areas for additional exploration. By examining both studies side by side, a comprehensive understanding of the subject matter is pursued, enriching academic discourse and offering valuable insight into the field, as demonstrated by **Table 7.**

Table 7. Comparative Study between the current Study and the study conducted by (**Tang et al., 2020)**

Study	(Tang et al., 2020)	Present study
Aim of the study	This research aims to develop a new solution dependent on governing equations to solve the issue of Seepage effectively.	The primary aim of this study is to contribute valuable insights and tools aimed at enhancing the monitoring and management of seepage-related issues ensuring the safety and efficiency of the Hilla Canal Regulator and similar hydraulic structures.
Region	Not designated	Al- Hilla Canal Regulator in Babylon -Iraq
Software used	ANN AND OTHERS	ANN
Statistical Coefficients	RMSE	Mean Error (ME) Root mean Square Error (RMSE) Maximum relative error Model Efficiency (EF)
Used Points for seepage	300	400
Input Data	Water height $Y = 9 \times 10^{-5} \times 10^{0.0491x}$	Upstream, downstream, seepage from Geo studio $y = -0.182 + (0.580 \times up) - (0.570 \times ds) - (0.013 \times X) - (0.0002336 \times Y)$
Safety factors	This study, along with other research, did not address the calculation of safety factors.	The study delved into calculating the safety factor equation.

3. RESULTS AND DISCUSSION

This study investigates seepage within the foundation of the Canal using Geo-Studio software and compares it to results obtained using the JASP. It was determined from above that the JASP program demonstrated its capacity for accurate hydraulic water pressure prediction, achieving a maximum relative error of just 0.01 and an R-squared value of 95% as shown in **Fig. 4.**

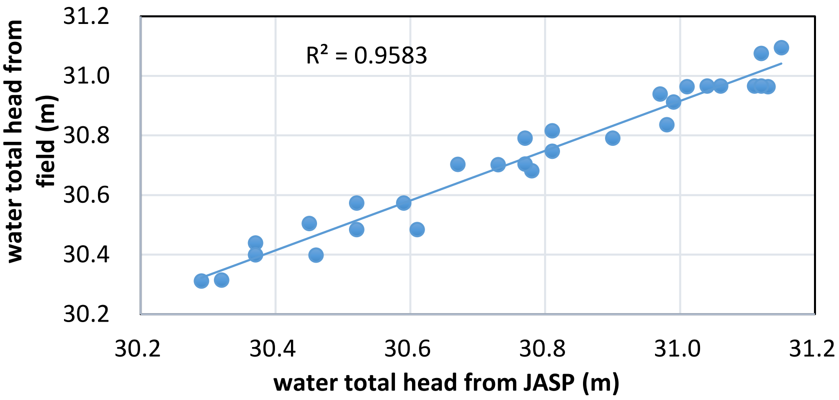

Figure 4. Comparison of the water pressure obtained from the JASP program and the field results.

Notably, both Geo-Studio and JASP analyses converged on the governing seepage equation within the Canal foundation, with an R-squared value of 97% as shown in **Fig. 5**. These results highlight the strong agreement between the chosen analytical tools and provide robust validation for our understanding of the system's hydraulic behavior.

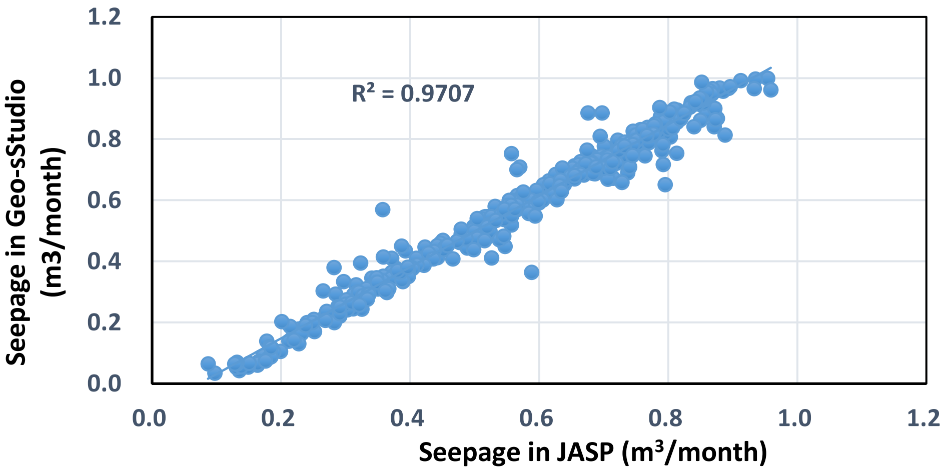

Figure 5. A comparison of seepage results obtained from the Geo-Studio program and the JASP

Fig. 5 illustrates that there is a linear relationship between the seepage values produced by both programs. In general, the seepage values produced by JASP seem to be in good agreement with the Geo-Studio values. Both Geo-Studio and JASP software clearly excelled in assessing the seepage within the Hilla Canal foundation, the outstanding accuracy of the models provides powerful evidence of their ability to simulate seepage behavior reliably. This result confirms their potential in facilitating Proactive management of potential risks. Additionally, the exceptional consistency between their predictions, including the seepage equation, enhances the validity of our findings and instills trust in the robustness of the importance of AI for the hydraulic system.

In the previous study, a seepage equation was identified. However, when applied to our data, it yielded an R^2 value of 0.14, as indicated as shown in **Fig. 6.**

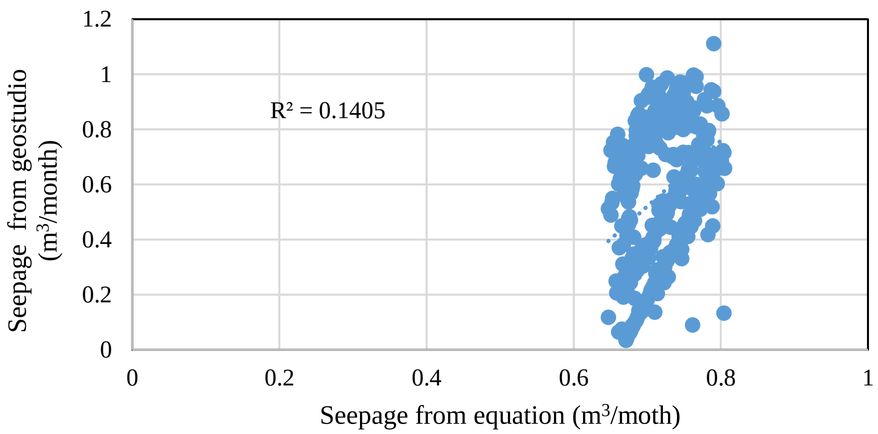

Figure 6. Comparing seepage from equation vs seepage from Geo studio

This suggests that 86% of the points did not align with the equation. Consequently, relying on single equation for any project or case becomes impractical. Instead, it is essential to apply these steps independently to each project. In this study, it is concluded that the seepage of this canal did not pose a threat to its integrity. However, recommendations and remedial methods can be provided in the event of seepage occurrence.

4. CONCLUSIONS

This research illustrates how both GeoStudio and JASP effectively assess seepage within the AL-Hilla Canal regulator. The high accuracy of the models, successful prediction of hydraulic pressure, and development of the seepage equation offer valuable tools for managing and mitigating potential seepage-related risks. The strong agreement between the results from both programs further solidified the credibility of the findings. This study contributes significantly to the field of water infrastructure management by providing a thorough understanding of seepage behavior within the Canal foundation. The derived equations and insights can be utilized to design and execute effective seepage control measures, ensuring the long-term safety and sustainability of these crucial structures. The research study successfully identified liner relationship between the observed and simulated hydraulic pressure head data, confirming the validity of the models used, the close alignment between the results obtained from JASP and the field measurement further underscore the accuracy of the derived hydraulic head. Additionally, the derived seepage equation from JASP effectively captured the relationship between upstream and downstream conditions and the result seepage rates. The findings emphasize the importance of using tailored approaches for different hydraulic systems to ensure the accuracy and reliability of seepage predictions. Given the success of Geo-studio and JASP in simulating seepage, these tools can be valuable for designing and evaluating potential seepage treatment solutions.

NOMENCLATURE

Symbol	Description	Symbol	Description
C	Cohesion	Q	Seepage
DS	Downstream Variable	US	Upstream Variable
Ho	The Observed Head Value	Y	The Depth of a Specific Point
Hoa	The mean or average of the heads observed	$\gamma_{sat.}$	Saturated unit weight

K	Hydraulic Conductivity	Ø°	Angle of Internal Friction
X	The Horizontal Distance to a Specific Point		

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Credit Authorship Contribution Statement

Ruaa M. Khazaal: Writing – original draft. Maysam Th. Al-Hadidi: Writing – review & editing, Validation

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تنبؤ تسرب المياه في أساس القناة باستخدام الشبكات العصبية الاصطناعية: منظم الحلة

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الخلاصة

يلعب التباين في تسرب المياه تحت المنشاءات الهيدروليكية دورا مهما في التأثير على استقرارها وإدارة المياه الفعالة، خاصة مع الاخذ بعين الاعتبار تحديات ندرة المياه الحالية. تهدف هذه الورقة الى حساب التسرب والتحقيق في الأداء الهيدروليكي لقاعدة منظم قناة الحلة. تتضمن المنهجية بناء نموذج (SEEP/W) ومقارنة نتائجه بقراءات البايزوميتر في الموقع. باستخدام نهج الأساليب المختلطة، تدمج هذه الدراسة بين نمذجه البرامج وتحليل البيانات الإحصائية. يوفر برنامج Geo–studio تسهيلات لنمذجة تدفق المياه المتسربة، بينما يتم استخدام البرامج JASP للتحليل الاحصائي وتطوير المعادلات التنبوئيه. تتكون المنهجية من جمع البيانات ونمذجة Geo–studio، وتحليل JASP، واثبات دقة المعادلة. بعد التحقق من كفاءة النماذج، تم انشاء بيانات معادلة التسرب تحت ظروف المنبع والمصب المختلفة، مع دمج خوارزميات الذكاء الصناعي. يتم تحليل هذه البيانات لاستخراج معادله تنبوئيه للتسرب مع معامل تحديد (R2) مرتفع يبلغ 97%. بالإضافة الى ذلك، تم صياغة معادلة (3) لتحديد رأس الضغط الكلي للمياه، محققه قيمة (R2) تبلغ 95 %. تعتبر هذه المعادلات أدوات لا تقدر بثمن للتنبؤ برأس الضغط الكلي والتسرب، مم يعزز إدارة المنشاءات الهيدروليكية.

الكلمات المفتاحية: التسرب، الشبكة العصبية الاصطناعية، منظم الحلة، البيزوميتر، معامل الامان.