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Geostudio-Assisted Numerical Investigation of Seepage Mitigation in Earthen Irrigation Canals Using HDPE Geomembrane Liners

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Abstract: Water efficiency and overall system performance are greatly impacted by seepage losses in irrigation canals, especially in semi-arid areas where water is a valuable and limited resource. This study uses High-Density Polyethylene (HDPE) geomembranes in conjunction with a thorough numerical analysis using GeoStudio software to examine seepage control in the Chanda Distributary Canal in the Lambhua region of Sultanpur District, Uttar Pradesh.

The project's objective is to assess how well HDPE geomembrane lining works to lower seepage rates, improve structural integrity, and increase the canal's operational efficiency. To describe the subsurface conditions along important Chanda Distributary sections, a thorough geotechnical survey was carried out. To model current seepage conditions and evaluate the effectiveness of various lining designs, field data were integrated into GeoStudio's SEEP/W module. Under steady-state flow conditions, the research contrasted scenarios with and without geomembrane liner. The results show that when HDPE geomembranes are erected correctly with protective soil cover, seepage loss is significantly reduced—up to 85%. Additionally, the study emphasizes important design factors such interface shear strength, anchoring methods, and the possibility of geomembrane damage from hydraulic pressure or settlement.

According to a cost-benefit analysis, the adoption of geomembrane lining is justified by the long-term water savings and lower maintenance costs, despite the substantial initial expenditure. The importance of combining cutting-edge geosynthetic materials with numerical modeling tools to maximize water-saving techniques in irrigation infrastructure is highlighted by this study. Future canal rehabilitation initiatives in comparable hydrological and geological environments can benefit from the findings.

Keywords: HDPE geomembrane, Seepage control, GeoStudio, Irrigation canal, Finite element modelling, Hydraulic conductivity, Canal lining, Sustainable irrigation.

I. INTRODUCTION

Socioeconomic development, agricultural productivity, and ecological sustainability all depend on water. Particularly in developing nations like India, where agriculture is still largely dependent on seasonal rainfall and surface irrigation infrastructure, irrigation systems are essential to maintaining food security (Chatrabhuj et al. 2024). Canal networks are the most popular method of transporting water for agricultural purposes among the several irrigation systems. However, seepage losses through canal beds and embankments severely reduce irrigation canal efficiency (Al-Hadidi and Hashim, 2021). One of the biggest reasons irrigation systems lose water globally is seepage in clay canals. According to studies, depending on soil type, canal geometry, hydraulic conditions, and climatic considerations, unlined canals may lose between 30 and 50 percent of conveyed water by seepage (Elshaarawy and Elmasry, 2024). In addition to decreasing irrigation efficiency, these losses lead to serious geotechnical and environmental issues, such as rising groundwater tables, water logging, salinity development, embankment erosion, pipework, and structural instability. Even though India has one of the biggest canal irrigation networks in the world, a sizable amount of this infrastructure is still made up of unlined or badly maintained earthen canals. Improving canal conveyance efficiency has become crucial for climate resilience and sustainable agricultural management in water-deficient areas (Rahimi and Nasimi, 2025; Omofunmi et al. 2017). As a result, efficient seepage management has become a top research priority in geotechnical and hydraulic engineering.

A. *Canal Seepage and Its Environmental Implications*

When water seeps through porous soil layers under hydraulic gradients created by water held within the canal section, this is known as canal seepage. Soil permeability, canal geometry, hydraulic head, saturation level, and the presence or absence of lining materials all affect how much seepage occurs (El-Gendy and El-Agha, 2021).Many negative effects result from excessive seepage, including decreased irrigation water availability, decreased conveyance efficiency, soil erosion and piping, waterlogging of nearby agricultural land, development of salinity and alkalinity, higher maintenance costs, and structural degradation of canal embankments (Chatrabhuj et al., 2026).

By artificially elevating groundwater levels, persistent seepage can also change local hydrogeological conditions, upsetting the region's agricultural and ecological balance. Due to these difficulties, effective seepage mitigation strategies that guarantee long-term hydraulic and structural stability must be developed (Fell et al., 2003; Peng and Hao, 2013).

B. HDPE Geomembranes in Canal Engineering

The exceptional hydraulic, mechanical, and durability properties of geosynthetics have transformed modern geotechnical and hydraulic engineering. High-Density Polyethylene (HDPE) geomembranes are widely acknowledged as one of the best seepage barrier materials amongothergeosyntheticproducts. Extremely low permeability, high tensile strength, superior puncture resistance, chemical inertness, UV resistance, long service life, flexibility, and adaptability are all characteristics of HDPE geomembranes. Under realistic engineering conditions, HDPE geomembranes are nearly impermeable due to their hydraulic conductivity, which is usually between 10^{-12} and 10^{-11} m/s (Jamel, 2016).

Their use in canal lining systems has shown a significant decrease in seepage losses, enhanced water conservation, and lower maintenance needs.

Additionally, HDPE liners can be rapidly installed and adapted to varying canal geometries, making them suitable for both rehabilitation and new canal construction projects.

C. Numerical Modelling in Seepage Analysis

Advancements in computational geotechnics have enabled engineers to simulate complex seepage phenomena using finite element modelling approaches. Numerical modelling provides an efficient means to analyse:

- Seepage pathways
- Pressure head distribution
- Hydraulic gradients
- Pore-water pressure
- Phreatic surface behaviour
- Effectiveness of lining systems

One of the most popular numerical modeling programs for seepage analysis in geotechnical engineering is GeoStudio SEEP/W. The program uses finite element formulations to solve groundwater flow equations in both transient and steady-state scenarios. SEEP/W is a great tool for studying canal seepage since it can simulate layered soils, anisotropic permeability, unsaturated flow conditions, and geosynthetic interfaces.

II. CRITICAL ANALYSIS OF LITERATURE

Because seepage management is important for both structural safety and irrigation efficiency, it has been thoroughly studied in hydraulic structures. Numerous seepage mitigation strategies involving conventional lining systems, geosynthetics, and numerical modeling techniques have been investigated by researchers worldwide. (Torabi et al. 2020) used HDPE geomembranes for seepage studies on earthen embankments and found significant improvements in slope stability and seepage resistance under steady-state circumstances. In Maharashtra, India, (Shirodkar and Gidde, 2022) conducted a comparative analysis of unlined, concrete-lined, and HDPE-lined canals. According to their research, HDPE liner systems significantly reduced seepage losses and improved irrigation efficiency. (Kosichenko and Baev, 2021) examined the selection criteria for seepage-control linings and found that, when compared to traditional materials, geosynthetic liners offer better filtration resistance and long-term performance.

(Al-Nawawi and Al-Hadidi, 2020) utilized GeoStudio SEEP/W for seepage analysis in earth dams and demonstrated the reliability of finite element modelling in evaluating seepage pathways and hydraulic gradients. (Zhang, 2013) examined the role of geosynthetics in canal seepage control and emphasized the long-term durability and impermeability of HDPE geomembranes under varying environmental conditions.

The literature indicates that HDPE geomembranes provide superior seepage reduction performance compared to traditional lining systems.

However, several limitations exist in previous studies:
1) Limited integration of field conditions with numerical modelling
2) Lack of defect sensitivity analysis
3) Inadequate consideration of soil-liner interaction
4) Insufficient focus on distributary canal systems in Indian conditions
5) Limited economic evaluation for rural irrigation infrastructure

The present study addresses these limitations through integrated finite element modelling and comparative seepage assessment using realistic canal geometry and soil conditions (ElMolla and Kilit, 2026; Kheiri et al., 2020).

A. Research Gap
Although several studies have investigated seepage reduction using geomembrane liners, limited research has focused on:
1) Integrated GeoStudio-based analysis for irrigation canals in Uttar Pradesh
2) Comparative seepage behaviour under multiple lining scenarios
3) Influence of localized geomembrane defects
4) Hydraulic response of silty clay loam canal soils
5) Practical implications for distributary canal systems in semi-arid agricultural regions

Therefore, the present study attempts to bridge this research gap by conducting a detailed GeoStudio-based numerical investigation of seepage mitigation using HDPE geomembrane liners in the Chanda Distributary Canal.

B. Objectives of the Study
The primary objectives of this study are:
1) To analyse seepage behaviour in unlined earthen irrigation canals.
2) To evaluate the effectiveness of HDPE geomembrane lining in reducing seepage losses.
3) To develop finite element seepage models using GeoStudio SEEP/W.
4) To assess hydraulic behaviour through pressure head contours and flow vectors.
5) To compare seepage reduction efficiency under various lining conditions.
6) To evaluate the practical applicability of HDPE geomembranes for sustainable irrigation infrastructure.

III. MATERIALS AND METHODOLOGY

A. Study Area Description
The study area comprises the Chanda Distributary Canal located in the Lambhua region of Sultanpur District, Uttar Pradesh, India. The canal serves agricultural command areas characterized by intensive irrigation demand and seasonal water scarcity.

The region experiences semi-arid climatic conditions with variable monsoonal rainfall, making efficient water management essential for agricultural sustainability.

B. Soil Characterization
The canal bed soil predominantly consists of silty clay loam locally referred to as “Domat Soil.” The soil exhibits moderate permeability and relatively high moisture retention capacity as shown in Table 1.

Table 1. Key engineering properties of soil

Parameter	Value
Hydraulic Conductivity	1×10^{-6} m/s
Porosity	0.45
Unit Weight	18.5 kN /m³
Saturated Unit Weight	20 kN /m³

C. HDPE Geomembrane Properties

The HDPE geomembrane used in this study possessed:

- Thickness: 1.5 mm
- Hydraulic conductivity: 1×10^{-15} m/s
- Tensile strength: ≥ 25 kN/m
- High UV resistance
- Design lifespan exceeding 25 years

The liner was modelled as a thin near-impermeable interface layer within the finite element domain.

D. Numerical Modelling Framework

The numerical seepage analysis was conducted using GeoStudio SEEP/W based on the finite element method.Seepage through porous media was governed by Darcy's law:

$$Q = kiA$$

where:

- Q= discharge
- k= hydraulic conductivity
- i= hydraulic gradient
- A= cross-sectional area

The finite element formulation solved the governing groundwater flow equations for steady-state saturated conditions.

E. Model Geometry

The canal geometry included:

- Bottom width: 3 m
- Canal depth: 2 m
- Side slope: 1.5H:1V
- Model width: 20 m
- Model depth: 5 m

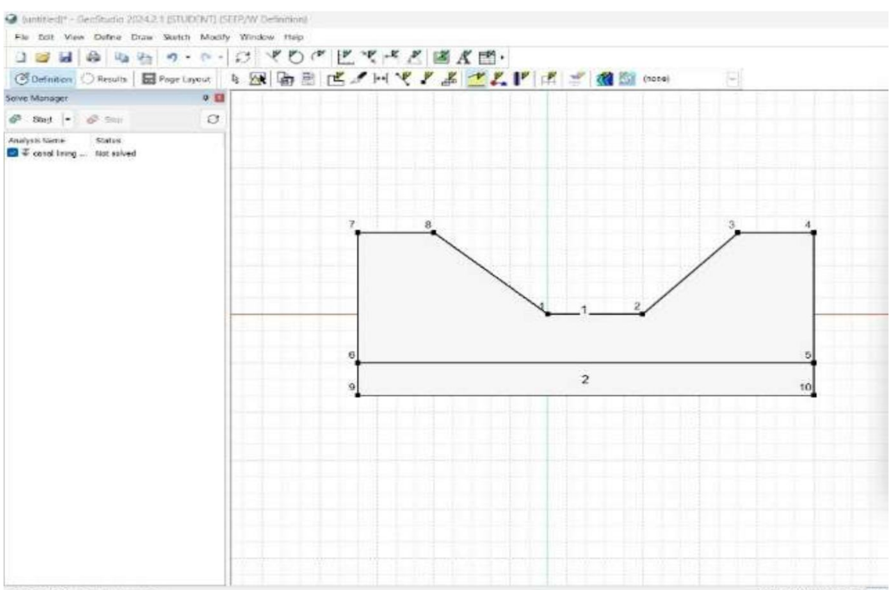

Figure 1. Defining Canal Geometry

The computational mesh was refined near the canal boundaries and geomembrane interfaces to improve solution accuracy as in Figure 1.

F. Boundary Conditions

The following hydraulic boundary conditions were applied:

- Total head boundary at canal water surface
- No-flow condition at model base
- Atmospheric pressure boundaries at side edges
- Internal impermeable layer for HDPE lining

G. Simulation Scenarios

Four seepage scenarios were investigated:

- Unlined canal
- Fully HDPE-lined canal
- Bed-only lined canal
- HDPE-lined canal with defects

IV. RESULTS AND DISCUSSION

The Chanda Distributary Canal's hydraulic behavior under various lining circumstances was thoroughly revealed by the finite element seepage analysis carried out using GeoStudio SEEP/W. For both lined and unlined canal layouts, the models allowed for the observation of pressure head distributions, hydraulic gradients, phreatic surface fluctuations, and seepage flow patterns.

A. Seepage Behaviour in Unlined Canal

In a seepage examination, the direction and amount of water movement through the soil matrix surrounding a canal are referred to as the flow profile. GeoStudy shows a noticeable and continuous flow of water from the canal into the adjacent subsurface in the unlined condition.

In the unlined canal simulation result, as shown in Figure 2: The flow vectors, which are usually shown as arrows in the GeoStudio output, are clearly large and pointed away from the side slopes and canal bed. This shows that water is easily leaking from the canal both laterally and vertically. Near the canal–soil interface, especially at the bottom corners (where the canal bed meets the side slopes), the vectors are closely packed. This area is crucial for seepage initiation since it usually encounters larger hydraulic gradients. Water tends to flow from regions of high hydraulic head (inside the canal) to regions of lower head (surrounding soil). Since there's no impermeable lining, nothing obstructs this flow, leading to significant loss.

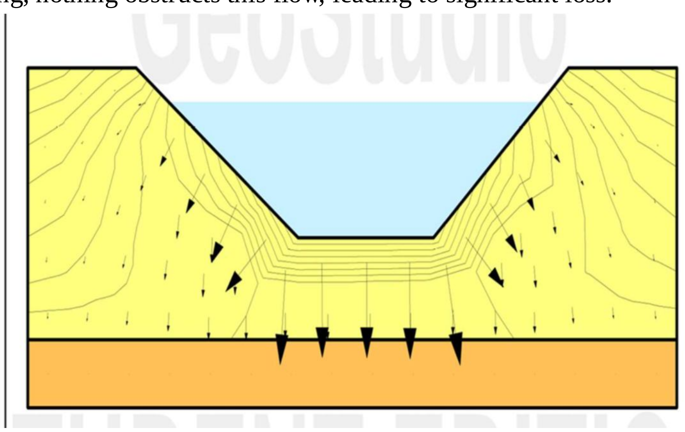

Figure 2. Flow Profile of Unlined Canal

In the picture from GeoStudio: The entire canal's wetted perimeter is where the flow vectors originate. As water moves into the soil, the magnitude of the vectors (length and density) diminishes with depth and distance, indicating the dissipation of hydraulic energy. The absence of deflection or redirection confirms that natural soil borders provide minimal resistance. In addition to causing water loss and decreasing conveyance efficiency, such unchecked seepage increases the risk of internal erosion, pipe work, or soil weakness beneath the canal bed. This could eventually lead to the canal's structural failure or the embankments being undermined.

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B. Pressure Head Contours – Unlined Canal

The hydraulic potential over the canal and surrounding soil mass is shown in detail in the pressure head contour plot for the unlined canal. This is an essential diagnostic tool for seepage analysis using GeoStudio because, as Figure 3 illustrates, it shows how spatial variations in water energy levels (or piezometric heads) affect flow direction and magnitude.

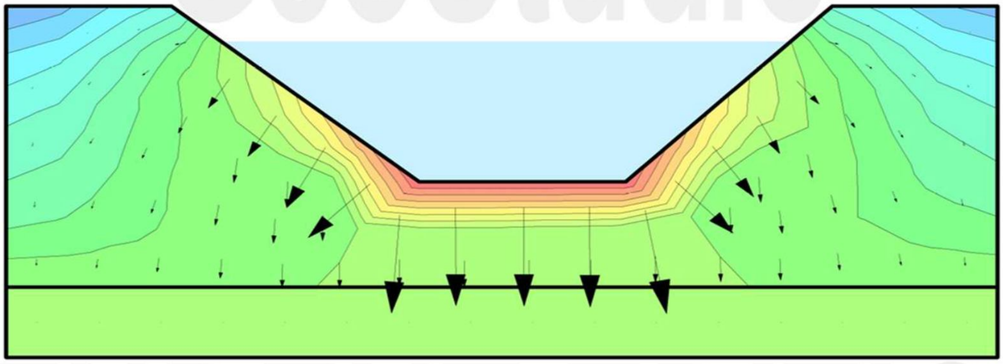

Figure 3. Pressure Head Contour Plot for Unlined Canal

Observations from the Contour Plot

1) Canal Water Level (Top Boundary Condition):
- The canal is filled with water at a constant head level, applied as a boundary condition in GeoStudio.
- This high head drives the seepage through the side slopes and bottom of the canal.

2) Contour Densification beneath Canal Bed:
- There is significant convergence and densification of contour lines at the base and immediate sides of the canal.
- This denotes a high hydraulic gradient, implying intense seepage flux through the unlined canal body.

3) Vertical and Radial Flow Paths:
- Water is observed to seep downward from the bed and laterally through the side slopes, creating radial dispersion.
- This typical behaviour is due to the absence of a barrier layer, allowing unrestricted percolation into the surrounding soil.

4) Pressure Gradient Dissipation with Depth:
- As the water moves deeper into the subsoil, contour spacing increases, suggesting attenuation of hydraulic energy.
- This corresponds with reduced flow rates at depth, but the volume is still significant due to large seepage area.

C. Quantitative Analysis for Unlined Canal

Without any artificial lining or seepage control, the unlined canal simulation is used as the baseline model to evaluate seepage behavior under natural settings. As seen in Figure 4, this section uses numerical output from GeoStudio's SEEP/W module to quantify the rate of water loss by seepage through the canal bed and sidewalls.

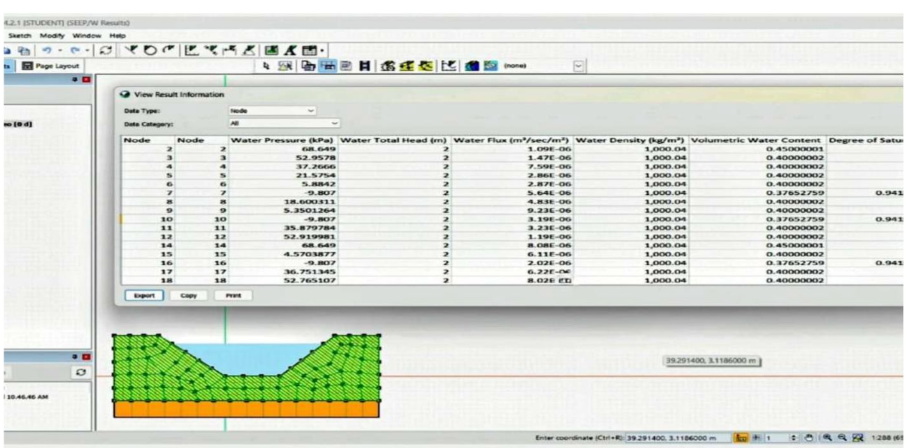

Figure 4. Seepage Data of Unlined Canal

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Seepage Flux (q) from Simulation

We need to compute specific discharge from seepage per meter of canal. That requires dividing the seepage ($m^3/s/m$) by the wetted cross-sectional seepage area per meter of canal length. Cross-section data of the canal:

- Canal bed width = 4.0 m
- Seepage-effective depth (e.g., influenced zone) = 1.0 m (standard assumption for per meter calculation)
- Side slopes = (1.5:1), Each slope area over 1 m canal length = approx. 1.5 m^2
- Total seepage-affected area per meter =A=4.m (bed)+1.5×2 (slopes)=7.0 m^2

Using the SEEP/W analysis, the total seepage flux through the unlined canal was computed as:

$$Q_{unlined} = (2.877\times10^{-5}\ m^3/s/m)$$

Converting to $m^3/s/m^2$:

$$Q_{unlined'} = (2.877\times10^{-5}\ m^3/s/m\ ) / 7m = 4.11\times10^{-6}\ m^3/s/m^2$$

D. Seepage Behaviour in Canal Lined with HDPE Geomembrane

Flow profiles in seepage analysis show how water moves through the subsurface domain under the influence of the continuity equation and Darcy's Law. Because of the hydraulic gradient between the canal water and the dry surrounding soil, flow vectors in a typical unlined canal show lateral and downstream percolation. However, the system is drastically changed by the addition of an impermeable barrier.

The HDPE geomembrane has an extremely low coefficient of permeability (typically $<1\times10^{-14}$ m/s), effectively interrupting the hydraulic connectivity between the canal waterand the underlying soil. This causes a redirection or complete suppression of the flowvectors thatwere otherwise prominent in the unlined scenario, as shown in Figure 5.

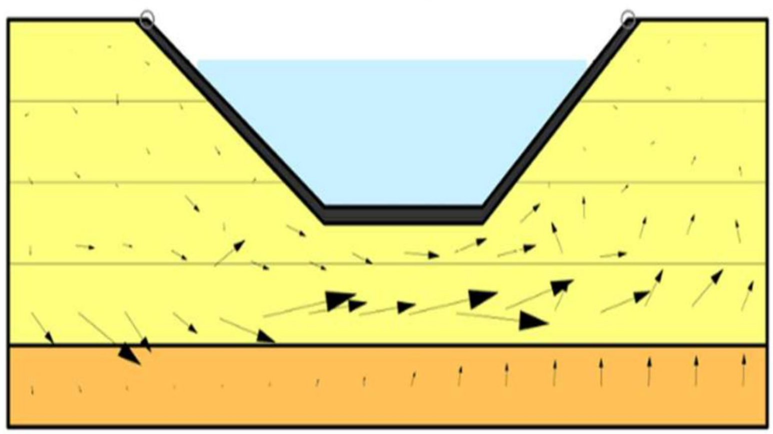

Figure 5. Flow Profile of HDPE Lined canal

We can make the following observations from the flow profile of the HDPE lined canal:

1) Absence of flow vectors below the canal bed: The most prominent feature of the flow profile is the near-total elimination of seepage flow beneath the canal. Unlike the unlined case where vectors indicated water infiltrating the subsoil, the lined profile exhibits almost no downward flow, confirming the impermeability of the HDPE membrane.
2) Redirection of flow paths: The vectors that do appear are minimal in magnitude and are mostly horizontal or constrained to the surface water layer, suggesting conserved flow within the canal section. This reflects the liner's role in confining water and maintaining a higher water level for a longer duration.
3) Very minimal vertical percolation below slopes: Side slopes also show very minimal seepage loss, which is critical for preventing slope instability and subsurface erosion.
4) Uniform hydraulic regime: The flow domain now demonstrates a more hydraulically stable environment, with reduced gradients and no concentrated zones of seepage, piping, or exit gradients—phenomena that were visible in the unlined condition.

The flow profile for the HDPE-lined canal visually and quantitatively confirms the near elimination of seepage, as anticipated from the physical characteristics of the liner.

E. Pressure Head Contours – HDPE Lined Canal

Contour shading demonstrates a steep drop in water pressure across the liner, with a notable absence of high-pressure gradients within the soil beneath the liner. Most pressure is retained within the canal water body, indicating effective containment.

The color-coded pressure zones indicate a general pressure head of 0 to 2 m beneath the liner zone, compared to 0 to 6 m in the unlined condition — illustrating reduced water penetration, as shown in Figure 6.

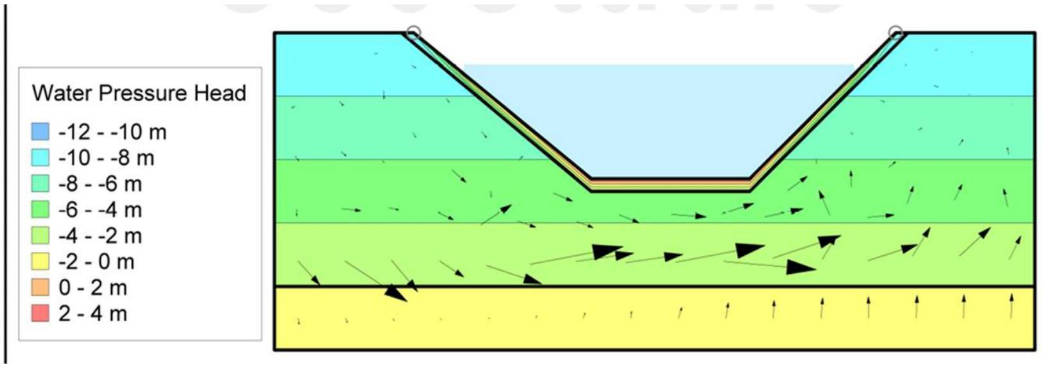

Figure 6. Contour Plot for HDPE Lined Canal

F. Quantitative Analysis for HDPE Lined Canal

We may evaluate seepage behavior in canals lined with High Density Polyethylene (HDPE) geomembrane by using the HDPE lined canal simulation model. This part uses numerical data from GeoStudio's SEEP/W module to quantify the rate of water loss from seepage through the canal bed and sides. The effectiveness of HDPE geosynthetic lining in separating canal water from the underlying soil mass is visually confirmed by the pressure head contours. The lined canal has excellent seepage resistance and long-term geotechnical stability with low gradients, suppressed pore pressures, and uniform hydraulic distribution. This research supports the suggestion for geomembrane lining in irrigation infrastructure where ground stability and water conservation are goals, as illustrated in Figure 7, when combined with flow vectors and seepage flux data.

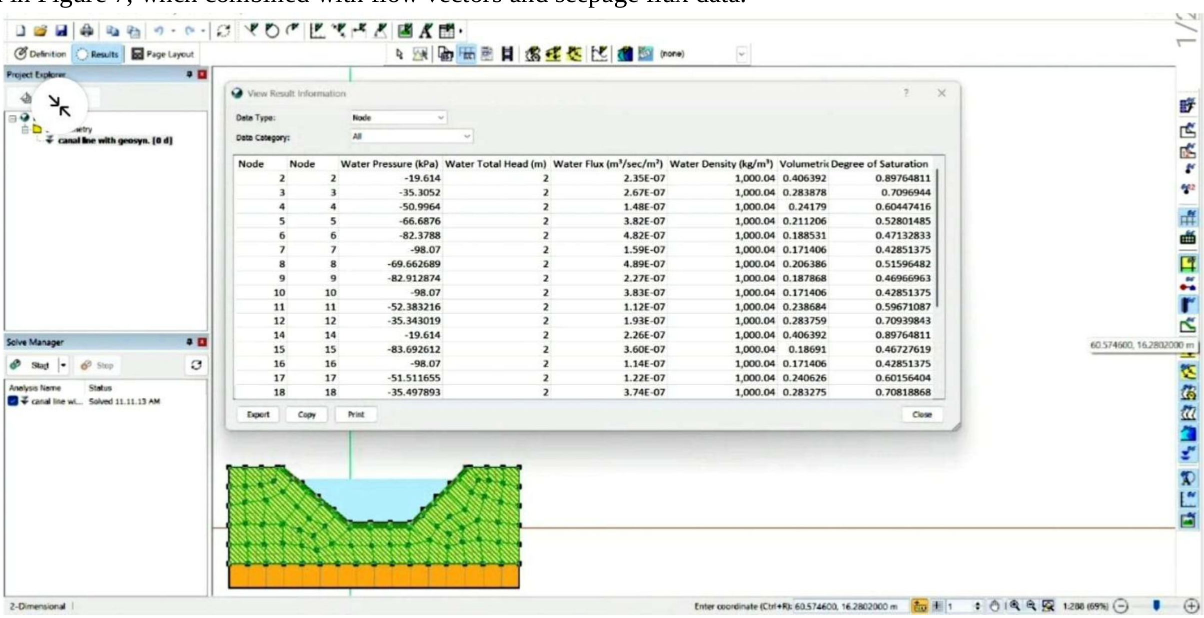

Figure 7. Seepage Data after Lining with HDPE

The use of HDPE geomembrane, with its very minimal permeability, drastically reduces seepage by interrupting the natural flow paths of water into the subsoil. Using the SEEP/W analysis, the total seepage flux through the unlined canal was computed as:

$$q_{lined}=(8.26\times10^{-7} m^3/s/m)$$

Converting to m³/s/m²:

$$qlined'= (8.26\times10^{-7}\ m^3/s/m)/7m=1.18\times10^{-7}\ m^3/s/m^2$$

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G. Seepage Reduction Efficiency of HDPE Lining

To evaluate the effectiveness of the HDPE geosynthetic liner, we calculate the percentage reduction in seepage flux:

$$\textbf{Seepage Reduction}\ (\%) = (q_{unlined} - q_{lined}) / (q_{lined})$$
$$= [(4.11 \times 10^{-6}) - (1.18 \times 10^{-7})] / (4.11 \times 10^{-6})$$
$$= 97.12\%$$

Thus, the HDPE liner achieves a **97.12%** reduction in seepage, confirming its high efficiency in canal lining applications, as shown in Figures8, 9 and 10.

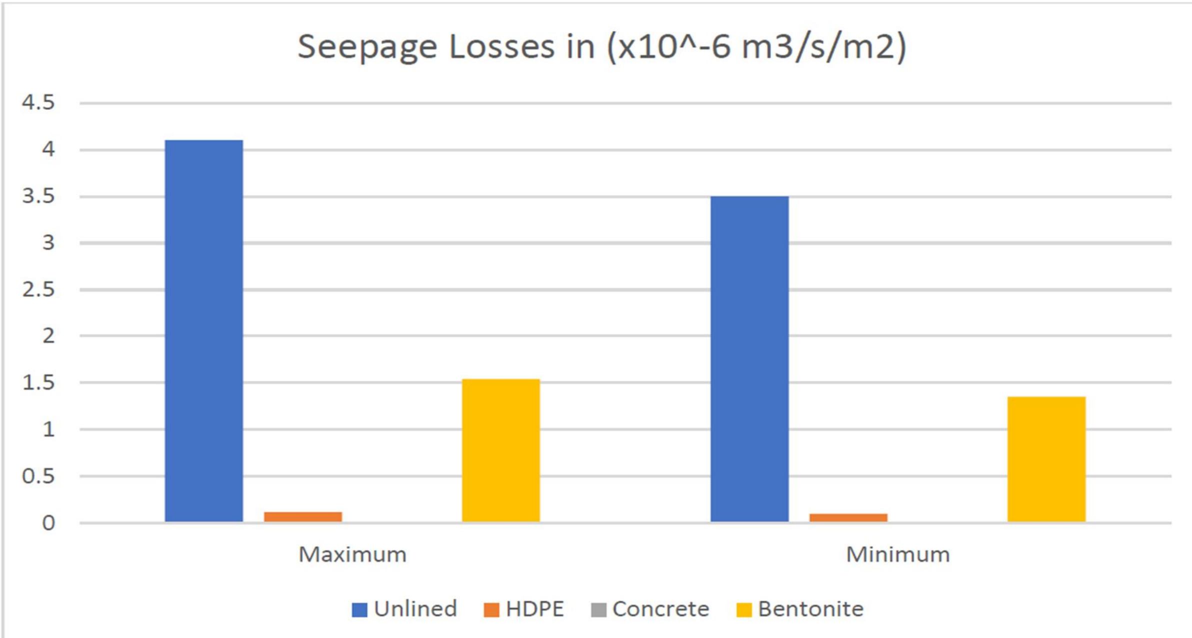


Figure 8. Seepage Losses in various types of Lining

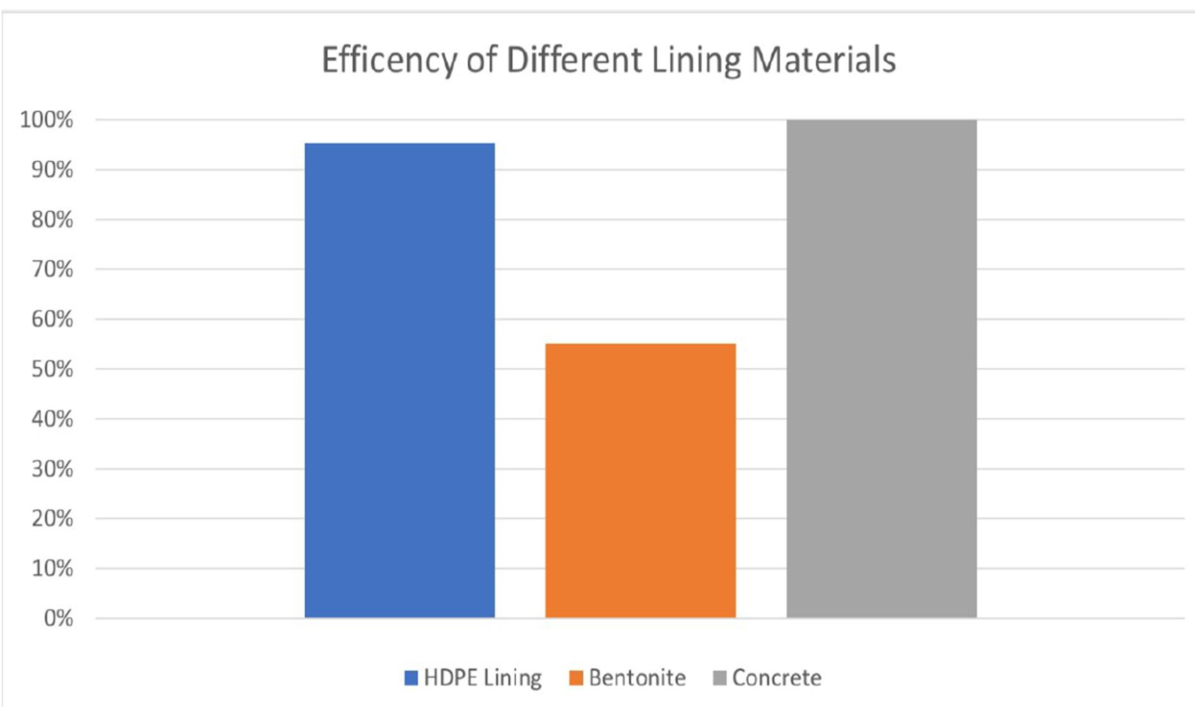


Figure 9. Efficiency of Different Lining materials

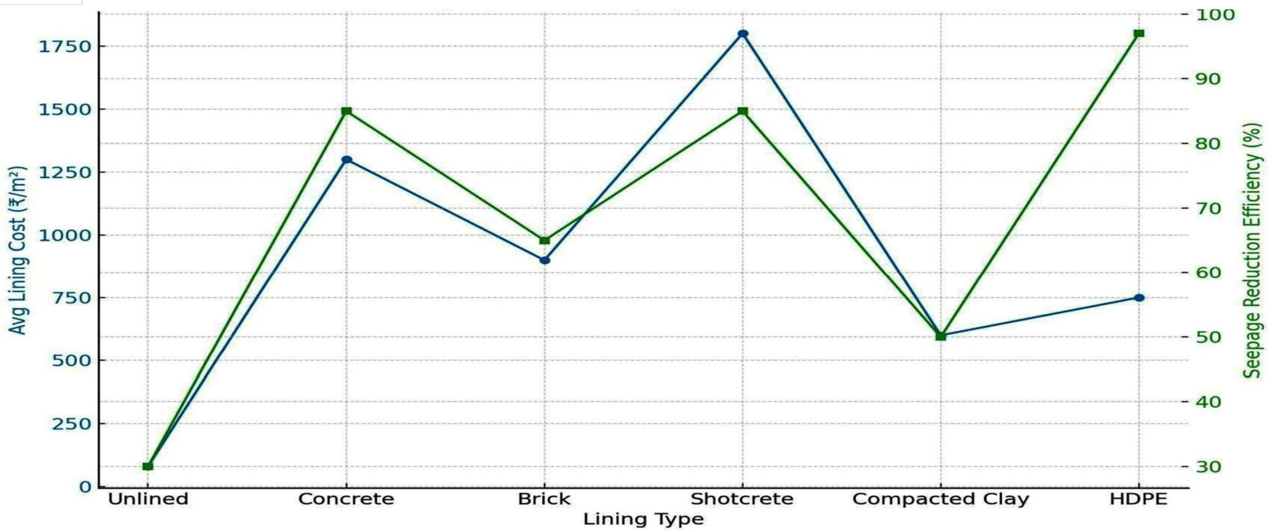


Figure 10. Seepage Efficiency vs. Cost Analysis Curve

V. CONCLUSION

Our primary objective in this study was to analyse and evaluate the effectiveness of High-Density Polyethylene (HDPE) geosynthetic liners in mitigating seepage losses in the Chanda Distributary Canal using advanced numerical modelling through GeoStudio. The significant water losses from seepage in unlined earthen irrigation canals, which result in ineffective water distribution, subsurface saturation, and long-term stability problems, served as the impetus for the study. Two thorough numerical models were created in order to accomplish the goals: one simulated the canal after an HDPE geomembrane liner was installed, and the other represented the unlined canal.

To guarantee consistency and enable a direct comparison, both models were exposed to the same boundary conditions, soil parameters, and hydraulic loads. The flow profile of the unlined canal revealed significant downward and lateral seepage, characterized by dense flow vectors propagating into the foundation and embankments. This active seepage was also reflected in the pressure head contours, which showed steep gradients and hydraulic connectivity between canal water and the surrounding soil for the unlined scenario, the computed seepage flux was 2.877×10^−5 m3/s/m. The specific discharge was found to be 4.11×10−^-6 m3/s/m2 when normalized to the seepage area (7.0 m2), showing a high rate of water loss per unit area. The HDPE-lined canal, on the other hand, displayed a very different seepage behavior. Nearly all of the flow vectors were contained within the water body, and the flow profile showed very little seepage activity beneath the canal bed. In a similar vein, the pressure head contours were widely separated and smooth, indicating that the low permeability of HDPE liners suppressed lateral and vertical seepage.

The seepage flux in the lined condition was reduced to (8.26×10^-7 m^3/s/m) which corresponds to a specific discharge of 1.18×10^−7 m3/s/m^2. From an engineering and operational perspective, the results clearly establish the feasibility and efficiency of using HDPE geosynthetic liners for seepage control in irrigation infrastructure. This intervention not only supports water conservation but also promotes sustainable irrigation practices, particularly in water-scarce regions.

VI. RECOMMENDATIONS

Based on the findings of the present investigation, the following recommendations are proposed:

1) HDPE geomembrane lining should be prioritized for rehabilitation of existing earthen canals experiencing significant seepage losses.
2) Full canal lining covering both the canal bed and side slopes is recommended to achieve maximum seepage reduction efficiency.
3) Proper subgrade preparation and installation quality control should be strictly implemented to minimize liner defects and puncture risks.
4) Protective geotextile cushioning layers should be incorporated to enhance geomembrane durability and resistance to mechanical damage.

5) Periodic inspection and maintenance programs should be established to identify and repair localized liner defects before significant leakage develops.
6) GeoStudio-based numerical modelling should be integrated into irrigation infrastructure planning and design processes for accurate seepage assessment and optimization of lining systems.
7) Future irrigation projects in water-scarce regions should incorporate geosynthetic lining systems as part of sustainable water resource management strategies.
8) To increase irrigation efficiency at regional levels, policymakers and irrigation authorities should support geomembrane lining technologies through technical recommendations, incentives, and demonstration projects.

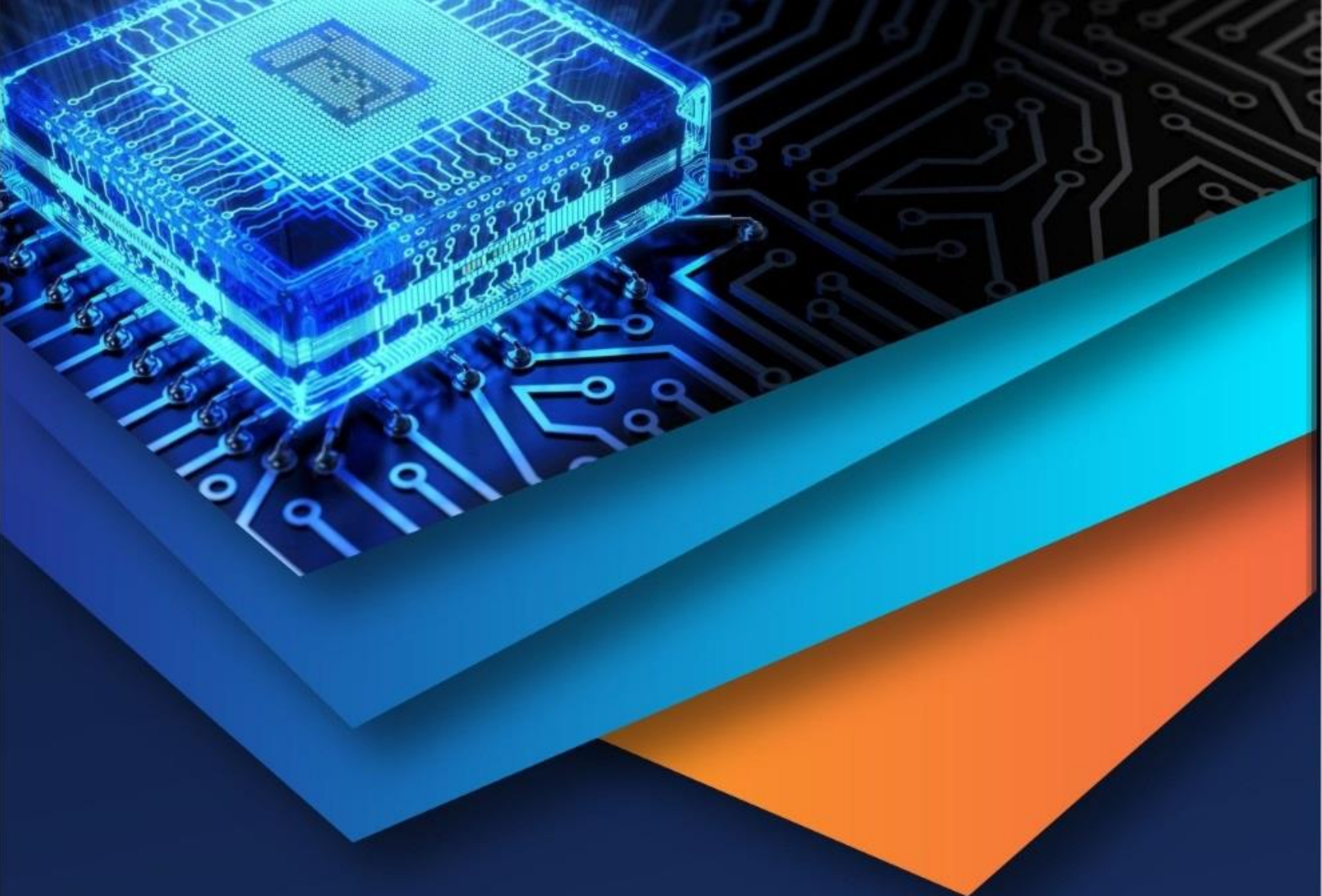
VII. FUTURE SCOPE

The present study provides a strong foundation for further investigations in seepage mitigation and irrigation infrastructure optimization. Future research may focus on the following areas:

1) Transient seepage analysis under fluctuating canal water levels and seasonal conditions.
2) Coupled seepage–stability analysis using integrated GeoStudio modules such as SLOPE/W.
3) Comparative assessment of alternative geomembrane materials including PVC, EPDM, and bituminous liners.
4) Long-term field monitoring of lined canals for validation of numerical simulation results.
5) Investigation of climate change impacts on seepage behaviour and irrigation performance.
6) Development of machine learning-based predictive models for seepage estimation.
7) Cost-benefit and lifecycle assessment of geomembrane lining systems under different environmental conditions.
8) Three-dimensional numerical modelling for complex canal geometries and heterogeneous soil profiles.
9) Integration of remote sensing and GIS techniques for large-scale seepage vulnerability mapping in canal networks.

REFERENCES

[1] El-Molla, D. A., & Kilit, M. (2026). Seepage control, detection, and treatment in embankment dams: A state-of-the-art review. *Arabian Journal for Science and* Engineering, 51, 3823–3849. https://doi.org/10.1007/s13369-025-10185-y
[2] Rahimi, J., & Nasimi, M. N. (2025). Numerical analysis of channel seepage using Geo-Studio modeling: A case study in an artificial river, Afghanistan. Journal of The Institution of Engineers (India): Series A, 1–21. https://doi.org/10.1007/s40030-025-00933-6
[3] Chatrabhuj, Meshram, Kundan, & Omar, P. J. (2026). Geo-artificial intelligence for smart irrigation management systems. In Agricultural Insights from Space (pp. 195–212). Academic Press. https://doi.org/10.1016/B978-0-443-34113-7.00007-9
[4] Elshaarawy, M. K., & Elmasry, N. H. (2024). Experimental and numerical modeling of seepage in trapezoidal channels. Knowledge-Based Engineering and Sciences, 5(3), 43–60. https://doi.org/10.51526/kbes.2024.5.3.43-60
[5] Chatrabhuj, Meshram, K. Mishra, U., et al. (2024). Integration of remote sensing data and GIS technologies in river management system. Discover Geoscience, 2, 67. https://doi.org/10.1007/s44288-024-00080-8
[6] Shirodkar, T. K., &Gidde, M. (2022). Study of canal lining and canal seepage HDPE sheet for Nira Deoghar Canal, Bhor. Journal of Emerging Technologies and Innovative Research (JETIR), 9(7).
[7] Al-Hadidi, M. T., & Hashim, S. H. (2021). Finite element analysis of seepage for Kongele earth dam using Geo-Studio software. Journal of Physics: Conference Series, 1895(1), 012003. https://doi.org/10.1088/1742-6596/1895/1/012003
[8] El-Gendy, A., & El-Agha, D. (2021). Numerical canal seepage loss evaluation for different lining and crack conditions. Water, 13(21), 3135. https://doi.org/10.3390/w13213135
[9] Al-Nedawi, N. M., & Al-Hadidi, M. T. (2020). Finite element analysis of seepage for Hemrin earth dam using Geo-Studio software. Diyala Journal of Engineering Sciences, 13(3), 66–76. https://doi.org/10.24237/djes.2020.13307
[10] Kheiri, G., Javdanian, H., & Shams, G. (2020). A numerical modeling study on the seepage under embankment dams. Modeling Earth Systems and Environment, 6, 1075–1087. https://doi.org/10.1007/s40808-020-00742-9
[11] Kosichenko, Y. M., &Baev, O. A. (2021). Selection of an effective seepage-control lining for canals made of traditional and geosynthetic materials. Power Technology and Engineering, 54, 819–824. https://doi.org/10.1007/s10749-021-01293-4
[12] Omofunmi, O., Kolo, J., Oladipo, A., Diabana, P., & Ojo, A. (2017). A review on effects and control of seepage through earth-fill dam. Current Journal of Applied Science and Technology, 22, 1–11. https://doi.org/10.9734/CJAST/2017/28538
[13] Jamel, A. (2016). Seepage losses from trapezoidal earth canals with an impervious layer. Water Practice and Technology, 16(2), 530–540. https://doi.org/10.2166/wpt.2021.038
[14] Peng, Y. F., & Hao, D. (2013). Seepage characteristics analysis of geomembrane earth-rock dams. Advanced Materials Research, 739, 278–282. https://doi.org/10.4028
[15] Zhang, L. M. (2013). Study on geosynthetics in canal seepage control project. Applied Mechanics and Materials, 329, 40–44. https://doi.org/10.4028
[16] Fell, R., Wan, C. F., Cyganiewicz, J., & Foster, M. (2003). Time for development of internal erosion and piping in embankment dams. Journal of Geotechnical and Geoenvironmental Engineering, 129(4), 307–314. https://doi.org/10.1061/(ASCE)1090-0241(2003)129:4(307)



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