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HYDROLOGICAL CHALLENGES IN KOLE LANDS: INVESTIGATING CANAL WATER LOSS DYNAMICS

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ABSTRACT

Sustainable water management in kole lands requires precise quantification of canal water losses. This study conducted in Thrissur North kole lands evaluates evaporation and seepage losses through a combination of field measurements, empirical equations and SEEP/W modelling analyses. The research quantified canal evaporation dynamics, which are primarily influenced by climatic conditions and water levels. Evaporation losses reached their peak at 15,199.60 m^3 during the second decade of February and declined to their lowest level of 3,748.64 m^3 in the third decade of August, resulting in total annual evaporative losses of 3.14 Mm^3. Analysis of seepage losses in unlined canals using SEEP/W modelling revealed maximum losses of 182,325.14 m^3 in May and minimum losses of 136,633.87 m^3 in August, with cumulative annual seepage losses of 5.61 Mm^3. Through detailed examination of these loss patterns, this study highlights the significant seasonal variability in water losses and demonstrates the critical impact of regulator operations on water management. The findings emphasize the necessity of implementing strategic water management practices to enhance irrigation efficiency and promote sustainable agricultural water use in kole lands.

Key words : Kole lands, Evaporation, Seepage, SEEP/W.

Introduction

Kole lands, located in the state of Kerala, India, form a vital wetland ecosystem that supports agricultural activities, biodiversity and water management. Here "kole'' means higher yield under favourable conditions (Sivaperuman and Jayson, 2000). These lands geographically located below mean sea level and submerged for 3-4 months in year due to huge rainfall during monsoon season. During non-monsoon season, the submerged field will made be empty by dewatering into canals by various axial flow pumps (Harisankar *et al.*, 2023). The dewatered water stored in canals and made use for cultivation of paddy throughout the non-rainy days. These canals are special in kole as canals are interconnected and act as drainage canals during monsoon season whereas it acts as irrigation system during non-monsoon season (Chethan *et al.*, 2024). The main sources of water are through Keecheri and Puzhakkal rivers as well as dewatered from kole lands. However, water loss from these canals through evaporation and seepage presents significant hydrological challenges, adversely affecting water availability for irrigation and overall ecosystem sustainability in kole lands.

Evaporation and seepage are the primary contributors to water loss in kole lands' canals. While evaporation is governed by climatic factors such as temperature, wind speed and relative humidity, seepage is influenced by canal design, soil properties and the presence of unlined surfaces. Most canals in the kole lands, constructed by the Kerala Land Development Corporation (KLDC), remain unlined, resulting in considerable seepage losses.

There are many methods available for estimation of evaporation. Direct methods include measuring evaporation from a specific surface and indirect methods**,** which estimate evaporation using meteorological or hydrological parameters (Yoder *et al.*, 2005: Xu and Singh, 2005; Snyder, 1992). Among these, the pan evaporation method is one of the most widely used approaches due to its simplicity, cost-effectiveness and reliability under diverse climatic conditions (Dingman, 2015). Traditional methods to estimate seepage, including inflow-outflow measurements and ponding tests, face limitations in the unique hydrological and operational context of kole lands. Challenges such as low flow velocities during the non-monsoon season and continuous water presence in canals complicate field experiments. Numerical approaches, such as SEEP/W software, offer a practical alternative for modelling seepage dynamics under complex conditions.

This study focuses on the quantification of canal water losses in the kole lands, with a specific emphasis on evaporation and seepage dynamics. By employing pan evaporation data and numerical modelling techniques, the research aims to provide actionable insights into canal water loss patterns, thereby contributing to more efficient water management practices and enhanced agricultural productivity in the region.

Materials and Methods

Study area description

The kole lands, situated within the latitudes of 10° 17' N to 10° 35' N and longitudes of 76° 05" E to 76°15" E. These lands experience a moderate climate without extreme heat or cold, with temperatures ranging from 21°C to 38°C. The soils in the region are acidic and rich in organic matter. Rainfall in the Kole lands is characterized by two distinct monsoon seasons: The South-West (SW) monsoon, occurring from June to September and starting between May 25 and June 1, and the North-East (NE) monsoon, from mid-October to November. The region receives an average annual rainfall of 2930.5 mm, with the SW monsoon contributing 67.3% of the total precipitation (Chethan *et al*., 2025). The hydrology of the area depends on seasonal rainfall, runoff, reservoirs and the operation of hydraulic structures like the Enamakkal and Idiyanchara regulators, which manage floodwaters and control water levels in canals (Binilkumar, 2010). These structures influence water storage, flow patterns and agricultural water availability. The unique geographic, climatic, and hydrological conditions of the kole lands make them ideal for studying canal water loss dynamics and creating sustainable water management practices to wetland ecosystems. The kole lands are categorized into two main divisions: the Thrissur kole lands and the Ponnani kole. Furthermore, the Thrissur kole is subdivided into the Thrissur North kole and the Thrissur South kole, as shown in Fig. 1. This study focuses on the canal system in the Thrissur North kole lands as it is well-developed canal network and lower susceptibility to canal breaches.

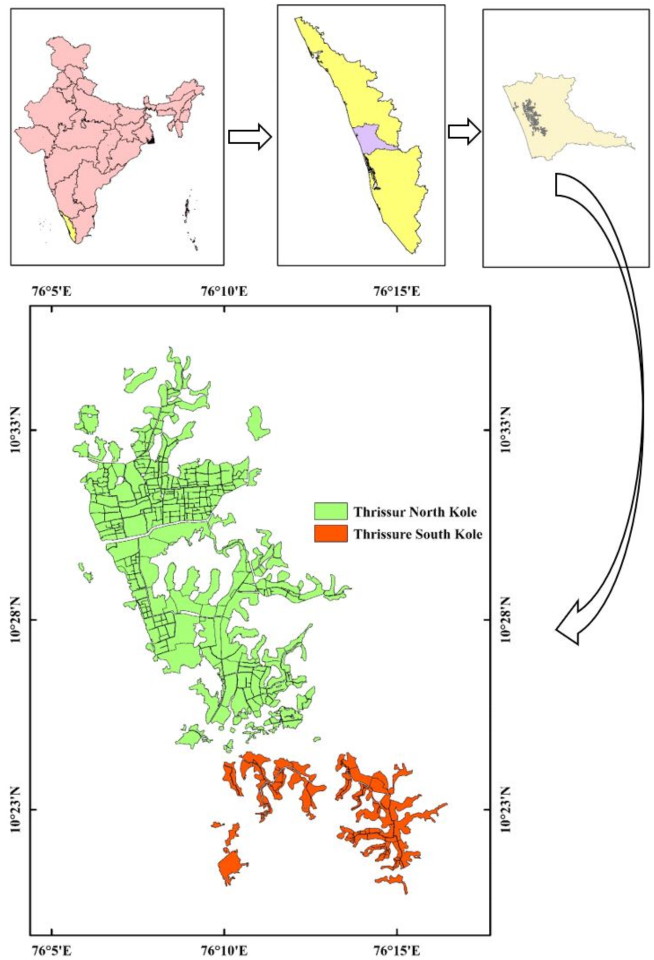

Fig. 1 : Location map of Thrissur Kole.

Canal system in kole lands

The canals in the Thrissur North kole lands, spanning 77.2 km are fed by dewatering from kole fields and discharge from the Keecheri (Kadamthodu) and Puzhakkal rivers as shown in Fig. 2. The Keecheri River enters through a valley between Orakam and Elavatur, while the Peramangalam Thodu flows via Adat, Mullor, and Orakam. The Puzhakkal River drains through Puzhakkal Thodu and the Kokkalathodu manages western Thrissur's drainage. Locks at Karanchira and Herbert Canal control water flow to prevent flooding during the monsoons. Canals like Chettupuzha and Perumpuzha connect the Puthenthodu to the Kottachal Canal, enabling efficient flood drainage to Enamakkal. The Enamakkal and Idiyanchira regulators serve as critical flood control structures, diverting excess water to backwaters and the sea. These canals, all unlined, are interconnected, ensuring proper drainage and irrigation. A spatial map of the 25 canals (shown in Fig 3) was created using ArcGIS with hydraulic data provided from the KLDC (Table 1).

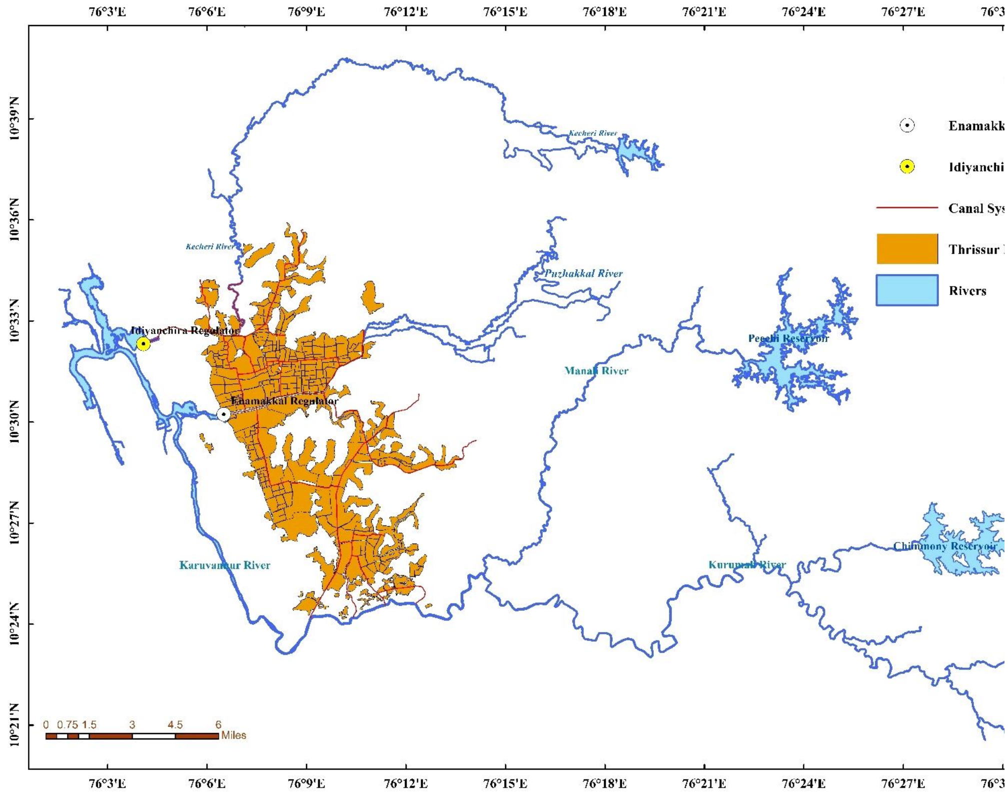

Fig. 2 : Map of Thrissur Kole with Rivers and canals.

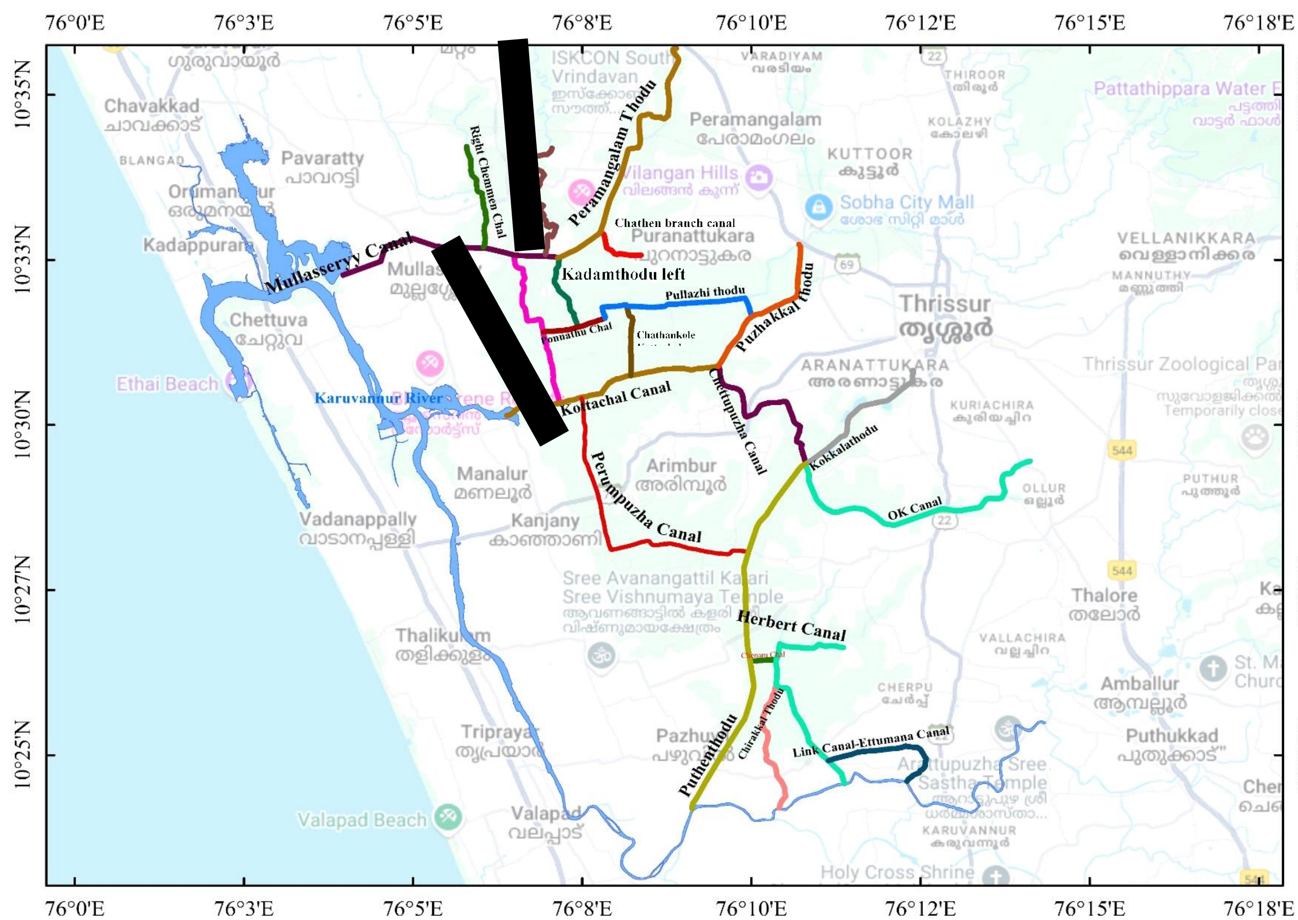

Fig. 3 : Canal system of Thrissur North kole.

Table 1 : Canals of Thrissur North Kole.

S. no.	Canal name	Length (m)
1	Herbert Canal - 1st ,2nd and 3rd reach	7845
2	Puthenthodu 1st, 2nd and 3rd reach	10370
3	O.K.Canal	6627
4	Kokkalathodu	3886
5	Mullassery canal - 1st reach	1600
6	Mullassery canal - 2nd reach	1520
7	Mullassery canal – 3rd reach	3143
8	Peramangalam thodu 1st reach	1812
9	Peramangalam thodu 2nd reach	550
10	Peramangalam thodu 3rd reach	1120
11	Peramangalam thodu 4th reach	2358
12	Left Chemmenchal	4670
13	Right Chemmenchal	2913
14	Kadamthodu left	2160
15	Kandamthodu right	2752
16	Ponnathuchal	935
17	Pullazhithodu	3840
18	Chathankole Kottachal link canal	1975
19	Puzhakkalthodu	4500
20	Chathen branch canal	1450
21	Kottachal	4523
22	Enamakkal phase canal	1600
23	Perumpuzhathodu	8200
24	Chenamchal	686
25	Chettupuzha Canal	5019

Estimation of Canal Evaporation

Measuring evaporation in the kole lands canals is crucial for efficient water management. It helps estimate water losses, optimize irrigation schedules and ensure adequate canal storage during dry periods. The procedure for estimating canal evaporation is outlined below.

Step 1: Measurement of the Depth of Water in the Canal

Water depth measurements were taken in all canals when the Enamakkal and Idiyanchira regulators were fully closed. The differences in water depth readings for each canal with respect to the Enamakkal regulator were then calculated. These differences were used to determine water depth variations along each canal in relation to changes in the Enamakkal water depth reading. Using the bed slope of each canal, the water depths at the starting, middle, and ending locations of the canal were computed.

Step 2: Calculation of the Top Width of the Canals

The top width of the canals depends on the water level, which changes with time. Once the depth was

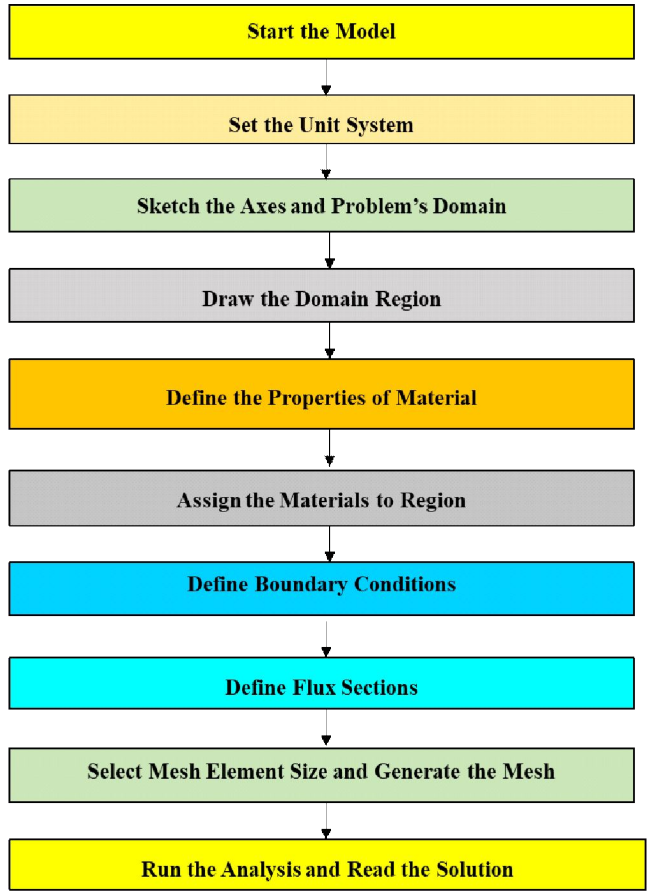

Fig. 4 : Workflow Chart for Estimation of Seepage in SEEP/W.

determined, the decade water level readings from the Enamakkal regulator is used to find the corresponding top width of the canal.

Step 3: Determine the Evaporation Loss

Pan evaporation data is collected from Department of Agricultural Meteorology, College of Agriculture, KAU, Thrissur. The evaporation loss from canal is calculated as

$$EL = W \times L \times E \times Kp \qquad \text{(i)}$$

Where, E_L is Evaporation loss from canals (in m^3),

W is top width of canal in m,

L is length of canal in m,

E is pan evaporation in m

K_p is pan coefficient which is taken as 0.8.

Estimation of Canal Seepage Losses

Estimating seepage in kole lands canals is vital for efficient water management, as unlined canals contribute to significant water loss. Accurate seepage data aims to optimize irrigation, reducing waterlogging, and ensuring sustainable water distribution for paddy cultivation. SEEP/W is a numerical method that estimates seepage over time and space, allowing for complex conditions to be

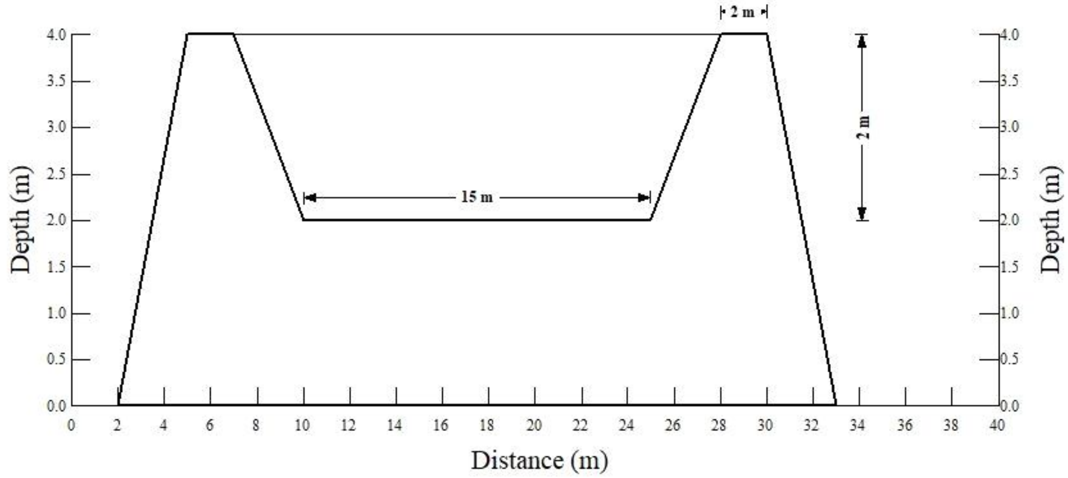

Fig. 5 : Drawing Domain region in SEEP/W for Peramangalam Thodu 2nd Reach, Right Chemmen Chal, Herbert Canal and Chenam Chal.

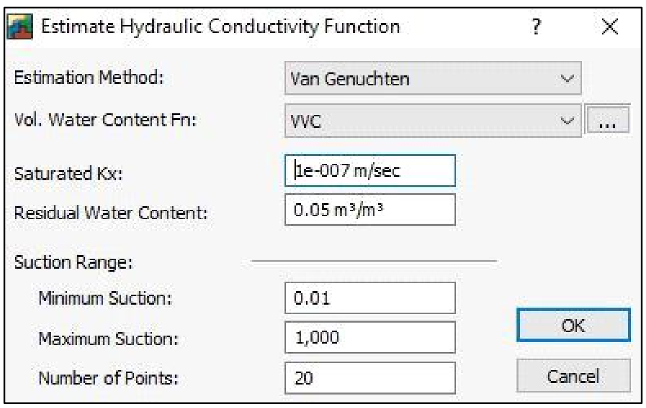

Fig. 6 : Interface for estimating Hydraulic Conductivity Function in SEEP/W.

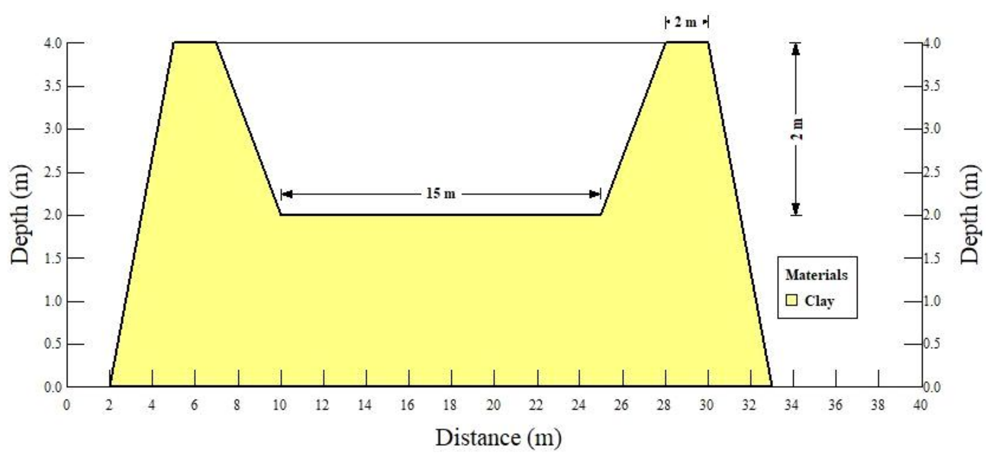

Fig. 7 : Drawing Canal Dimensions in SEEP/W for Peramangalamthodu 2nd Reach, Right Chemmen Chal, Herbert Canal and Chenam Chal.

considered.

SEEP/W, developed by Geo-Slope International Ltd. in Calgary, Canada, is a widely utilized software program in engineering and environmental fields. SEEP/W developed by Geo-Slope International, uses the finite element method to analyse groundwater flow in saturated porous media (Malik and Karim, 2020; El-Molla and Molla, 2022). It applies Darcy's law and the continuity equation to evaluate seepage through earth dams, slopes and infrastructure. The software allows for modelling porous media systems, defining boundary conditions and simulating groundwater flow.

Mathematical Model of SEEP/W

Discharge in soil follows Darcy's law which can be expressed as

$$Q = -KA\frac{\partial h}{\partial x} \tag{ii}$$

where, Q is discharge (m^3/s), K is hydraulic conductivity (m/s), A is the cross section of the water flow (m^2) and $\partial h/\partial x$ indicates the hydraulic gradient (m/m) of the flow. The fundamental equation directing the flow of water within a porous medium is the Poisson equation, which generalised form of the Laplace equation is given by Eq. (iii).

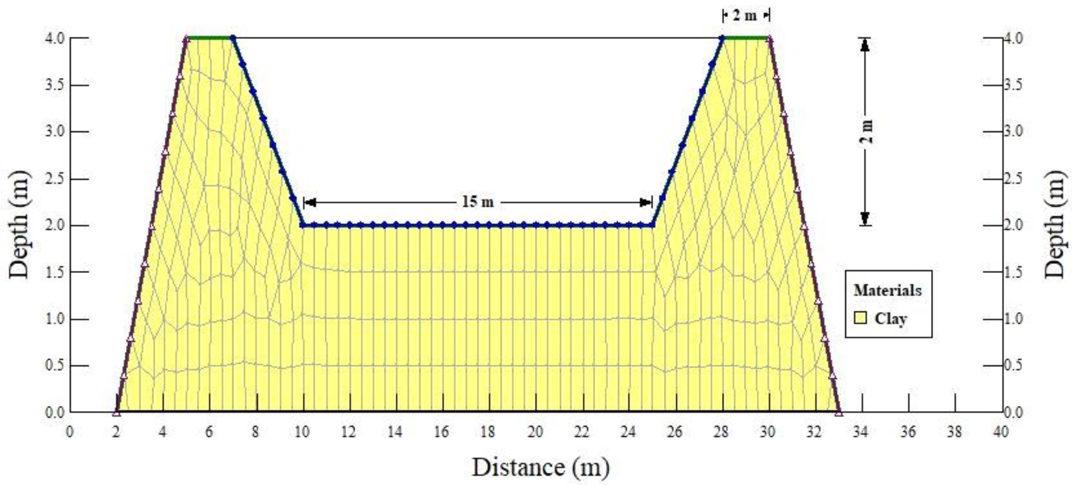

Fig. 8 : Mesh Generated in SEEP/W for Peramangalam Thodu 2nd reach, Right Chemmen Chal, Herbert Canal and Chenam Chal.

Table 2 : Canals with Dimensions.

S. no.	Canal name	Bottom width (m)	Canal depth (m)
1.	Peramangalam Thodu Ist reach	6	2
2.	Ponnathu Chal	8.5	3
3.	a. Chathan Kole b. Kottachal Link Canal c. PullazhiThodu d. Chathen *kole* lands *Branch* Canal e. Kandan thodu Left f. Kandan thodu Right	10	2
4.	Left Chemmen Chal	12	2
5.	a. Herbert Canal – 1st reach b. Herbert Canal – 2nd reach c. Herbert Canal – 3rd reach d. Chenam Chal e. Right Chemmen Chal f. Peramangalam Thodu 2nd reach	15	2
6.	a. K canal b. Kokkala Thodu	18	2
7.	Perumpuzha Thodu	20	3
8.	Puthenthodu 1st , 2nd and 3rd reach	20	2
9.	Peramangalam Thodu 3rd reach	22	2
10.	Peramangalam Thodu 4th reach	25	2
11.	Mullassery Canal – 1st Reach	30	2
12.	Chettupuzha Canal	45	2
13.	Mullassery Canal -2nd Reach	58	2
14.	Puzhakkal Thodu	70	3
15.	Mullassery Canal -3rd Reach	90	2
16.	a. Enamakkal phase Canal b. Kotta Chal	100	2

$$Q = K_x \frac{\partial^2 h}{\partial x^2} + K_y \frac{\partial^2 h}{\partial y^2} \qquad \text{(iii)}$$

Where, K_x and K_y represent the soil's hydraulic conductivity along the horizontal and vertical axes respectively. The variable h corresponds to the water potential within the soil (m), while Q indicates the flow rate at either the soil mass's inlet or outlet. Above equation is used for steady state flow condition. For unsteady condition the equation is

$$Q + \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) \qquad \text{(iv)}$$

Where, $\frac{\partial \theta}{\partial t}$ is the volumetric change in water content in time. Solving Poisson's equation is extremely challenging and typically requires computational methods. The SEEP/W software solves Poisson's equation by employing the finite element method.

By defining the problem geometry, boundary conditions and material properties, SEEP/W analyse the flow of water within the system and obtain valuable insights into factors such as pore pressure distribution, flow velocities and seepage paths (Fattah *et al.* 2015). The workflow for estimation of seepage is shown in Fig. 4.

Initialize model set up

To configure a SEEP/W analysis, specify the initial pore-water pressure conditions, establish convergence criteria, determine the time duration and increments and select the analysis type as steady-state.

Configure Unit System

For this study, the metric system has been employed

Table 3 : Permeability of different Soil Texture.

Soil Type	Permeability (m/day)
Clean gravel	$8.64*10^{10}$ to 864
Clean sands, clean & gravel mixtures	864 to 0.0864
Very fine sands, organic & inorganic silts, mixtures of sand silt & clay	0.0864 to $8.64*10^{-3}$
Stratified clay deposits	$8.64*10^{-3}$ to $8.64*10^{-4}$
Impervious soils	$8.64*10^{-5}$ to $8.64*10^{-7}$

for all analyses

Sketch Axes and Problem's Domain

To set up a problem in SEEP/W, define the domain and coordinate axes can be done by inputting the axis titles and the increment size for the coordinate system.

Draw Domain Region

The problem's domain was defined within the established coordinate system by delineating the boundaries and shapes of the canals. Seepage analysis was carried out in 15 canals. For other canals with similar dimensions, seepage results were assumed to be identical. The canals with similar dimensions are listed in Table 2. The desired shape and boundaries of the domain were created as shown in Fig. 5. This process involved drawing horizontal and vertical lines to establish the Cartesian coordinate system.

Define the Properties of Material

It is essential to define the material properties, allocate them to specific regions within the domain, and set the initial pore-water pressure conditions. Users can choose to add or select materials for the analysis. Given that the canals in the kole lands are constructed on clay soil, "Clay" was selected as the material type.

Define and assign the volumetric water content function describes the proportion of voids that remain water-filled as the soil drains. SEEP/W includes pre-defined "sample functions" for volumetric water content for various soil types. Once the saturated water content is assigned, SEEP/W can calculate the volume of water content at varying matric pressures (Moharrami *et al.*, 2014). SEEP/W provides built-in predictive methods to estimate the hydraulic conductivity function once the volumetric water content function is defined. In this study, the Van Genuchten equations were used to calculate hydraulic conductivity at varying matric pressures. Permeability values derived from experimental results by Terzaghi *et al.* (1996) were utilized to calculate the hydraulic conductivity function, as shown in Table 3. These values were then assigned for further estimation, as illustrated in Fig. 6.

Assign the Materials to Region

In SEEP/W, users can assign specific material properties to different regions within the domain. For the kole lands, where the canals are constructed from clay, homogeneous material properties were assigned uniformly across the entire region. Material properties assigned in SEEP/W is shown in Fig. 7.

Define Boundary conditions

Defining boundary conditions in SEEP/W involves assigning water levels, pressures, or fluxes at specific boundaries. In this study, water levels for each canal were assigned. Seepage analysis was conducted for the canal depth corresponding to the Enamakkal water level readings. Water depths for various canals in 2022 were determined as described in Section 2.3. Once the water depths were established, decadal averages were calculated and used as input for defining boundary conditions in SEEP/W.

Define Flux/boundary Sections

Defining flux and boundary sections in SEEP/W involves specifying water levels in the canals and identifying areas where seepage occurs. In the kole lands, seepage occurs on both sides of the canals, so both sides were defined as drainage sections, with the water level assigned as the head section.

Select Mesh Element Size and Generate Mesh

Within the Draw Mesh Properties dialog box in SEEP/W, several parameters can be adjusted to control the mesh generation process, including element size, element type, mesh refinement options, and boundary conditions. Smaller element sizes offer more detailed domain representations but may increase computational demands. In this study, a mesh size of 1 m was selected to balance accuracy and computational efficiency as shown in Fig. 8.

Run the analysis

Once the problem is fully defined, next step is to initiate the analysis process through the Solver Manager window in SEEP/W. The initial results can then be observed in the Results window. These results typically include contour plots that display hydraulic heads, flow rates, and other relevant outputs, providing insights into the seepage behavior within the defined domain.

Results and Discussion

Estimation of Evaporation Loss

Fig. 9 illustrates the evaporation losses from canals

Table 4 : Evaporation Loss from Canals.

S. no.	Decade	Evaporation loss (m³)	S. no.	Decade	Evaporation loss (m³)
1	1st Jan	149161.38	19	1st Jul	76975.97
2	2nd Jan	111427.83	20	2nd Jul	77742.38
3	3rd Jan	77742.38	21	3rd Jul	115377.55
4	1st Feb	173709.75	22	1st Aug	100399.24
5	2nd Feb	155282.38	23	2nd Aug	77193.04
6	3rd Feb	44541.22	24	3rd Aug	42841.70
7	1st Mar	74621.63	25	1st Sep	80030.20
8	2nd Mar	112994.64	26	2nd Sep	61058.11
9	3rd Mar	85884.45	27	3rd Sep	76975.97
10	1st Apr	86030.37	28	1st Oct	76643.36
11	2nd Apr	86322.20	29	2nd Oct	64783.66
12	3rd Apr	50134.01	30	3rd Oct	88618.94
13	1st May	88618.94	31	1st Nov	92430.33
14	2nd May	51035.27	32	2nd Nov	76776.41
15	3rd May	90286.61	33	3rd Nov	49318.58
16	1st Jun	79746.94	34	1st Dec	75394.14
17	2nd Jun	75379.45	35	2nd Dec	130460.00
18	3rd Jun	97091.81	36	3rd Dec	71014.10
				Total	**3124044.94**

Table 5 : Seepage Loss from Canals.

S. no.	Decade	Seepage loss (m³)	S. no.	Decade	Seepage loss (m³)
1	1st Jan	172368.91	19	1st Jul	156668.09
2	2nd Jan	175828.64	20	2nd Jul	141494.49
3	3rd Jan	141494.49	21	3rd Jul	137719.63
4	1st Feb	146518.85	22	1st Aug	147420.51
5	2nd Feb	164620.01	23	2nd Aug	138839.93
6	3rd Feb	154448.82	24	3rd Aug	136633.87
7	1st Mar	157461.02	25	1st Sep	140502.7
8	2nd Mar	167935.46	26	2nd Sep	145439.57
9	3rd Mar	174136.97	27	3rd Sep	156668.09
10	1st Apr	174324.15	28	1st Oct	153592.75
11	2nd Apr	180774.16	29	2nd Oct	160089.97
12	3rd Apr	165762.78	30	3rd Oct	149213.65
13	1st May	149213.65	31	1st Nov	163016.65
14	2nd May	182325.14	32	2nd Nov	155545.44
15	3rd May	144712.85	33	3rd Nov	150291.26
16	1st Jun	139515.43	34	1st Dec	170244.18
17	2nd Jun	142541.36	35	2nd Dec	165979.49
18	3rd Jun	158755.93	36	3rd Dec	147420.51
				Total	**5609519.41**

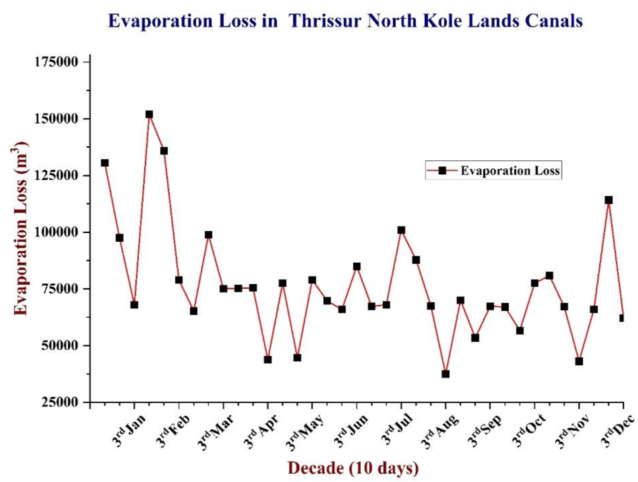

Fig. 9 : Evaporation loss in Canals of *Kole* lands.

in the kole lands over 36 decades in 2022. The highest evaporation loss of 15,199.60 m³, occurred in the first decade of February, while the lowest, 3,748.64 m³, was recorded in the third decade of August. The figure highlights significant temporal variability in evaporation losses, with peaks observed in February and December and notable lows in August and November since the water level is low. The total evaporation loss occurred during 2022 is 3124044.94 m³/ year (3.12 Mm³/ year). These fluctuations are influenced by variations in canal water levels and climatic conditions, indicating the role of regulator operations and environmental factors in evaporation rates. Detailed evaporation loss estimated for each canal is provided in Table 4.

Estimation of Canal Seepage Losses

Fig. 10 shows decadal seepage loss with respect to Enamakkal water level. In case of decadal seepage

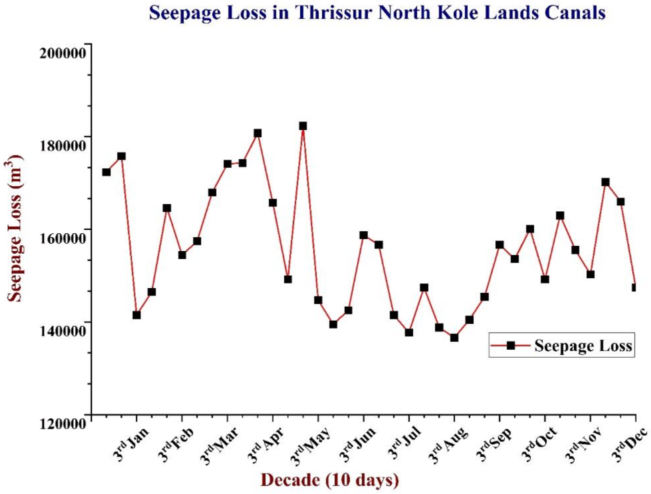

Fig. 10 : Seepage Loss in Canals of *Kole* lands.

analysis, the highest seepage loss occurred in second decade of May with a loss of 1,82,325.14 m^3 and lowest observed in third decade of August with seepage loss of 136633.87 m^3. The total seepage loss occurred during 2022 is 5609519 m^3/ year. The detailed seepage loss estimated is given in Table 5.

Conclusion

Analysing water depth in canals provides insights into evaporation and seepage losses, highlighting seasonal variations in these losses. These findings highlight the critical impact of environmental factors and regulator operations on water loss dynamics. Optimizing regulator schedules, enhancing canal infrastructure and implementing water-saving strategies such as canal lining and efficient irrigation methods could significantly mitigate these losses. This study provides valuable insights for improving water management practices in kole lands, emphasizing the need to reduce evaporation and seepage during critical periods to enhance water availability for agricultural and other uses.

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