Assessment of Canal Storage Dynamics for Sustainable Water Management in Thrissur North Kole Lands

ABSTRACT

Aims: The aim of this study is to estimate the canal storage capacity in Thrissur North kole lands to support effective water management for irrigation, drainage and flood control.
Study design: The study involvesestimating canal storage in Thrissur North kole lands using water depth measurements, bed slope data and trapezoidal rule calculations, conducted on a decadal basis.
Place and Duration of Study: The study was conducted in Thrissur North kole lands, located in Kerala, India, during 2022.
Methodology: Accurate estimation of canal storage capacity in Thrissur North kole lands is essential for managing water resources to support irrigation and mitigate floods. The study measured water depths in canals while the Enamakkal and Idiyanchira regulators were fully closed and calculated depth variations along the canals using bed slope data and measurements taken at multiple points (start, middle, and end). All canals were digitized within an ArcGIS environment to determine their total length. The trapezoidal rule was applied to estimate the storage capacity of each canal, enabling an accurate evaluation of the canal system's overall storage potential.
Results: The total canal length in the Thrissur North kole lands was determined to be 77.02 km. Decadal storage capacity estimations for 2022 revealed a range of 29.0 to 53.86 Mm^3, with an average storage capacity of 42.40 Mm^3. Additionally, a relationship between the water level at the Enamakkal regulator and canal storage capacity was developed.
Conclusion:
The study concludes that accurate estimation of canal storage capacity using water depth measurements, bed slope data, and trapezoidal rule calculations offers valuable insights for optimizing water management strategies, ensuring effective irrigationand mitigating flood risks in the Thrissur North kole lands.

***Keywords**: Kole lands, Cana storage, Trapezoidal rule, ArcGIS*

1. INTRODUCTION

The kole lands, a vital wetland ecosystem in central and northern Kerala, India, play a significant role in the state's rice production. These lands are an integral part of the Vembanadkole wetland ecosystem, designated as a Ramsar site in 2006 (Safnathmol*et al.*,,2022). In Malayalam, "kole" translates to "abundant yield" or "significant returns," reflecting the high agricultural productivity of the region(Johnkutty and Venugopal, 1993).Primarily used for paddy cultivation, the kole lands lie below sea level and remain submerged for 3–4 months during the monsoon season due to inflows from surrounding rivers, canals, and rainfall (Sivaperuman and Jayson, 2000; Nayar and Nayar, 1997). Effective water management in this ecosystem is crucial to balancing flood mitigation, drainage, and irrigation, enabling sustainable double cropping practices (Nikhil and Azeez, 2009; Mitsch and Gosselink, 2000). A network of main and cross canals, which remain unlined, interconnects various regions of the kole lands. During the monsoon, these canals act as drainage channels, efficiently removing excess water through axial flow pumps

(*Harisankar et al.,*2023:Ayisha*et al., 2016*). In the crop-growing season, the same canals serve as irrigation channels, supplying water for paddy cultivation (Chethan *et al.,* 2024). Estimating the storage capacity of these canals is crucial for understanding the available water resources and planning for their optimal utilization. By quantifying canal storage, it becomes possible to gauge how much excess runoff can be collected, stored, and utilized for irrigation. Accurate assessment of canal storage enhances water flow regulation, improves flood control, and boosts agricultural productivity. This study aims to evaluate the canal storage capacity in kole lands during the monsoon season through field measurements. The findings will contribute to developing comprehensive strategies for sustainable water resource management in the region. By advancing the understanding of canal storage dynamics, this research supports informed decision-making for flood control, irrigation scheduling, and enhancing overall agricultural productivity.

2. MATERIAL AND METHODS

2.1 Description of Study Area

The kole lands are located between latitudes 10° 17' N to 10° 35' N and longitudes 76° 05' E to 76° 15' E. The region experiences a moderate climate with no extremes of heat or cold, characterized by temperatures ranging from a minimum of 21°C to a maximum of 38°C(*Harisankar et al.,* 2023).The soils in the kolelands are acidic in and rich in organic matter(Hammed, 1975).The region has two distinct rainy seasons: the South-West (SW) monsoon, which lasts from June to September and typically begins between May 25 and June 1, and the North-East (NE) monsoon, occurring from mid-October to November. From December to April, the area experiences minimal to no rainfall. The average annual rainfall is 2930.5 mm, with 67.3% of the total rainfall occurring during the SW monsoon(Chethan *et al.,* 2024). 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, given its well-developed canal network and lower susceptibility to canal breaches.

2.2 Canal System in Thrissur North Kole Lands

The primary sources of water for the canals are dewatering from kole lands and discharge from the Keecheri and Puzhakkal rivers as shown in Fig. 2. The Keecheri River (locally known as Kadamthodu) enters the kole lands through a valley situated between Orakam and Elavatur. Similarly, the Peramangalam Thodu flows into the kole lands via the valley located between the elevated regions of Adat, Mullor, and Orakam.

The Puzhakkal river drains water through puzhakkal thodu canal, while the Kokkalathodu drains the western and partly southern areas of Thrissur town. It converges with the Puthenthodu on the southern side near Aranattukara. OllurKannimangala (OK) canal, also known as Chiyyaramthodu, drains Kanimangalam and Chiyyaranm area before joining the Puthenthodu approximately 1 km south of the Kokkala stream. The downstream area aredrained via the Puthenthodu throughthe Karanchira lock into the Karuvannur river when the water levelsare low.

During the southwest monsoon, when water levels in the Karuvannur River rise, the Karanchira lock and the lock at the Herbert Canal are fully closed to prevent river water from entering the North kole lands. Conversely, during the northeast monsoon, the Chirakkal Thodu and Herbert Canal drain their respective catchment areas into the Karuvannur River due to the lower water levels, ensuring no submergence occurs in the kole fields during this season. The lock and regulator at Karanchira efficiently manage the water flow of the Puthenthodu.

The Chettupuzha Thodu links the Puthenthodu to the Kottachal Canal across Enamakkal. A completed drainage system allows floodwaters from the Puzhakkal, Chiyyaram, and Chettupuzha canals to be directly drained to Enamakkal via the Kottachal Canal. Additionally, the parallel canals of Chettupuzha and Perumpuzha connect the Puthenthodu to the Kottachal Canal.The Enamakkal and Idiyanchira regulators have been constructed as flood control structures in North kole as shown in Fig. 2. Both these regulators serve as salt barriers and diverts part of flood water of North kole lands to the back water (Canoli canal) and subsequently to the sea (Srinivasan, 2012).

All these canals are interconnected, with the main water exit through the Enamakkal and Idiyanchira regulators (Binilkumar, 2010). The canal system in the Thrissur North kole lands spans a total length of 77.20 km, with all canals being unlined. There are 25 canals in total, and a spatial map was prepared through field surveys and using a base map provided by the Kerala Land Development Corporation (KLDC) in the ArcGIS environment, as shown in Fig. 3. Hydraulic data for the canals in the North kole lands were also collected from the KLDC and are presented in Table 1.

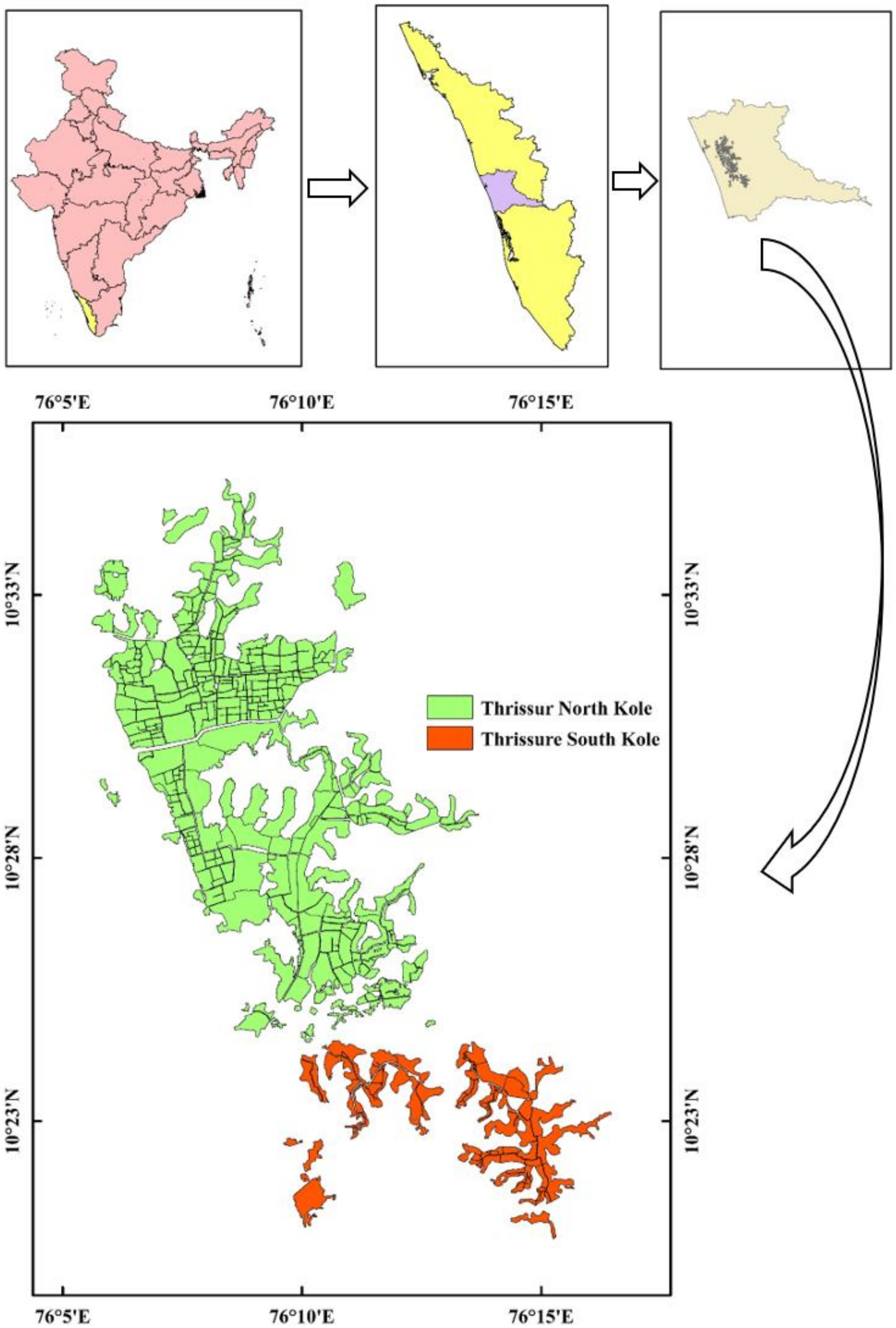

Fig. 1 Location Map of ThrissurKole

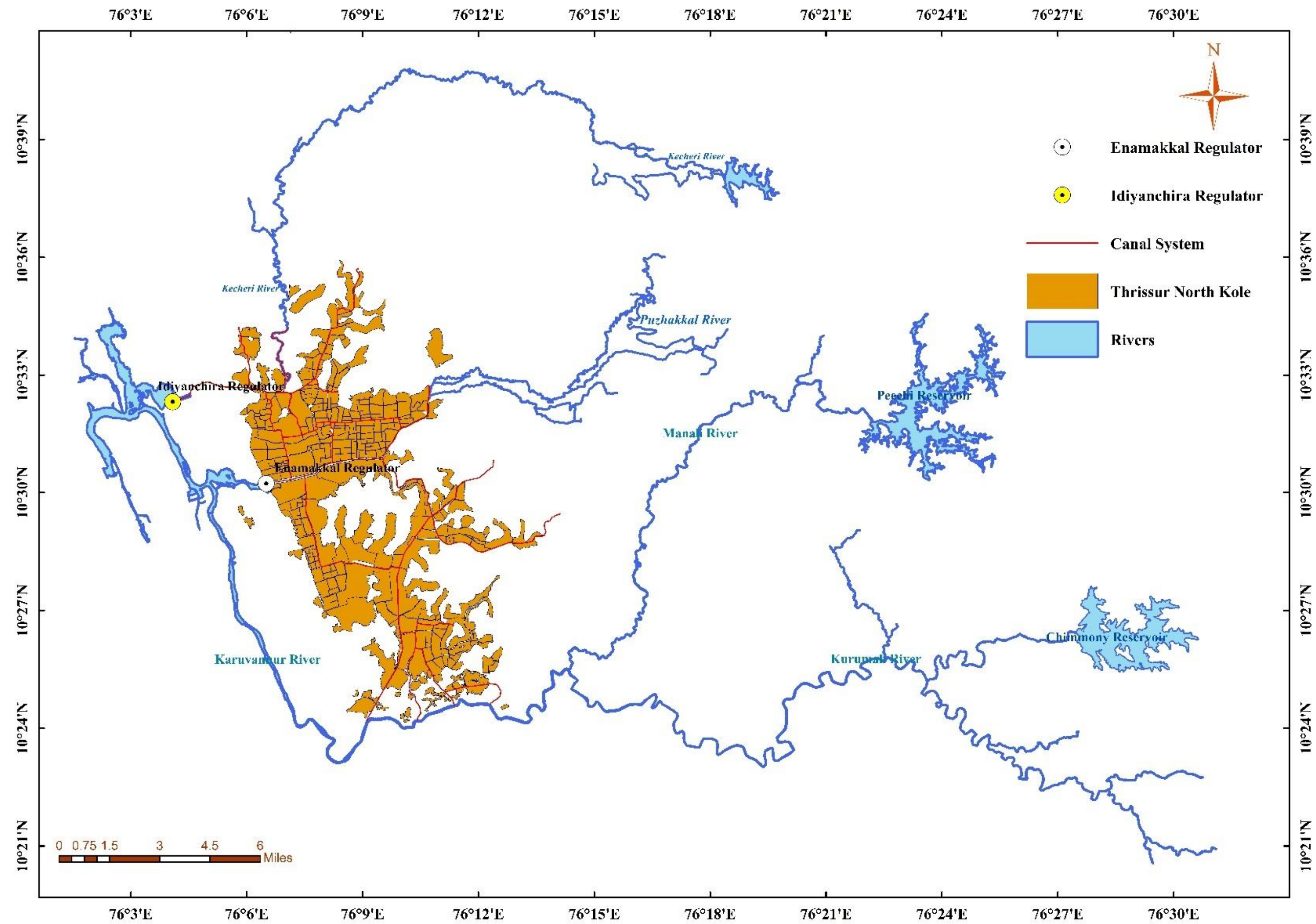

Fig. 2 Map of Thrissur Kolewith Rivers and canals

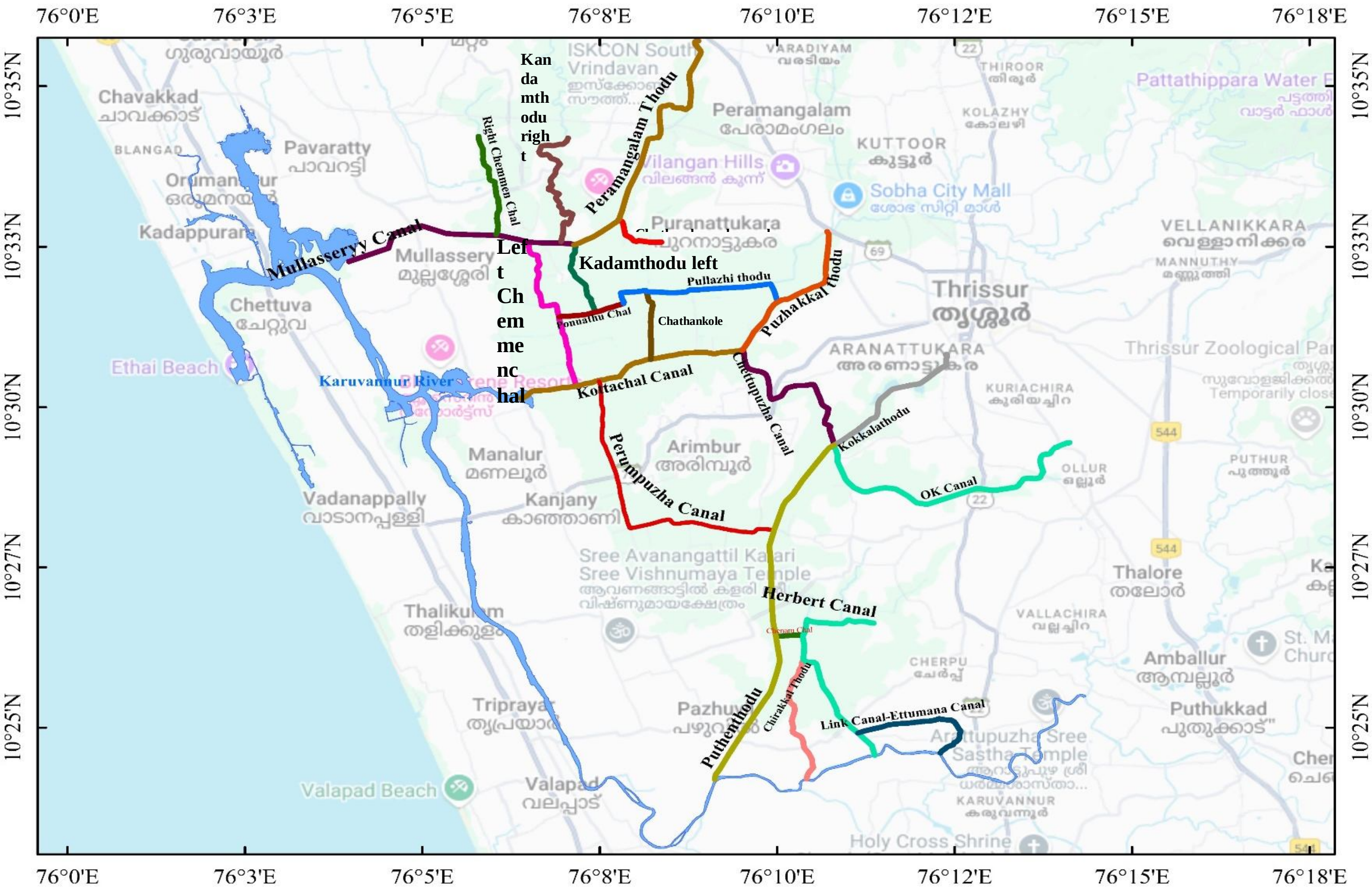

Fig. 3 Canal system of Thrissur North kole

2.3 CANAL STORAGE ESTIMATION

Estimating canal storage is crucial for effective water resource management in the Thrissur North kole lands, given that the canal network spans a total length of 77.20 km. 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. Once these water depths were established, the trapezoidal rule was applied to estimate the storage capacity of each canal.

Table 1 Canals of Thrissur North Kole

Sl. No	Canal Name	Length (m)
1	Herbert Canal - 1st,2nd and 3rdreach	7845
2	Puthenthodu 1st,2nd and 3rdreach	10370
3	O.K.Canal	6627
4	Kokkalathodu	3886
5	Mullassery canal - 1st reach	1600
6	Mullassery canal - 2nd reach	1520
7	Mullassery canal –3rdreach	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	ChathankoleKottachal 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

The trapezoidal rule is a numerical integration technique used to estimate the definite integral of a function over a given interval (Epperson, 2013). It is named after the trapezoid shapes formed when approximating the area under the curve of the function (Yeh,2002). This method provides a reasonable approximation, particularly when the function is relatively smooth over the interval. The more subintervals used, the closer the approximation will be to the actual value of the integral. It is a straightforward and commonly used technique for estimating definite integrals, particularly when more accurate methods such as Simpson's rule or Gaussian quadrature are not feasible or unnecessary and is widely used in various fields of science, engineering, and mathematics (Fornberg, 2021).

The method involves dividing the interval into trapezoids and summing their areasto estimate the total integral(Sazeli,2024). To apply the trapezoidal rule, the interval of integration is divided into equally spaced sub

intervals. The length of each subinterval, denoted by "Δx", is calculated by dividing the total length of the interval by the number of subintervals: $\Delta x = (b - a) / n$, where a and b are the limits of integration.

For each subinterval, the function values at two endpoints are evaluated, and the area of the trapezoid is calculated as function values and multiplied by the width of the subinterval: Generalized trapezoidal formula is given by

$$\int_a^b f(x)dx = \frac{\Delta x}{2}((f(x_0) + 2f(x_1) + f(x_2) + \dots\dots\ f(x_{n-1}) + f(x_n)) \quad \text{\_\_\_\_Eq.2.1}$$

where $f(x_0)$,$f(x_1)$, $f(x_2)$, $f(x_{n-1})$, $f(x_n)$ are the function values at the endpoints of the subinterval.

In this study three cross sectional dimensions were considered for calculating storage and corresponding area was calculated. Dimensions at the starting, middle and ending locations of canals were considered for calculation. Hence the equation 2.1 becomes

$$\int_a^b f(x)dx = \frac{\Delta x}{2}((f(x_0) + 2f(x_1) + f(x_2) \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_ Eq.2.2}$$

For canal storage estimation, f(x) is area. a and b are canal length between starting and ending. Storage was found out by considering dimensions from starting to ending, hence the limit a → b changes to 0→L, then equation 2.2 becomes

$$\int_0^L A.dx = \frac{\Delta x}{2}\left((A_0) + 2\ (A_1) + (A_2)\right) \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Eq. 2.3}$$

Where A_0, A_1, A_2 are area of cross section at starting, middle and end locations of canal.

The storage volume for each canal in North kole lands was computed on a decadal basis using Equation 2.3. The total storage, relative to the Enamakkal water depth reading, was obtained by summing the storage calculated for each individual canal.

3. RESULTS AND DISCUSSION

The decade-wise waterdepth variations atthe Enamakkalregulator arepresented in Fig. 4, showing an average water depth of 0.71 m. The highest water depth, 1.03 m, was observed in the second decade of May, while the lowestdepth, 0.23 m, recorded in the third decade of August. Water depths were higher between January and May, likely due to the regulator being fully closed during this period. In contrast, water depths decreased from June to August, when the regulator was fully opened leading to increased inflow to the regulator. The canal storage calculations for the first decade of January, is detailed in the Table 2.The storage volume for all thirty-six decades were Similarly computed. Fig. 5 illustrates the relationship between canal storage and the Enamakkal water level.

The highest canal storage was recorded in the second decade of May at 53.86 Mm^3, indicating the peak water storage capacity during this period. The lowest storage at 29.00 Mm^3, occurred in the third decade of August, with an average canal storage of 48.13 Mm^3. Seasonal trends in canal storage showed that from January to May, canal storage remained relatively high, fluctuating between 50.34 Mm^3 and 53.86 Mm^3. The highest values were observed in April and May, due to closed regulators retaining water in the canals. From June to August, storage declined sharply, reaching thelowestlevels in August as the canals discharging water through the open regulators. From September to December, canal storage gradually recovered, maintaining storage above 40 Mm^3.

The relationship between the Enamakkal water level and canal storage is shown in Fig.6 and is described by the following linear equation (Eq. 2.4):

$$y=32.136x + 20.86 \qquad \text{Eq. 2.4}$$

Where,

y = Canal storage (Mm^3)

x = Water level (m)

Table 2- Canal Storage Calculations for First Decade of January Month

Sl no	Canal	L (m)	WL (m)	D1 (m)	D2 (m)	D3 (m)	BW (m)	Side Slope (%)	A1 (m^2)	A2 (m^2)	A3 (m^2)	L/2 (m)	Canal Storage (Mm^3)
1	Herbert Canal - 1st,2nd and 3rdreach	7845	0.92	2.00	1.89	1.78	15.00	1:1.50	36.08	34.11	32.13	3922.50	0.27
2	Puthenthodu 1st,2nd and 3rdreach	10370	0.92	2.25	1.89	1.52	20.00	1:1.50	52.56	44.08	35.59	5185.00	0.46
3	O K canal	6627	0.92	1.96	1.63	1.30	18.00	1:1.50	41.15	34.21	27.26	3313.50	0.23
4	Kokkalathodu	3886	0.92	1.37	1.18	0.98	18.00	1:1.50	27.55	23.66	19.76	1943.00	0.09
5	Mullassery Canal – 1streach	1600	0.92	2.07	2.05	2.04	30.00	1:1.50	68.53	68.00	67.47	800.00	0.11
6	Mullassery Canal - 2ndreach	1520	0.92	2.12	2.10	2.09	58.00	1:1.50	129.70	128.77	127.84	760.00	0.20
7	Mullassery Canal - 3rd reach	3143	0.92	2.38	2.35	2.32	90.00	1:1.50	222.89	219.95	217.01	1571.50	0.69
8	Peramangalam thodu 1st reach	1812	0.92	0.92	0.92	0.92	6.00	1:1.50	6.79	6.79	6.79	906.00	0.01
9	Peramangalam thodu 2nd reach	550	0.92	1.07	1.07	1.07	15.00	1:1.50	17.77	17.77	17.77	275.00	0.01
10	Peramangalam thodu 3rd reach	1120	0.92	1.12	1.12	1.12	22.00	1:1.50	26.52	26.52	26.52	560.00	0.03
11	Peramangalam thodu 4th reach	2358	0.92	1.41	1.17	0.94	25.00	1:1.50	38.23	31.84	25.44	1179.00	0.08
12	Left Chemmen Chal	4670	0.92	1.62	1.62	1.62	12.00	1:1.50	23.38	23.38	23.38	2335.00	0.11
13	Right Chemmen Chal	2913	0.92	1.82	1.82	1.82	15.00	1:1.50	32.27	32.27	32.27	1456.50	0.09
14	Kandanthodu Right	2752	0.92	1.62	1.62	1.62	10.00	1:1.50	20.14	20.14	20.14	1376.00	0.06
15	Kadanthodu Left	2160	0.92	1.57	1.57	1.57	10.00	1:1.50	19.40	19.40	19.40	1080.00	0.04
16	PonnathuChal	935	0.92	1.57	1.57	1.57	8.50	1:1.50	17.04	17.04	17.04	467.50	0.02
17	PullazhiThodu	3840	0.92	1.52	1.52	1.52	10.00	1:1.50	18.67	18.67	18.67	1920.00	0.07
18	ChathankoleKottachal Link Canal	1975	0.92	1.62	1.44	1.26	10.00	1:1.50	20.20	17.91	15.61	1843.50	0.07
19	Puzhakkalthodu	4500	0.92	1.48	1.17	0.87	70.00	1:1.50	106.79	84.75	62.71	3051.50	0.52
20	ChathenKole Branch Canal	1492	0.92	1.37	1.30	1.22	10.00	1:1.50	16.52	15.62	14.72	746.00	0.02
21	Kotta Chal	4523	0.92	2.08	1.85	1.63	100.00	1:1.50	214.35	191.03	167.71	2261.50	0.86
22	Enamakkal phase Canal	1600	0.92	1.92	1.84	1.76	100.00	1:1.50	197.53	189.30	181.07	800.00	0.30
23	Perumpuzha Thodu	8200	0.92	1.95	1.54	1.13	20.00	1:1.50	44.79	35.39	25.98	4100.00	0.29
24	ChenamChal	686	0.92	1.77	1.73	1.70	15.00	1:1.50	31.22	30.62	30.01	343.00	0.02
25	Chettupuzha Canal	5019	0.92	1.90	1.65	1.40	45.00	1:1.50	90.86	78.86	66.85	2509.50	0.40
	Total	89411											**5.03**

L- Length of canal, WL- Enamakkal water level, D1, D2, D3- Depth at starting, middle and ending location of canal, BW- Bottom width of canal, A1, A2, A3- Area at starting, middle and ending location of canal.

The equation demonstrates a high coefficient of determination (R^2=0.9998), indicating an excellent fit. This relationship provides a valuable tool for understanding and managing the water storage dynamics of the Enamakkal regulator system and can be effectively used for future studies.

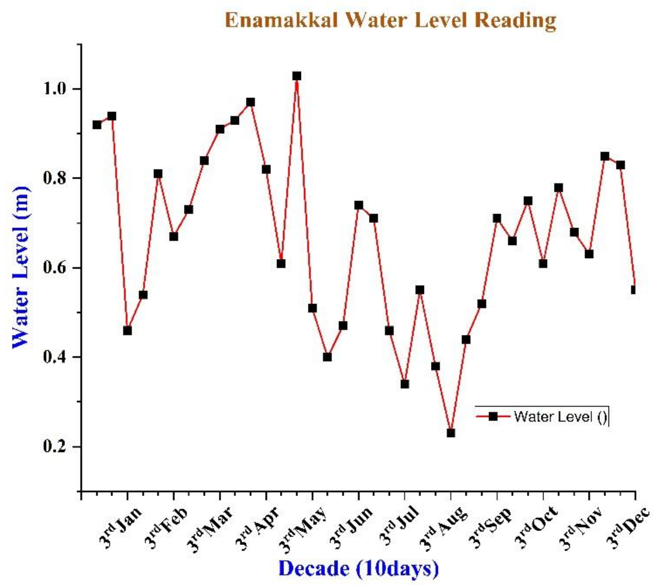

Fig. 4Water Level of Enamakkal Regulator during the Year 2022

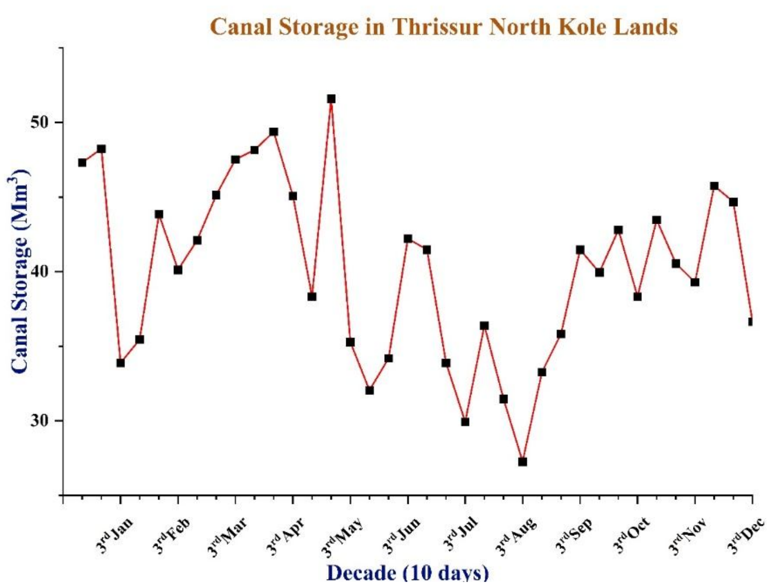

Fig. 5 Canal Storage with respect to Enamakkal Water Level

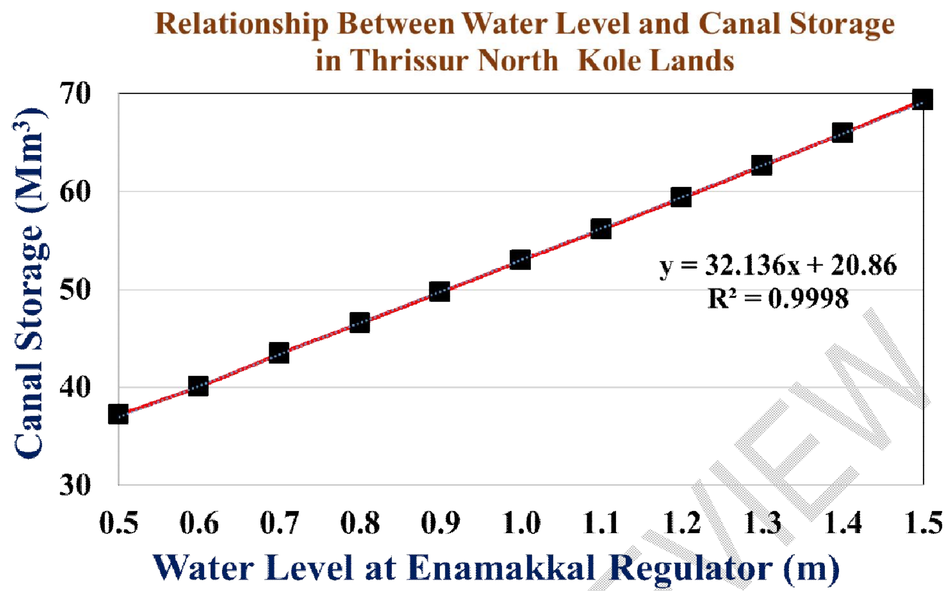

Fig. 6 Relationship between Water Level in Enamakkal Regulator and Canal Storage

4. CONCLUSION

The analysis of water depth and canal storage at the Enamakkal regulator highlights significant seasonal variations and their implications for effective water management in kole lands. A direct relationship between water levels at the Enamakkal regulator and canal storage serves as a predictive tool for estimating canal storage based on water levels, providing valuable insights for planning and operational decision-making. The seasonal trends and the established storage-water level relationship emphasize the critical role of regulator operations in balancing water retention during dry months and accommodating monsoonal inflows. These findings can be effectively utilized to prepare dewatering schedules, optimize crop calendars, and enhance water resource management, ensuring agricultural sustainability in kole lands. The results from this study enhance the results for developing optimization model for regulator operation.

Ethical Approval:

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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ABBREVIATIONS

^{1}	:	Minute
&	:	And
et al.	:	and others
ARC GIS	:	Aeronautical Reconnaissance Coverage- Geographic Information System
KLDA	:	KoleLand Development Agency
KLDC	:	Kerala Land Development Corporation
KML	:	Keyhole Markup Language
km	:	Kilometer
m	:	Meter
Mm^3	:	Million cubic meter
R^2	:	Coefficient of Determination