Crop Diversification in Kaluvankulam: Replacing Paddy with Flower Crops under Pollution Stress

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Abstract: Traditional paddy irrigation has become increasingly critical due to climate change–induced rainfall variability, freshwater scarcity, and the impacts of climatic anomalies such as El Niño. These factors have adversely affected conventional irrigation practices, particularly in semi-urban agricultural regions. This study assesses the chances of adaptability of treated municipal wastewater reuse for marigold irrigation in the Kaluvankulam region of Madurai District, Tamil Nadu, India where paddy yields have declined consistently in recent years. Treated wastewater samples were analyzed for pH, oil and grease, total dissolved solids (TDS), chemical oxygen demand (COD), hardness, and chloride, while soil samples were evaluated for pH, electrical conductivity (EC), macronutrients (N, P, K), and micronutrients (Fe, Cu, Zn). A reconnaissance survey and structured questionnaire were conducted to identify the causes of paddy yield reduction and to assess farmers' socio-economic conditions and acceptance of treated wastewater irrigation. Results indicate that oil and grease and COD levels exceeded permissible irrigation standards, while soil analysis revealed elevated phosphorus, potassium, and iron concentrations, suggesting nutrient accumulation. Despite these limitations, most farmers expressed willingness to adopt treated wastewater irrigation due to its nutrient-rich characteristics, provided adequate treatment and monitoring are ensured. The study concludes that optimized wastewater treatment and integrated soil–water management, combined with a shift from paddy to low-water-demand, high-value crops such as marigold, can enhance irrigation sustainability and farm profitability in semi-urban regions.

Keywords— Irrigation, Paddy, Marigold, Kaluvankulam**.**macronutrients (N, P, K), and micronutrients (Fe, Cu, Zn), hardness, chloride, COD levels

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1.Introduction

Growing global water scarcity, driven by climate variability, rapid population growth, and increasing agricultural water demand, has intensified the need for alternative and sustainable irrigation strategies. Treated wastewater (TWW) reuse has emerged as a key component of integrated water resource management, particularly in arid and semi-arid regions where reliance on conventional freshwater sources is increasingly unsustainable (QTEISHAT, et al., 2024), (Al Hamedi, et al., 2023). International experiences from water-stressed regions such as Jordan, the United Arab Emirates, and Palestine demonstrate that wastewater reuse is no longer optional but a strategic necessity to sustain agricultural productivity and enhance climate resilience (A. I. Khader & A M. McKee, 2013) (Garduno-Jim, et al., 2023).

These global challenges are strongly reflected at the local scale in semi-urban regions of India. In Tamil Nadu, erratic monsoon patterns, recurrent droughts, and growing competition for freshwater have significantly affected irrigated agriculture. The Kaluvankulam region of Madurai District represents a typical semi-urban agricultural landscape where traditional paddy cultivation, dependent on surface water and seasonal rainfall, has experienced declining productivity. Concurrently, increasing discharges of treated municipal wastewater from nearby urban settlements present both challenges and opportunities for agricultural reuse. From an agronomic perspective, TWW offers a reliable irrigation source enriched with nutrients capable of supplementing fertilizer inputs and improving soil fertility. However, long-term application without proper monitoring may result in soil salinization, nutrient imbalance, and heavy-metal accumulation (Supriya, Behera, Verma, & Meena, 2024), (Hoogendijk, Myburgh, Howell, & Hoffman, 2023).

Beyond agronomic concerns, the foremost barrier to widespread adoption is the multifaceted risk to public and environmental health. A primary threat stems from the potential transmission of pathogens, with wastewater acting as a vector for parasitic contamination of soils and crops, posing direct risks to farmers and consumers alike, as extensively reviewed by (Amahmid, et al., 2023)

To navigate this complex landscape of opportunities and threats, effective governance must be underpinned by strategic planning and systematic evaluation tools. Advanced modeling platforms, like the Water Evaluation and Planning (WEAP) model, enable policymakers to simulate scenarios, assess demand, and make informed strategic decisions for sustainable water allocation, as applied in various regional studies (Bessedik, et al., 2023)Marigold (*Tagetes erecta L.*), a high-value ornamental flower with strong cultural and market demand in India, is well suited for wastewater-based irrigation due to its non-food nature and tolerance to variable water quality.

Ultimately, the goal transcends mere reuse; it involves transitioning toward a regenerative urban water circular economy. This systemic shift requires metrics to measure progress, such as the Water Circularity Indicator, which can help prioritize strategies that maximize resource recovery, minimize waste, and close the water loop (Nikita S. Kakwani, 2024). Previous studies conducted in semi-arid regions have demonstrated that marigold cultivated with TWW exhibits comparable growth, yield, and flower quality to freshwater-irrigated systems, with limited health and environmental risks when managed appropriately. In this context, the present study focuses on the Kaluvankulam region of Madurai District to evaluate the feasibility of treated wastewater reuse through integrated water and soil quality assessment, crop performance analysis, and farmer perception surveys. The study further explores the replacement of water-intensive paddy with marigold cultivation as a climate-resilient, economically viable, and environmentally sustainable adaptation strategy for semi-urban agriculture.

1.1Water demand

Kaluvankulam village, located in the Madurai South region of Tamil Nadu, is experiencing increasing stress on freshwater resources for agricultural use due to erratic monsoon rainfall, rising temperatures, declining groundwater levels, and growing competition from urban water demand. Agriculture in the region primarily depends on seasonal rainfall and groundwater extraction, both of which have become unreliable, resulting in severe irrigation stress. Paddy (*Oryza sativa*), the predominant crop in the study area, is highly water-intensive. Under conventional flood irrigation practices prevalent in Tamil Nadu, paddy requires approximately 1200–1500 mm per crop season, equivalent to 12,000–15,000 m^3 ha^{-1}. In contrast, marigold (*Tagetes erecta*), a non-edible ornamental crop with lower evapotranspiration demand, requires only 500–700 mm per season (5,000–7,000 m^3 ha^{-1}). Thus, marigold cultivation can reduce irrigation water demand by approximately 50–60% compared to paddy. In semi-urban regions such as Madurai South, meeting the high irrigation requirement of paddy has become increasingly difficult, leading to yield instability and economic stress for farmers. This imbalance between water demand and availability threatens agricultural sustainability and local food security. Given that agriculture accounts for over 70% of global freshwater withdrawals, and food demand is projected to rise significantly by 2050 (FAO, 2016), alternative irrigation sources and crop diversification are essential. The substantial reduction in water demand associated with marigold cultivation highlights its suitability as a climate-resilient alternative for water-scarce semi-urban agricultural systems.

1.2Waste Water Crisis

In several villages, diluted wastewater is increasingly used for agricultural irrigation due to growing freshwater scarcity; however, the direct application of untreated or inadequately treated wastewater poses significant risks to human health and the environment through exposure to pathogenic organisms and chemical contaminants. Prolonged use of poor-quality wastewater has been associated with declining rice yields, soil degradation, nutrient imbalance, and the accumulation of harmful substances in the soil–plant system, leading to reduced agricultural productivity and economic stress for farmers. This situation is further aggravated by rapid population growth, inadequate sanitation infrastructure, and extreme climatic events such as El Niño and La Niña, which cause irregular rainfall, flooding, and sewage system overflows in semi-urban regions. Consequently, improving wastewater treatment efficiency and implementing regulated reuse strategies are critical for safeguarding public health, sustaining agricultural productivity, and enhancing climate resilience in water-stressed communities.

2.Objective of the Study

1. To study the factors affect the paddy yield in kaluvankulam treated wastewater

Irrigation.

2. To investigate the farmer's preference, perception and willingness of using treated

Wastewater in kaluvankulam

3.To analyze and evaluate the soil and water parameter and find out the suitable, recommendations for sustainable management.

3. Methods

This research synthesizes peer-reviewed journal articles, conference proceedings, and English-language book chapters that examine the reuse of treated wastewater for the production of animal feed. Studies addressing at least the three sustainability dimensions—environmental, social, and economic—were considered for inclusion. In most of the reviewed social science studies, treated wastewater reuse for livestock feed irrigation was not the primary focus, particularly in publication-oriented research. While many journal articles did not clearly specify treatment levels, the majority focused on the use of treated wastewater rather than untreated sources. In addition to the literature review, field-based data were collected and analyzed to assess real-world supply and demand conditions of agricultural products in local markets. The review further incorporates treated wastewater irrigation data obtained directly from farmers, reflecting actual field practices, as illustrated in Fig. 1.

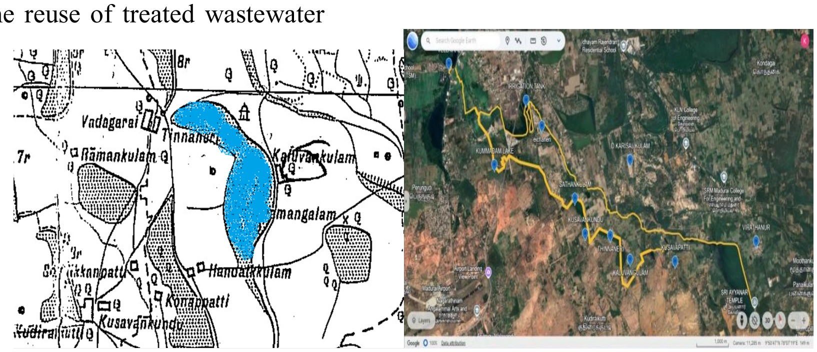

Fig 1: StudyArea

A total of 120 field samples were collected from village agricultural areas and analyzed through face contact investigations. Civil engineering laboratory studies were conducted for both soil and water samples, complemented by questionnaire-based surveys and reconnaissance field observations. Secondary data were obtained from multiple sources, including peer-reviewed journal articles, books, government offices, local administrative bodies, and the Tahsildar office. Information regarding demographic profile such as income of farmers, labors and water bodies, drainage channels, wastewater irrigation practices, and other environmental issues in the study area was gathered through direct interaction with local residents. Structured questionnaire surveys were designed to collect primary data from farmers in the field. In total, 120 samples were analyzed using appropriate statistical tools to evaluate spatial and environmental variations across the study region.

4.Results & Discussions

4.1. Farmers willingness and Perception of treated Waste Water Availability for cultivation:

In the Avaniyapuram French drain command area, diluted sewage irrigation has been continuously practiced by the farming community since 1924, with no recorded legal or regulatory restrictions governing the use of wastewater conveyed through the drainage system.

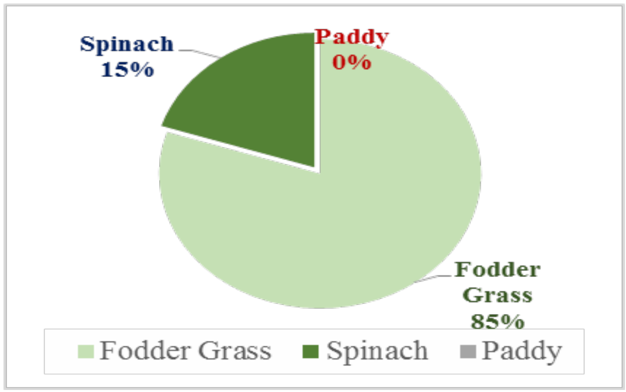

Fig 2 Farmers Responses Regarding Crops Choice

Figure 2 indicates that the majority of respondents in the exposed locations are willing to use wastewater for irrigation due to limited availability of freshwater, the inherent nutrient content of wastewater, and reduced fertilizer costs. Although more than 85% of farmers reported that wastewater irrigation is highly reliable for fodder grass cultivation, only 15% adopted it for spinach production. Seasonal water scarcity was reported in paddy cultivation during the months of March and April, primarily due to reduced flow in earthen canals and substantial upstream abstraction of freshwater. In addition, several farmers expressed a preference for cultivating spinach and grasses using wastewater irrigation owing to their higher economic returns and shorter crop maturity periods.

Fig 3 : Field Visit Avaniyapuram Région

The continuous availability of diluted wastewater as a perennial irrigation source throughout the year has resulted in higher crop yields compared to conventional freshwater-irrigated areas. In the studied sites, the predominant crops cultivated include fodder grasses and spinach, as depicted in Figure 3, indicating the potential of treated wastewater to enhance biomass production and nutrient uptake efficiency.

4.2. Comparison of economic gains and production in Avaniyapuram

Table 1 Economic gains & production Comparison

Description	Fooder Grass	Spinach
Average Bunch Production /Acre	3000	2000
Price in Market / Bunch	70	20
Profit in rupee / acre	210,000	40,000
cost savings in fertilizer / Acre	7000	7000
Revenue /Acre	217,000	47,000
Expenses of Ploughing / Acre	--	3200
Seeding Expenses / Acre	--	2000
Removing Weeds Expenses / Acre	--	3000
Pest control Expenses / Acre	--	2200
Harvesting Expenses / Acre	5000	5000
Total outgoing expenses / Acre	5000	15400
Revenue /Acre	212,000	31,600

Table 1 presents the results of the field study, demonstrating that irrigation with diluted wastewater consistently enhances fodder grass productivity and yields greater economic returns compared to spinach. The cultivation of fodder grass generated a maximum income of ₹2.12 lakh, in contrast to only 31,600 spinach plants, highlighting its positive economic impact. Consequently, a majority of farmers prefer cultivating fodder grass. The adoption of wastewater irrigation practices is largely driven by these financial incentives. The study further indicates that farmers prioritize fodder crops due to their higher market value and profitability, particularly during periods of freshwater scarcity. From the farmers' perspective, fodder grass yields are significantly higher under wastewater irrigation, even when average annual rainfall is recorded.

4.3 Questionnaire Samples and farmers perspective :

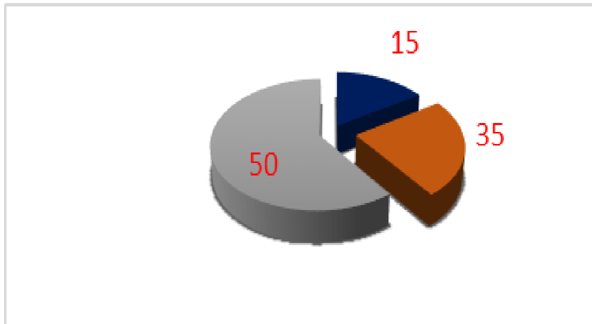

Fig 4 : Farmer Acceptance of edible or Non edible crop in %

Figure 4 illustrates the farmers' willingness to cultivate non-edible cash crops using treated wastewater, provided government initiatives support such practices. Approximately 50% of respondents reported that both edible and non-edible crops have high commercial value and achieve good yields under treated wastewater irrigation, reducing the need for synthetic fertilizers. About 15% of farmers preferred only traditional freshwater for marigold crop, such as paddy, while 35% indicated that marigold is also a viable option for cultivation using wastewater.

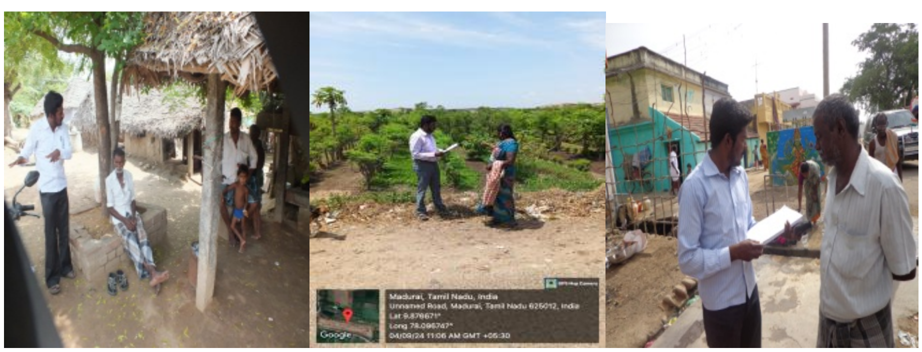

Fig: 5 Questionnaire survey

4.4 Farmers % about health issues in Avaniyapuram

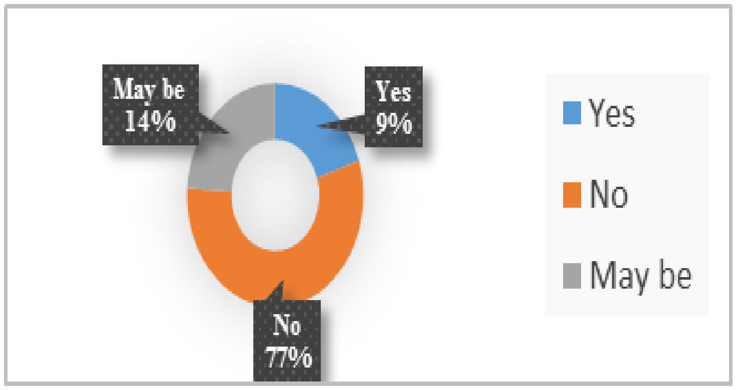

Fig 6. Farmers % about health issues in avaniyapuram

In Figure 6. The results indicate that farmers nobody face any serious health problems in this environment. In the field study it was understood that about 14% of samplers says maybe affect, and 77% reported that no problem and remaining of farmers reported that it may be affect the health.

4.5. A research on factors affecting agricultural Productivity in %

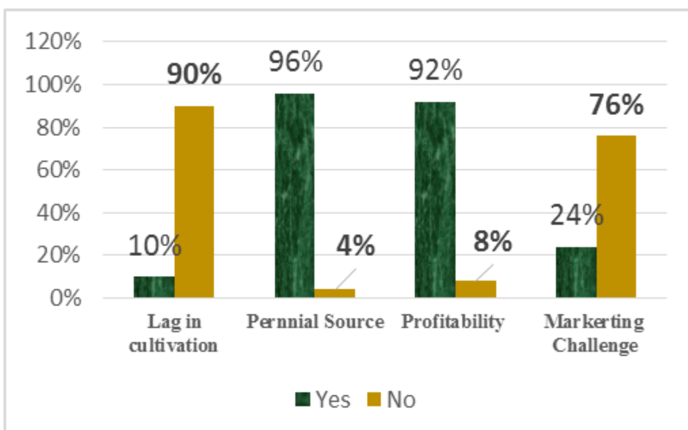

Fig 7: A research on factors affecting Crop Productivity in %

The Figure 7, illustrates this inquiry aims to comprehend the farmers' perspectives regarding the use of wastewater and whether there are any delays or drawbacks in marketing their crops. All the participants indicated that this presents a great opportunity for increased profit, and fodder grass is the most favorable choice as it demands nutrient content with minimal quality standards, yet it continues to grow abundantly.

4.6 Benefits of Waste Water Irrigation in avaniyapuram agri economy

Table 2: Benefits of Waste Water Irrigation in Avaniyapuram economy

Particulars	harvest income / Acre	No. Of Harvesting / year	Harvest Income / Acre / year	Irrigating area in acre	Total Income from waste water /year
Spinach	31,000	24	744,000	5	37,20,000
Fodder grass	212,000	24	5088000	20	10,17,60,000

Table 3.2 presents the annual advantages and costs of wastewater irrigation in Vellakal. In the study area, approximately 20 acres of fodder grass are cultivated, with harvesting occurring once or twice per month. Due to the perennial availability of treated wastewater, fodder grass can be harvested 24 to 30 times annually. Spinach is harvested 24 times per year, with additional yields of 27 to 30 harvests possible during the wet season. The total annual profit is calculated by summing the net returns from the cultivated area, which covers 500 acres under wastewater irrigation.

The advantages and expenses of wastewater irrigation in Vellakal for a year are displayed in Table 3.2. About 20 acres of fodder grass are grown in the research area, and harvesting occurs once or twice a month. It is feasible to collect 24 to 30 times a year due to the perpetual source of waste water. Twenty-four times a year, spinach is grown and harvested. An additional advantage of 27 to 30 times the yield is also attainable during wet seasons. The overall profit of one year is determined by adding the annual net return and the 500 acres of irrigated area.

5. Quality of treated Wastewater in kaluvankulam

Physico-chemical test analysis of wastewater are represented in table 5.1

Table 3 Wastewater Quality in kaluvankulam (1 Acre)

Location Point `	Observed Parameter						
	pH	Grease and Oil	Tds (Mg/L)	Cod (Mg/L)	Hardness (Mg/L)	Chlorides (Mg/L)	Nitrates (Mg/L)
Middle	7.25	136	1170	250	550	130	88.01
East	7.35	81	1105	295	492	282	51
West	7.45	91	1080	275	463	280	51.3

North	7.55	66	1010	223	481	105	81.
South	6.05	96	1150	313	406	245	35.8
Range normal as per CPCB	***5.5 – 9.0***	***10***	***2100***	**--**	**--**	***600***	**--**

Table 3 clearly representing the oil and grease is exceeding the permissible limits. All other wastewater analysis indicates that pH values at all sampling locations were well below the permissible limits, while total dissolved solids (TDS) remained within allowable bounds. Chemical Oxygen Demand (COD) was used as the primary indicator of pollutant load. Contributions from wastewater disposal by several small-scale industries may have influenced the overall pollutant load. The sampled stations exhibited low COD levels and low hardness at all points. Nitrate concentrations were found to be particularly high at Kaluvankulam, whereas avaniyapuram showed elevated chloride levels.

Fig 8: Water Collection and Testing

6. Soil Quality in kaluvankulam

The pH is in the low range at every station, including the control sample, according to the assessed data (Table 3.4). kaluvankulam was found to have medium electrical conductivity, increased phosphorus concentrations at all sample locations, and high potassium concentrations.

Table 4: Soil Quality in kaluvankulam (1 Acre)

Location Point `	**Observed Parameter**							
	PH	**Ec (Ds/m)**	**n (Kg/ha)**	**p (kg/Ha)**	**K (KG/Ha)**	**Fe (mg/l)**	**Cu (Mg/L)**	**Zn (Mg/L)**
Center	6.99	1.5	499	66.47	426.5	12.75	20.81	9.39

East	6.50	0.56	256	55	392	8.05	99.3	18.07
West	7.54	1.24	215	33	1205	52.51	3.58	1.14
North	8.69	0.61	192	75	897	21.42	5.63	1.19
South	8.90	1.57	142	66	1176	47.70	4.07	1.2
Normal Range as per CPCB								
Low	6.5-8	0.1-1	0-279	0-11	0-118	0.2-9.8	0.2-2.9	0.2-2.9
Medium	>8 (alkaline)	1.1-2.9	281-447	22-Dec	121-279	10.1-19.7	3.2-5.9	3.2-5.9
High	<6 (acidic)	>3.0	>447	>22	>281	19.7-59.3	6.1-12.3	6.1-12.3

7.Conclusion

In Tamil Nadu's Madurai district's avaniyapuram region farmers have practicing treated wastewater irrigation over 100 years from 1924. In this 100 year irrigation so far the contributed a much to this society in term of food production, economic development, livelihood, zero poverty and hunger, and mitigating climate change by carbon sequestration by this irrigation. The findings of this study indicate that the presence of oil and grease in irrigation water has a detrimental effect on paddy cultivation in the Kaluvankulam region, resulting in reduced crop yield and impaired soil–water interactions. The formation of an oil and grease film on the soil surface restricts oxygen diffusion, disrupts nutrient uptake, and adversely affects root development in paddy fields. In contrast, marigold cultivation as a non-edible cash crop emerges as a viable and sustainable alternative under the prevailing water quality conditions of Kaluvankulam. Marigold demonstrates higher tolerance to marginal irrigation water, requires comparatively lower water input, and provides better economic returns without posing direct food safety risks. In AvaniyapSSuram Treated Wastewater supplements essential nutrients to the spinach and fodder grass and therefore no chemical fertilizer is required for high yield grass, which results in social, economic and environmental benefits. Same like that there is a potential in kaluvankulam for sustainable irrigation of marigold cash crops by using Treated with little care and keep economic benefits. Therefore, shifting from paddy to marigold cultivation in oil- and grease-affected areas of Kaluvankulam represents a practical adaptation strategy that enhances farmer income while reducing environmental and health concerns, thereby supporting sustainable agriculture in wastewater-impacted regions.

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Conflicts of Interest

The authors have no conflicts of interest to declare.

Data Availability

The data generated and analyzed during the current study are not publicly available due to institutional restrictions and ongoing related research. However, the datasets used in this study can be obtained from the corresponding author upon reasonable reques

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