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Impact of Irrigation Water Quality on Agro-Aquaculture Sustainability in the Konaseema Region of East Godavari

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KEYWORDS

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Abstract

The present study evaluates the suitability of groundwater and surface water for irrigation in agricultural and aquaculture-dominated regions of the Konaseema area in East Godavari district, Andhra Pradesh. Irrigation water quality parameters such as Percent Sodium (%Na), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Kelly's Ratio (KR) and Permeability Index (PI) were analyzed in both pre- and post-monsoon seasons in water and soil samples. Results indicate that in agricultural zones, %Na values were within permissible limits, whereas aquaculture zones showed significantly higher %Na, with several samples exceeding Wilcox (1955) guideline values, particularly in the post-monsoon season. SAR values in both agricultural and aquaculture regions remained within permissible irrigation limits. However, RSC levels in water frequently exceeded safe limits in both land-use types, suggesting possible carbonate hazard. Magnesium Hazard exceeded threshold values in several water samples during both seasons, indicating potential adverse effects on soil structure. Kelly's Ratio remained within permissible limits in agricultural areas but exceeded the guideline in most aquaculture water samples. The Permeability Index (PI) was generally within permissible limits in water samples but exceeded the acceptable range in soil samples during the pre-monsoon season. Overall, irrigation water near aquaculture areas shows higher salinity and alkali hazards compared to agricultural regions. The results highlight the need for careful monitoring and management strategies to prevent long-term soil degradation and maintain sustainable irrigation practices in the Konaseema region.

Introduction:

Konaseema, located in the Godavari delta of East Godavari district, is an agriculturally productive coastal plain where traditional paddy cultivation coexists alongside expanding brackish-water aquaculture (shrimp and fish ponds). Conversion of land to aquaculture, pond seepage and episodic saline water intrusion have raised concerns about progressive salinization and changing irrigation water quality in the region, with potential consequences for soil health and crop productivity [1].

Irrigation water quality is routinely evaluated using a set of indices — percent sodium (%Na), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Kelly's Ratio (KR) and Permeability Index (PI) — because these capture

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the salinity, sodicity and ion-balance hazards that influence soil structure, permeability and crop response. Modern reviews emphasise combining these indices with spatial analysis and seasonal monitoring to identify evolving risk zones and to guide management measures [2].

Coastal deltaic aquifers and shallow groundwater in the Godavari basin show strong vulnerability to salinization from both natural (marine/estuarine) and anthropogenic (aquaculture, irrigation return flows, over-pumping) drivers; recent regional assessments and remote sensing studies report localized pockets of elevated salinity and ion imbalances where aquaculture is intense. These processes can increase %Na, RSC and MH values in irrigation sources and thereby reduce the long-term suitability of water for crops unless managed [3]. The Irrigation Water Quality Index (IWQI) is a promising classification model that has been effectively used to convert groundwater quality data into easily understandable numerical values for evaluating potable groundwater quality [4, 5].

Due to climate change, more than 40% of the global population is currently facing water scarcity [6]. As a result, low-quality water sources have been increasingly used to mitigate water shortages in conventional irrigation systems [7, 8, 9]. Higher Magnesium Hazard (MH) values indicate that excessive magnesium concentrations in irrigation water can deteriorate soil quality, leading to reduced crop productivity in the study area [10]. However, because of the limited availability of freshwater, reclaimed water containing moderate to high levels of pollutants, sediments, and salinity has become a common alternative in various irrigation practices [11]. In addition, several countries in Asia and Sub-Saharan Africa are experiencing severe water pollution due to rising population density. For example, in Kenya, only about 20% of the land area has adequate water availability, and much of the country's water supply is obtained from dams, groundwater, and pans, particularly in semi-arid and arid regions [12], [13].

The present study characterizes irrigation-relevant chemical parameters in water and soil near agricultural and aquaculture areas of Konaseema for pre- and post-monsoon seasons. By comparing observed values against established guideline limits (e.g., Wilcox classification and Indian Standard IS 11624) and recent literature, the work aims to (i) map seasonal and land-use related differences in salinity/sodicity hazard, (ii) identify sites at risk of soil structural decline, and (iii) recommend monitoring and management measures appropriate for the Godavari deltaic setting [14].

Materials and Methods

Study Area

The study was conducted in the Konaseema region of East Godavari district, Andhra Pradesh, India, located between 16°30′–17°00′ N latitude and 81°45′–82°15′ E longitude [15]**.** The region forms part of the Godavari delta and is characterized by fertile alluvial soils, abundant canal irrigation and intensive paddy cultivation. In recent decades, large tracts of agricultural land have been converted into brackish-water shrimp and fish aquaculture ponds**,** leading to concerns of groundwater salinization and soil degradation**.** The area experiences a tropical monsoon climate**,** with average annual rainfall of ~1000–1100 mm, mainly from the southwest monsoon (June–September).

Sample Collection

- A total of (10 agricultural + 10 aquaculture) groundwater samples were collected from bore wells, irrigation canals and aquaculture pond peripheries.
- Samples were collected twice:
Pre-monsoon (April–May)
Post-monsoon (November–December)
- Clean polyethylene bottles (1 L) were rinsed with sample water before collection, labeled, and transported under cooled conditions to the laboratory.

Physico-chemical Analysis

Parameters were analyzed following APHA (2017) and BIS 3025 (part-wise) standards [16,17]:

Table-1:

Parameter	Method/Instrument
pH & EC	pH meter, EC meter
Ca^{2+}, Mg^{2+}	EDTA titration
Na^{+}, K^{+}	Flame photometer
HCO_3^{-}, CO_3^{2-}	Acid titration
Cl^{-}	Argentometric method

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SO_4^{2-}, NO_3^-	Spectrophotometry

Irrigation Water Quality Indices

From measured ions, the following indices were calculated:

Table-2:

Index	Formula	Reference
Percent Sodium (%Na)	$\%Na = (Na^+ + K^+) \times 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$	Wilcox (1955) [18]
Sodium Adsorption Ratio (SAR)	$SAR = Na^+ / \sqrt{[(Ca^{2+} + Mg^{2+})/2]}$	USSL (Richards, 1954) [19]
Residual Sodium Carbonate (RSC)	$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$	Eaton (1950) [20]
Magnesium Hazard (MH)	$MH = Mg^{2+} / (Ca^{2+} + Mg^{2+}) \times 100$	Szabolcs & Darab (1964) [21]
Kelly's Ratio (KR)	$KR = Na^+ / (Ca^{2+} + Mg^{2+})$	Kelly (1940) [22]
Permeability Index (PI)	$PI = [Na^+ + \sqrt{HCO_3^-}] \times 100 / (Ca^{2+} + Mg^{2+} + Na^+)$	Doneen (1964) [23]

(All concentrations expressed in meq/L.)

Standards for Evaluation

Water and soil suitability was evaluated using:

- Wilcox classification (1955) [18]
- US Salinity Laboratory (Richards, 1954) [19]
- Indian Standard IS 11624:1986 – Guidelines for Irrigation Water [24]
- FAO Irrigation Water Quality Guidelines (Ayers & Westcot, 1985) [25]

Results:

Irrigation parametric values of groundwater near Agricultural and Aquaculture areas are presented in table-3:

Sample code	*% Na (meq/l)*		*SAR (meq/l)*		*RSC (meq/l)*		*Kelly's Ratio*		*PI*		*MH*	
	Monsoon		*Monsoon*		*Monsoon*		*Monsoon*		*Monsoon*		*Monsoon*	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Agricultural activity area												
1/Ag	13.80	21.38	0.71	0.77	6.34	4.25	0.18	0.36	62.8	71.2	27.53	45.23
2/Ag	11.47	12.92	0.43	0.43	3.24	3.34	0.13	0.08	54.6	64.0	31.52	36.93
3/Ag	8.28	13.97	0.54	0.36	BDL	2.14	0.21	0.28	45.8	75.9	29.25	73.85

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4/Ag	12.14	19.53	0.23	0.46	2.94	2.34	0.13	0.32	89.6	77.4	42.15	49.39
5/Ag	25.42	13.04	2.89	0.54	BDL	12.02	0.25	0.48	45.2	88.9	29.10	21.23
6/Ag	13.26	23.91	0.68	0.81	9.21	2.66	0.24	0.39	53.1	65.2	63.92	51.39
7/Ag	15.46	14.15	0.28	0.37	3.27	2.52	0.11	0.17	66.6	73.5	52.24	48.61
8/Ag	17.15	18.03	0.63	1.56	4.32	BDL	0.13	0.31	58.5	47.8	14.68	46.06
9/Ag	12.34	13.88	0.49	0.38	0.76	2.35	0.11	0.17	55.3	71.5	45.82	57.30
10/Ag	8.21	13.04	0.31	0.39	2.36	1.52	0.08	0.28	56.3	67.7	53.40	28.08
Aquaculture activity area												
1/AQ	21.89	37.48	0.94	2.89	4.89	1.65	0.34	0.89	62.9	76.5	61.93	42.88
2/AQ	69.23	61.56	12.6	8.05	2.84	BDL	1.86	1.63	74.6	71.7	63.66	24.14
3/AQ	24.67	66.36	1.36	11.6	1.29	BDL	0.35	2.01	50.8	73.8	38.64	38.20
4/AQ	33.75	48.32	2.36	4.06	11.3	1.32	0.56	0.95	68.4	68.0	59.42	51.57
5/AQ	55.33	78.45	4.86	15.7	10.3	9.89	1.21	4.26	78.6	86.6	45.76	38.18
6/AQ	57.18	72.11	6.91	12.2	13.4	11.5	1.41	2.71	75.2	85.5	55.15	48.41
7/AQ	63.79	59.15	7.40	5.63	21.1	11.7	2.93	1.48	98.9	83.8	50.92	69.29
8/AQ	52.49	62.97	5.07	9.50	5.7	6.96	1.15	1.74	72.3	75.0	42.24	42.07
9/AQ	48.63	63.35	4.34	6.83	BDL	0.09	1.07	1.84	66.0	78.2	72.39	50.82
10/AQ	53.09	73.05	4.70	7.52	7.67	2.02	1.11	2.98	74.2	93.8	25.96	24.55

Ag: Agriculture AQ: Aquaculture BDL: Below Detectable Limit

The irrigation parametric values of groundwater during pre & post monsoon seasons near Agricultural and Aquaculture activity areas are represented graphically in figures from (a) – (n) respectively.

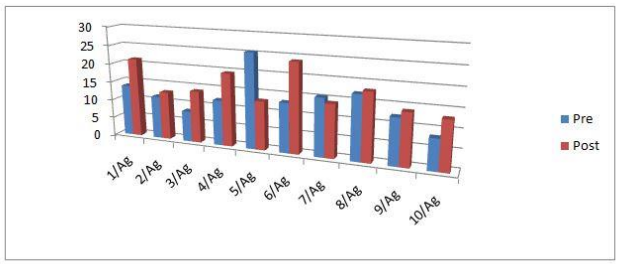

Fig (a) : **%Na**

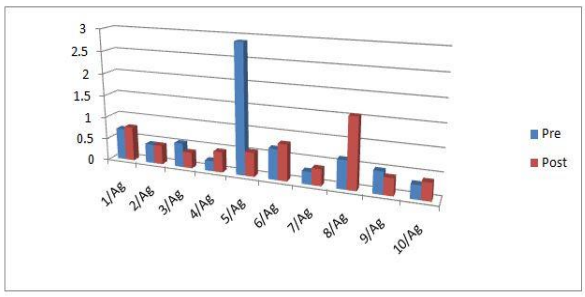

Fig (b): **SAR**

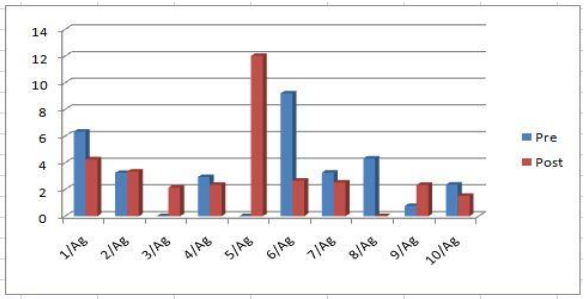

Fig.(c) RSC

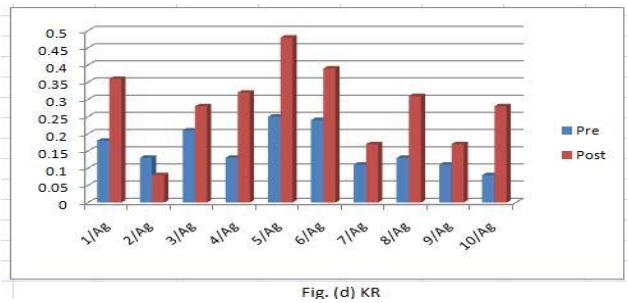

Fig. (d) KR

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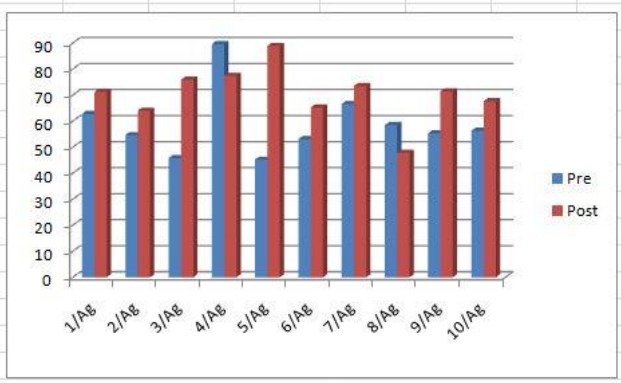

Fig. (d) PI

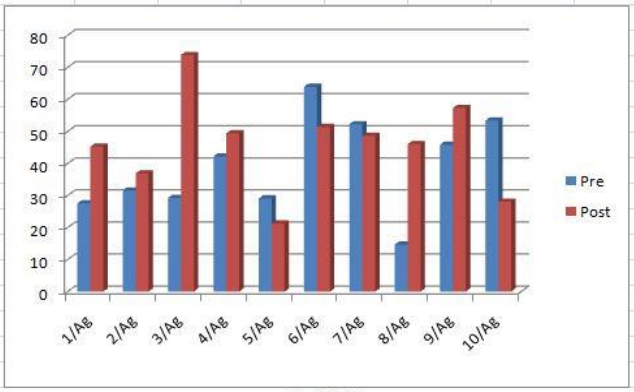

Fig.(f) MH

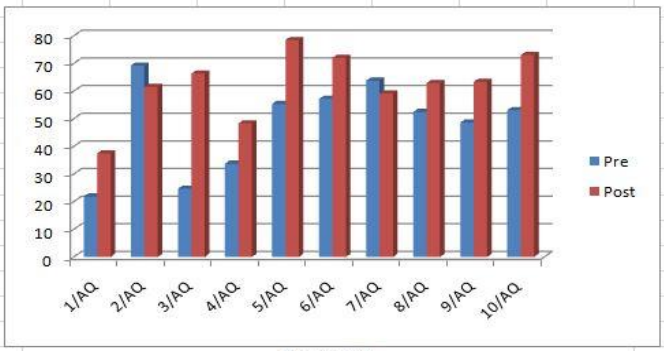

Fig: (g) %Na

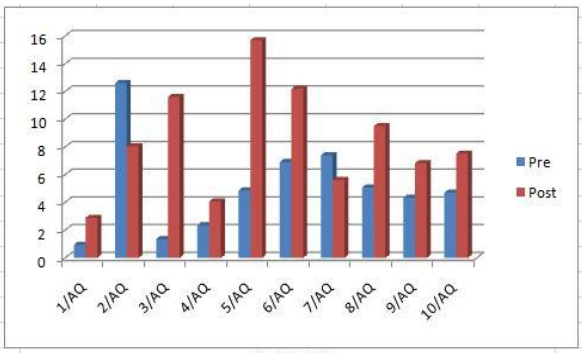

Fig: (h) SAR

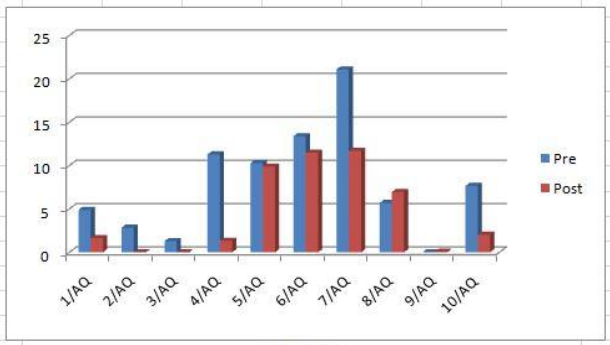

Fig: (i) RSC

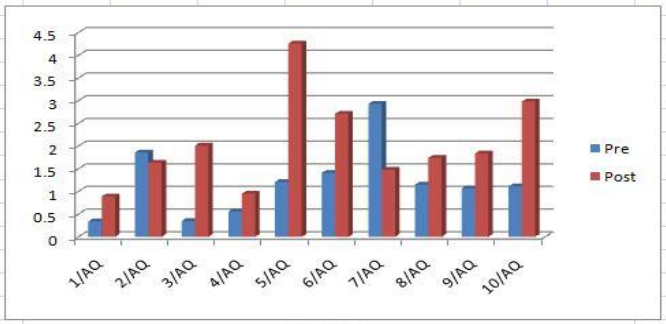

Fig: (j) KR

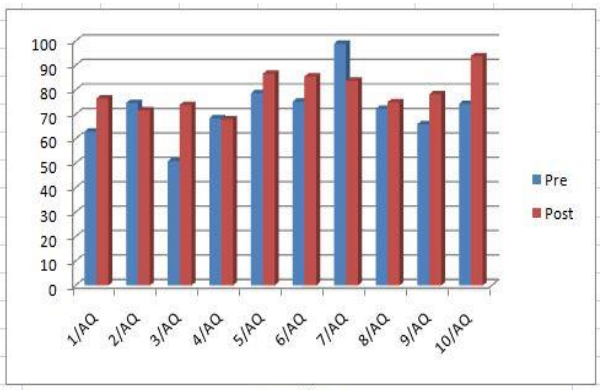

Fig: (l) PI

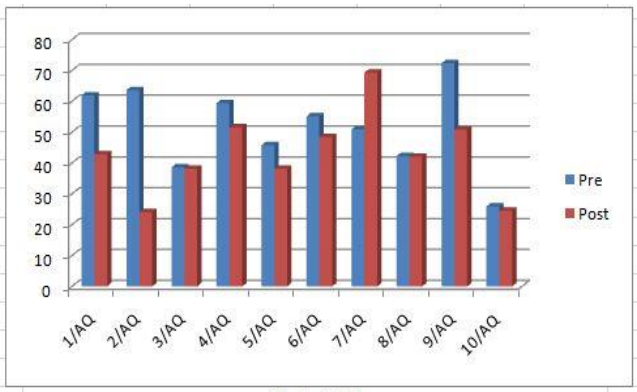

Fig: (n) MH

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Discussion:

Irrigation parameters

Percent Sodium (% Na)

Percent sodium in water samples near agricultural activity areas during pre and post monsoon seasons range from 8.21 – 25.42 and 12.92-23.91 me/l. % Na in water near aquaculture areas during pre monsoon season ranges from 21.89 to 69.23 me/l. In samples 2/AQ and 7/AQ, it crossed the guideline value (60 me/l) while in other samples it is within the limit. During post monsoon season %Na level ranges from 37.48-78.45 me/l. In samples 1/AQ, 4/AQ and 7/AQ it is within the guideline value while in other samples it exceeded the limit [18].

Sodium Adsorption Ratio (SAR)

SAR in water samples near agricultural activity areas during pre and post monsoon seasons range from 0.31 - 2.89 and 0.39-1.56 me/l respectively and the values are within the permissible limits of irrigation standards. SAR in waters near aquaculture activity areas during pre and post monsoon seasons range from 1.36 - 12.6 and 2.89-15.7 me/l. These values are within the guideline values (26me/l) [19]. All the values are within the guideline value.

Residual Sodium Carbonate (RSC)

RSC values in waters near agricultural activity areas during pre monsoon season ranges from BDL to 9.21 me/l with a mean value of 3.13 me/l. In samples 3/Ag, 5/Ag and 9/Ag it is within the guideline value while in other samples it crossed the limit. During post monsoon season it varies from BDL–12.02 me/l with a mean of 2.96 me/l. In all samples it crossed the permissible limit except KP-8 and KP-10/Ag. In waters near aquaculture areas during pre monsoon season ranges from BDL to 13.4me/l. In samples 3/AQ and 9/AQ, it is observed below the guideline value while the other samples it crossed the limit. During post monsoon season it is in limit of 2, 3, 4 and 9/AQ samples while it crossed the limit in other samples [20].

Magnesium Hazard (MH)

MH in waters near agricultural activity areas ranges from 14.68 to 63.92 during pre monsoon season. In samples 6/Ag, 7/Ag and 10/Ag, it crossed the guideline value. During post monsoon season MH ranges from 21.23 to 73.85. In samples 3/Ag, 6/Ag and 9/Ag, MH crossed the permissible limit (50) [21]. MH near aquaculture activity areas ranges from 25.96 to 72.39 during pre monsoon season. In samples 3/AQ, 5/AQ, 8/AQ, 10/AQ MH is within the guideline value. During post monsoon season it varies from 38.18 to 69.29me/l. In three samples 4/AQ, 7/AQ and 9/AQ it crossed the guideline value.

Kelly's Ratio (KR)

KR in water samples near agricultural activity areas during pre monsoon season ranges from 0.08 to 0.25. During post monsoon season it ranges from 0.32 to 0.39. All the values are within the permissible limit (1). KR in water samples near aquaculture activity areas during pre monsoon season ranges from 0.34 to 2.93. In samples 1/AQ, 3/AQ and 4/AQ it is within the guideline value and in remaining samples it crossed the permissible limit. During post monsoon season it ranges from 0.89 to 4.26. Except in two samples 1/AQ and 4/AQ in other samples KR exceeded the guideline value [22].

Permeability Index (PI)

PI ranges from 45.8 to 62.8 during pre monsoon season. During post monsoon season it ranges from 47.8 to 88.9. PI near aquaculture activity areas ranges from 50.8 to 98.9 during pre monsoon season. During post monsoon season it ranges from 68 to 93.8. All the values are within the guideline value of irrigation standards [23]. The mean PI of soils near agricultural areas during pre and post monsoon seasons was 129.79 and 59.99. In aquaculture areas the values were 116.3 and 83.59. In both agricultural and aquaculture areas during pre monsoon season the mean value of PI crossed the guideline value.

Conclusion

The assessment of irrigation water and soil quality in agricultural and aquaculture areas of the Konaseema region reveals significant spatial and seasonal variations in key irrigation parameters. Water in agricultural areas is largely suitable for irrigation, with %Na, SAR, KR, and PI values mostly within permissible limits. However, elevated RSC and Magnesium Hazard in some locations indicate early signs of alkalization and soil structural deterioration. In contrast, water samples from aquaculture zones exhibit higher concentrations of

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%Na, RSC, KR, and MH, especially during the post-monsoon season. This suggests that prolonged aquaculture activity and saline water intrusion may be contributing to increased sodicity and alkalinity hazards, posing risks to adjacent agricultural lands. Soil sample analysis confirms that while most parameters remain within acceptable ranges, higher PI and MH values during the pre-monsoon season indicate potential permeability issues and cation imbalance.

Overall, the study concludes that while irrigation water is generally suitable in agricultural regions, aquaculture-influenced waters require careful management. Adoption of integrated water management, periodic soil amendments (gypsum, organic matter), controlled aquaculture discharge, and continuous monitoring of irrigation parameters are essential to sustain soil fertility and agricultural productivity in the Konaseema region.

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