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Soil Salinity Levels Caused by Saltwater Intrusion in Coastal Paddy Areas of Sri Lanka

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Abstract

Rice is the staple food and main agricultural crop in Sri Lanka. Rice production is primarily concentrated in the dry zone of Sri Lanka, though it is also cultivated in the wet zone. The productivity of most of the paddy lands in the coastal zone of Sri Lanka has declined over the years due to salinization caused by tidal waves and sea water intrusion, both of which are linked to climate change-induced sea level rise. This study primarily focused on salinity-related issues in the coastal paddy fields due to saltwater intrusion. It was conducted in seven selected coastal districts of Sri Lanka, encompassing both the dry zone and wet zone of Sri Lanka. The dry zone districts included Jaffna and Mannar, which are located in the north of Sri Lanka, and the wet zone districts included Gampaha, Colombo, and Kalutara districts, located in the west of Sri Lanka, and Galle and Matara districts, located in the south of Sri Lanka. The soil samples were collected periodically during the dry season, between August to October in the year 2019 and checked for salinity levels using electrical conductivity measurements of 1:5 soil to water extract (EC 1:5). As per the results, the salinity levels within the study areas ranged from 0.105 dS m^{-1} (non-saline) to 4.002 dS m^{-1} (highly saline with significant impacts on paddy growth and yields). Over 70 percent of the sites in the wet zone districts and all the sites in the dry zone districts are found to be highly saline. According to the study, more than 50% of the land extent along the coastline of the study districts is severely affected by salinity. Due to prevailing high salinity conditions, the productivity of these lands is heavily affected, with the high salinity stress in their early growth stages severely affecting the survival rate. Therefore, it is recommended that urgent, long-term precautionary action be taken for the optimal control of salinity in the coastal paddy fields before it gets worse with time.

Key words: Saltwater intrusion, Soil salinity, Paddy cultivation, Electrical conductivity

Introduction

Rice (*Oryza sativa*) is the main agricultural crop in Sri Lanka. The rice production has significantly fluctuated during recent years. For instance, the rice production in Sri Lanka experienced a significant decline between the 2020-2021 and 2021-2022 marketing years. Specifically, rough rice production decreased from 3.89 million metric tons in 2020-2021 to 2.57 million metric tons in 2021-2022, marking a reduction of approximately 1.32 million metric tons (U.S. Department of Agriculture Foreign Agricultural Service, 2022). The ever-growing population of Sri Lanka demands an increase in rice production. However, the available land resources within the country are not sufficient to fulfill the country's needs. Unexpected weather patterns due to climate change and land degradation have also directly affected rice production (Jayasooriya, 2022; Samaraweera *et al.,* 2024; Samarasinghe *et al.,* 2025).

Salinity is considered one of the most crucial physical factors affecting the production of rice (Nejad *et al.,* 2010). At present, among the abiotic stresses that disturb the productivity of paddy cultivation in paddy-growing countries all around the globe, salinity can be determined as the second most important and widespread soil problem after drought (Gregorio, 1997). Agriculture, being the largest consumer of water, has been identified as both a contributor and the most vulnerable sector to saltwater intrusion. In the coastal areas, the salinity levels go up due to salt accumulation through tidal waves and saltwater intrusion

(Pradheeban *et al.,* 2015). These are the consequences of the climate change-induced rise in sea level (UNDP, 2012).

In Sri Lanka, the productivity of most of the paddy fields has decreased with time, mainly due to salinity-related issues. It has been found that about 100,000 ha of paddy lands are affected by salinity (UNDP, 2012). In the wet zone, salinization happens in the low-lying coastal areas mainly due to saltwater intrusion (Steele *et al.,* 1997). During the spring tide, the paddy fields are inundated by the tides of 45 – 60 cm. And during neap it is 10 – 25 cm. Saltwater comes onto land up to 50 cm above mean sea level during the dry season. Owing to this problem, the coastal paddy lands are subjected to salinization annually (Panabokke, 1977). Climate change would enhance the sea level rise and extreme weather events, including storm surges, and would contribute to increasing the salinity problem in coastal paddy fields of the country in the future (Sirisena *et al.,* 2010). It has been found that around 70 percent of the coastal paddy lands out of the total annual extent of rice-cultivated in Sri Lanka are affected by salinity (De Costa *et al.,* 2012). Coastal Salinity is present in districts such as Mannar, Puttalam, Jaffna, Trincomalee, Ampara, Hambantota, Galle, Kalutara, and Matara (Senanayake *et al.,* 2017). Paddy lands along the rivers and estuaries have been abandoned due to salinization. Unmaintained irrigation canals in coastal areas can be contaminated by saline water from estuaries, leading to the spread of salts with the irrigation water. This phenomenon, often referred to as saltwater intrusion, occurs when saline water from the sea moves into the freshwater sources, including irrigation canals, due to the interaction between tides, freshwater runoff, and estuarine dynamics (Berger *et al.,* 2009).

In Sri Lanka, very few systematic studies about the problem of soil salinization in the wet zone have been conducted. No systematic record is available on the salinity-affected total land extent or any data that indicate the trend of salinity change with time. Most of the available information is based on sporadic surveys. Since no adequate amount of research has been conducted on this area, the severity and the true facts about the problem in terms of economic and environmental aspects are mostly unknown (FAO/UNESCO, 1975). Jaffna and Mannar districts, both of which belong to the dry zone of Sri Lanka, have been identified as coastal salinity-affected districts in the Northern Province. Due to the geology (Miocene limestone aquifers), these districts are particularly vulnerable to salinity problems. Saltwater intrusion due to sea level rise induced by climate change could further aggravate the problem. Therefore, there has been an urgent requirement to do a proper assessment of the salinity affected lands in the paddy cultivating regions of the above districts to determine and evaluate the levels of salinity in those affected areas to find solutions to enhance the productivity of salt-affected paddy lands and improve the production of rice in the country to meet the increasing demand. This study was conducted to fulfill the above needs, and we hope that the salinity levels reported through this study will be useful in future policy decision-making in the country and the region.

The current study mainly focuses on the salinity levels and the impacts of saltwater intrusion on salinity levels in the identified coastal paddy fields in the Colombo, Gampaha, Kalutara, Galle, Matara (Wet Zone), Jaffna, and Mannar Districts (Dry Zone) of Sri Lanka. Further, it tries to highlight the significance of adaptive strategies such as good agricultural and land use practices, improved water management, construction of salinity barriers and coastal defense, etc., which assist farmers in facing the changed salinity levels in their paddy fields due to saltwater intrusion. The study findings will help farmers to choose more salt-tolerant paddy varieties for the identified salt-affected areas, do better tillage practices, and water management to enhance the crop survival rate. Department of Agriculture can take precautionary measures and create better awareness among the farmers on the need and strategies for proper salinity management in the identified salt-affected areas. Therefore, the present study was carried out under different objectives such as, 1) To identify and measure the salinity levels in selected costal paddy areas in Sri Lanka; 2) To categorize the identified areas as low, medium and high risk to salinity; and 3) To promote awareness among farmers about soil salinity to take precautionary measures to overcome salinity related issues with the help of Department of Agriculture, Sri Lanka.

Materials and Methods

Study sites and soil sampling

Eighty-five sites from seven districts in the wet and dry zones, which are known to be affected by salinity, were selected for the study, with the aid of the agricultural extension officers of the respective areas. These sites were selected based on the advice of the officers of the Department of Agriculture in Sri Lanka, who have identified these areas that might be affected by salinity with their experience over time, grounded in crop failures, soil conditions, etc. A systematic study has not been undertaken so far to find out the salinity levels of the fields and to find the total extent of the lands affected by high salinity levels. Therefore, soil samples were collected from the relevant sites during the dry season, from August to October. The zig-zag soil sampling method was used to collect soil samples, and areas where fertilizer had been applied were omitted when collecting the samples. Composite samples were collected up to a depth of 15 cm by traveling in a zig-zag pattern. Each composite sample consisted of 16 sub-samples spread evenly across the field, which were mixed before analysis. One composite was collected per twenty acres.

Soil salinity measurement

Salinity levels were determined by measuring electrical conductivity (EC). EC was measured by a portable Combined logging with GLP EC/TSD/NaCl/Temp bench meter (Model Mi170, Hungary). The instrument is calibrated with a standard solution before every measurement. Table 1 shows salinity ranking based on the measured EC (dS m^{-1}) using a 1:5 soil to water extract (EC 1:5). The soil samples were kept for a few weeks to air dry. Then the soil samples were ground and sieved with a 2 mm sieve. Then, 10g of the sample was added to 50 mL of distilled water. The suspension was stirred for 30 minutes using a glass rod, and the solution was allowed to stand for 1 hour. After 1 hour, the electrical conductivity of the sample was measured using a calibrated Electrical conductivity meter.

Table 1. Salinity ranking based on measured EC (dS m^{-1}) (Source: Agriculture and Food Division, 2023)

Electrical conductivity (dS m^{-1})*	Effect
< 0.15	Non-Saline
0.16 – 0.30	Slightly Saline
0.31 – 0.60	Moderately saline
0.61 – 1.20	Very saline
>1.20	Highly saline

*1:5 soil to water extract.

Farmer practices/adaptation measures

A purposive sampling method was carried out to select the farmers from salinity-affected areas. A total of 125 farmers with direct experience in rice cultivation in saline conditions were interviewed to gather the relevant data. In the identification of these farmers, support was taken from the respective extension officers of the Department of Agriculture in Sri Lanka and the local Farmer committees. Socio-economic data of the farmers and other required data for this study were collected using a mixed-methods approach. A structured questionnaire was developed to gather quantitative data on farmers' socioeconomic characteristics and adaptation measures. Furthermore, semi-structured interviews were conducted to collect qualitative data on farmers' perceptions, experiences, and detailed explanations of adaptive techniques they use locally to combat this issue. Adaptation measures used by farmers included the use of salt-tolerant rice varieties, short-duration rice varieties, traditional rice varieties, application of organic matter like compost, green manure, application of chemicals like gypsum, improved water and irrigation management techniques, and farming practices like deep ploughing, transplanting of seedlings instead of direct seeding, and scheduling cultivation dates to harvest before peak salinity periods. The distribution of the study districts is given in Fig.1.

Results

According to the findings, the majority of the identified areas with saline soils in the above

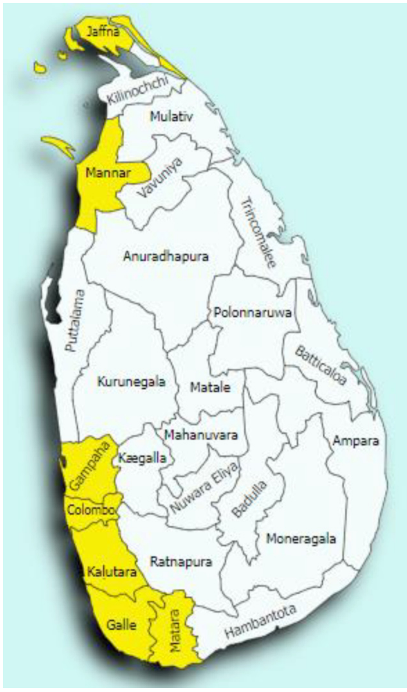

Fig. 1 Map showing the locations of the districts selected for the current study

districts are found to be highly saline (Table 2). The salinity-affected paddy cultivating areas in Jaffna and Mannar districts are given in Fig. 2 and 3, respectively. Over 70 percent of the sites in the wet zone districts and all the sites in the dry zone districts are found to be highly saline with EC 1:5 ranging from 1.3 to 4.0 dS m^{-1} (Table 2). According to the study, more than 50% of the land extent along the coastline of the study districts is severely affected by salinity.

Farmers' perception and practices used in adaptation to salinity intrusion

As mentioned in the methodology section, insights regarding farmer perception and practices used in adaptation to salinity intrusion were gathered through a questionnaire and semi-structured interviews. Table 3 provides information and the level of adoption of the different adaptive techniques used by farmers in response to salinity intrusion. As per the findings, the highly practiced adaptive measure among farmers across all study sites is the addition of organic matter. It is popular among farmers due to the widespread availability of resources and its effectiveness in reducing the salinity impact. The relatively low adoption rate, with only 30 percent of farmers using salt-tolerant paddy varieties, could be attributed to limited availability of seed, lower yield, lack of awareness and technical guidance, and higher cost. Agronomic measures like deep ploughing and deepening of canals, and building soil banks were adopted by only 25% of the farmers. On the other hand, chemical amendments in the form of gypsum application were the least adopted (5%) adaptation measure, due to constrained on availability, affordability, and knowledge gaps. The findings from this study highlight the higher dependence and preference among farmers for agronomic and biological approaches over chemical inputs in managing soil salinity. This may be due to a lack of awareness, inadequate technical knowledge,

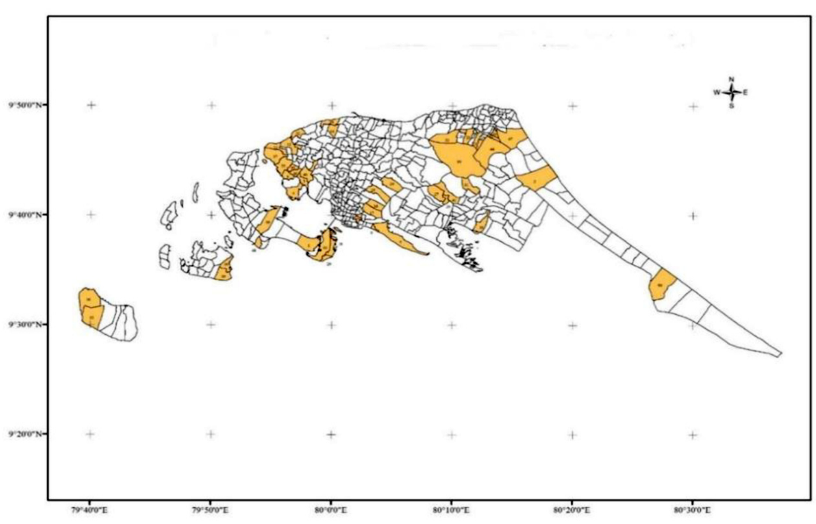

Fig. 2 Salinity levels of identified salinity-affected paddy areas in Jaffna district

Table 2. Average soil EC (dS m^{-1}) levels of different sites during the study period

District	Site	Average electrical conductivity (dS m^{-1})	Effect
Matara	Godagama 1	0.669	Very saline
	Godagama 2	1.296	Highly saline
	Kaburugamuwa	0.873	Very saline
	Dickwella	0.945	Very saline
Gampaha	Alawathupitiya	0.753	Very saline
	Batahira Heenatiyana	0.614	Very saline
Colombo	Kahapola	2.369	Highly saline
Kalutara	Urumulla	1.828	Highly saline
	Paadagoda	0.668	Very saline
	Munamalwaththa Yaaya	0.575	Moderately saline
	Tikiri Yaaya	1.008	Very saline
Galle	Okanda Yaaya	0.929	Very saline
	Thundawa	1.144	Very saline
	Gonapinuwala	0.979	Very saline
	Bogaha Yaaya	0.483	Moderately saline
	Weragoda	0.105	Non saline
	Ahungalla	0.178	Slightly saline
	Mahapalana	0.479	Moderately saline
Mannar	Marichchukaddi	1.559	Highly saline
	Periyanavatkulam	1.512	Highly saline
	Kallikattaikadu	1.603	Highly saline
	Pallamadhu	1.517	Highly saline
	Pappamoddai	1.543	Highly saline
	Nagathalvu	1.489	Highly saline
	Naruvilikulam	1.601	Highly saline
	Arippu East	1.604	Highly saline
	Arippu West	1.559	Highly saline
	Silavaththurai	1.633	Highly saline
	Potkerny	1.615	Highly saline
	Kokkupadayan	1.563	Highly saline
	Umanakiri	1.616	Highly saline
Jaffna	Allaipiddy	2.216	Highly saline
	Ampan	1.638	Highly saline
	Arali North	1.721	Highly saline
	Arali South	1.564	Highly saline
	Arali West	2.133	Highly saline
	Ariyalai Centre West	1.892	Highly saline
	Ariyalai East	1.681	Highly saline
	Ariyalai North West	1.565	Highly saline
	Ariyalai South West	1.891	Highly saline
	Chankanai East	2.720	Highly saline
	Chulipuram East	3.103	Highly saline
	Chulipuram West	2.454	Highly saline
	Iilavalai North	2.785	Highly saline
	Iilavalai North West	2.713	Highly saline
	Irupalai East	3.015	Highly saline
	Irupalai South	3.273	Highly saline
	Kachchai	3.742	Highly saline
	Kapputhu	2.893	Highly saline
	Karanavai	2.342	Highly saline

Contd...

District	Site	Average electrical conductivity (dS m^{-1})	Effect
Jaffna	Karanavai East	3.212	Highly saline
	Karanavai West	1.567	Highly saline
	Karaveddy Centre	2.314	Highly saline
	Karaveddy East	2.306	Highly saline
	Kopay Centre	1.547	Highly saline
	Madduvil East	2.145	Highly saline
	Madduvil North	3.453	Highly saline
	Mandaitivu East	3.213	Highly saline
	Mandaitivu South	3.120	Highly saline
	Mandaitivu West	3.031	Highly saline
	Manthuvil North	1.672	Highly saline
	Mathagal West	2.932	Highly saline
	Moolai	3.073	Highly saline
	Neervely South	1.574	Highly saline
	Panippulam	2.073	Highly saline
	Part of Delft West	3.432	Highly saline
	Ponnalai	2.412	Highly saline
	Pungudutivu East	2.922	Highly saline
	Pungudutivu South-East	3.821	Highly saline
	Sangarathai	2.371	Highly saline
	Sarasalai South	1.971	Highly saline
	Thunnalai East	2.744	Highly saline
	Thunnalai North	2.510	Highly saline
	Thunnalai South	2.144	Highly saline
	Vaddukkoddai South	1.670	Highly saline
	Vaddukkoddai South-West	2.017	Highly saline
	Vallipuram	3.128	Highly saline
	Velanai East	3.473	Highly saline
	Velanai North	4.002	Highly saline
	Vethilaikerny	3.642	Highly saline

Table 3. The different adaptive techniques used by farmers in response to salinity intrusion

Adaptive measures	Percentage of farmers applying
Application of organic matter	70%
Use of salt tolerant paddy varieties	30%
Farming practicesi.e. – Deepening of canals, deep ploughing	25%
Application of chemicals	5%

financial constraints, and a lack of available resources. Therefore, it is important that the local authorities take action to educate and empower farmers to adopt effective integrated salinity management strategies.

Discussion

Salinization has been identified as a limiting factor for local rice production in irrigated farming systems in the north-central and eastern plains, and in the rain-fed systems in the west coast and the Jaffna peninsula (Dasanayaka *et al.,* 2023). Recent research indicates that salinity can decrease rice production up to 29.3% compared to non-saline conditions (Oelviani *et al.,* 2024). In most of the areas, the salinity inspection has been carried out only based on the visual symptoms such as the loss of yield, leaves with white tips, leaves with pale, yellow, or yellow white patches, patchy field growth, and stressed or dying trees.

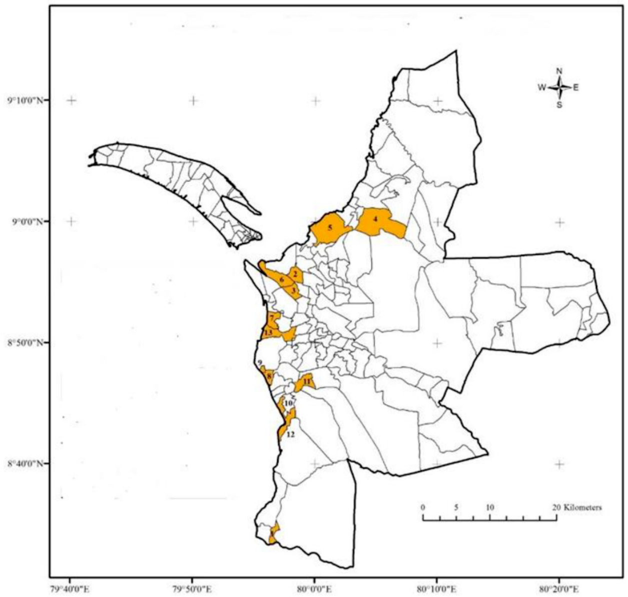

Fig. 3 Salinity levels of identified salinity-affected paddy areas in Mannar District

These symptoms can also be caused by other factors such as nutrient deficiency or pest attacks. Therefore, accurate measurement of soil salinity level is essential to effectively quantify its effect on crop production.

This study involved the collection of soil samples from Sri Lanka's salinity-affected paddy fields of selected coastal districts under the guidance of the officials of the Department of Agriculture. Having worked with local farmers for many years, their extensive knowledge was of great assistance in identifying the most salinity-affected areas. It was evident that most of the fields in these areas have been left uncultivated over the years due to the salinity problem. Despite this, systematic salinity assessments or management strategies aimed at restoring these areas have not been forthcoming. Hence, this study is particularly important given the unavailability of records of salinity measurements or the areal coverage of abandoned paddy fields, which makes in-depth research on salinity problems difficult. The findings in this research confirm that most of the regions surveyed have high salinity values, as expressed by EC 1:5 readings exceeding 1.2 dS m^{-1}. The implication is that there is a high likelihood of rising salinity, especially given extended dry seasons and increased temperatures related to diverse effects of climate change (Harper *et al.,* 2021). Considering the time variability of salinity, continuous monitoring is necessary to establish a complete database upon which the formulation of efficient remediation measures can be achieved.

Salinity, in most cases at its peak in dry months due to greater intrusion of saltwater. High rainfall and heavy irrigation remove salts from within the root zone and contribute to reducing the salinity in the fields, as salinity gets flushed away with the water. The interface of the saline wedge that is formed below the freshwater with the saltwater intrusion moves inland during the dry periods, when the freshwater supply decreases. Therefore, more saltwater moves more inland via rivers (Azevedo, 2018). The sea level rise and the unbalanced precipitation and evapotranspiration ratio affect the saltwater intrusion. In addition, weather events such as floods, storm surges, and hurricanes can have a triggering effect on the saltwater intrusion due to extremely high pressure caused. The latter will cause more saltwater to intrude towards land and cause salt contamination in soil within a very short time (Duan, 2016). It has been found that the tides also contribute to the seawater intrusion into land (Kuan *et al.,* 2012).

Another primary objective of this study was to understand the perception and adaptive techniques used by farmers to cope with the salinity changes in paddy fields. Through surveys, it was revealed that farmers employ organic amendments like compost, paddy husks, leaves of *Gliricidia sepium*, cow dung, and straw for mitigating salinity effects. Application of Gypsum effectively replaced exchangeable sodium with calcium, facilitating sodium leaching and enhancing soil aggregation (Zhao *et al.,* 2022). During the farmer interviews, it was found that most of them have applied gypsum without proper technical knowledge. Nevertheless, the deficiency in technical expertise concerning the application of gypsum highlights the necessity for extension services to assist in its proper utilization. Approximately 25% of the farmers adopt various methods to combat salinity, such as constructing soil bunds, placing logs in streams to block saline water, and maintenance of irrigation canals. These efforts are, however, generally insufficient due to a shortage of capital, poor cooperation, and a lack of technical expertise. Sometimes bunds fail to prevent saltwater ingress due to seepage around the structures.

Other practices adopted are transplanting of seedlings instead of direct seeding to prevent salinity-induced germination inhibition, and scheduling cultivation dates to harvest before peak salinity periods. Short-duration rice varieties are also attempted by farmers to coincide with favorable climatic windows. Although salt-tolerant varieties of rice exist, their adoption is not widespread because of perceptions of lower yields, limited variety options, and a lack of availability of seeds. This highlights the necessity for breeding programs that will create high-yielding, salt-tolerant rice varieties and make these available to farmers. Notably, farmers cultivate certain traditional rice varieties that are valued for their medicinal and nutritional qualities. Traditional varieties such as Pokkali, Rathdel, and Kuruluthuda are tolerant to salinity (De Costa *et al.,* 2012). The perception of salinity tolerance within traditional varieties, however, is variable, and there is a need for more research to validate and promote acceptable varieties for salt-affected areas.

In summary, the present research necessitates the urgent action for large-scale surveys of salinity, ongoing monitoring, and formulation of adaptive strategies according to focused contexts to alleviate the negative impacts of salinization on coastal paddy lands in Sri Lanka. Collaborative efforts among farmers, researchers, and policymakers must receive high priority to build resilience and promote sustainable rice cultivation amidst increasing threats posed by salinity.

Conclusions

The main objective of the current research was to evaluate the degree of soil salinity and to measure the effects of saltwater intrusion on some selected coastal paddy fields in selected coastal districts of Sri Lanka. Besides, the research focused on creating a preliminary dataset on coastal paddy field soil salinity levels in these areas, thereby filling an enormous gap in the current literature because no extensive data from past research is present. The findings of the salinity levels in terms of electrical conductivity of the selected areas confirm that most of the areas that were used in this study are highly saline. If no action is taken to solve the problem, these conditions can result in progressive yield reductions and further deterioration of agricultural lands. The study shows that farmers have utilized a range of adaptive strategies such as application of organic matter like compost, application of chemicals like gypsum, use of salt tolerant varieties, and use of different farming practices like deepening of canals, deep ploughing, building of salt bunds, and irrigation with fresh water from inland reservoirs or wells to overcome the salinity issue. This study presents important empirical evidence emphasizing the severity of saltwater intrusion and its impacts on paddy cultivation and the livelihood of farmers in the coastal areas in Sri Lanka. The findings of the study lay the scientific basis for developing focused mitigation and adaptation strategies and highlight the necessity for more detailed, region-specific studies to combat this escalating environmental issue in coastal areas of Sri Lanka.

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