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Assessing soil pollution vulnerability in agricultural systems: Insights from farmer and stakeholder perceptions

Lakshmi Muralikrishna and Guntukogula Pattabhi Sandeep

Ph.D. Scholars, Department of Agricultural Sciences, GKVK, UAS, Bangalore, Karnataka, India

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Corresponding Author: Lakshmi Muralikrishna

Abstract

Soil is an essential and dynamic component of the ecosystem, influencing crop productivity, food safety, and human health. However, rapid urbanization, industrialization, and agricultural practices have significantly contributed to soil pollution, particularly in the form of metals and other pollutants. This study examines the vulnerability of agricultural soils to pollution, focusing on the perceptions of farmers and stakeholders in the Thrissur and Palakkad districts of Kerala, India. The primary objective is to assess how different agricultural systems—rice-based, banana-based, and vegetable-based—are affected by various pollution sources. The research was conducted in six panchayaths across the two districts, with data collected from 90 farmers and 30 other stakeholders through structured interviews. A total of 120 participants provided insights into pollution sources such as the use of chemical fertilizers, pesticides, sewage, and industrial waste. Vulnerability indices were calculated based on perceived pollution levels, categorizing the regions into high, moderate, and low pollution zones. Key findings reveal that Puzhakkal, a rice-based system, exhibited the highest soil pollution vulnerability, mainly due to slash-and-burn agriculture and improper waste disposal. Water pollution caused by garbage and plastic waste was a significant concern across all systems. The banana and vegetable systems in Alathur and Puthur also showed moderate to high pollution levels from sewage and pesticide use. These findings underscore the need for targeted interventions, such as promoting sustainable farming practices, waste management, and pollution monitoring to mitigate soil degradation. The implications of this study are crucial for policy makers and agricultural extension programs, offering insights into localized pollution risks and potential strategies to improve soil health and agricultural productivity in Kerala.

Keywords: Soil pollution, Agricultural systems, Farmer perceptions, Sustainable practices

Introduction

Soil, a vital and dynamic component of our ecosystem, plays a fundamental role in sustaining human life and promoting social development. Its quality directly affects food safety, crop productivity, and ultimately human health. However, the rapid urbanization and industrialization of recent decades have led to significant soil and environmental pollution. This pollution is increasingly recognized as a major environmental issue in many regions, including Iran (Mishra *et al.*, 2016; Khan *et al.*, 2021) ^[5, 4]. Among the various pollutants affecting soil, metal(loid)s have garnered particular concern. These inorganic elements, with densities greater than 5 g/cm³, include arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, uranium, and zinc (Sezgin *et al.*, 2023) ^[9]. While metal(loid)s are naturally present in soil at low levels, human activities such as industrial emissions, mining operations, and the use of chemical fertilizers and pesticides can lead to their accumulation and high levels of contamination (Wuana & Okieimen, 2011; Rashid *et al.*, 2023) ^[12, 8]. Soil pollution from metal(loid)s can arise from various sources, including the discharge of industrial wastes, use of leaded gasoline, application of chemical fertilizers and pesticides, wastewater irrigation, and coal combustion (Sonon & Gaskin, 2009; Zhuang *et al.*, 2020) ^[11, 14].

Notably, phosphorus fertilizers often contain high concentrations of metals such as cadmium, copper, and lead, while livestock manures and wastewater sludge can also contribute to metal(loid) contamination (Zarcinas *et al.*, 2004) ^[13].

The presence of elevated levels of metal(loid)s in agricultural soils poses significant risks to crop health and productivity. These pollutants can adversely affect soil quality, leading to reduced crop yields and compromised food safety. Metal(loid)s are persistent and non-degradable in the environment, and their accumulation in soil can result in high uptake by plants, which then enter the food chain, potentially impacting human health (Huang *et al.*, 2019; Peirovi-Minaee *et al.*, 2023) ^[3, 7]. Several metal(loid)s, such as lead, cadmium, and mercury, are non-essential and toxic to human health. Prolonged exposure to these elements can lead to severe health issues, including cancers, neurological disorders, and developmental problems in children (Papillomaviruses, 2011; Singh & Kalamdhad, 2011) ^[6, 10]. Consequently, the contamination of soil with metal(loid)s is a significant concern for both developed and developing nations, necessitating vigilant monitoring and remediation efforts to prevent further soil degradation (Alturiqi *et al.*, 2020; Ahmad *et al.*, 2021) ^[2, 1]. In this scenario, it is important to study the vulnerability of farmer perceptions.

This study is crucial for assessing farmers' vulnerability to soil pollution in Thrissur and Palakkad, Kerala. It provides insights into the impact of environmental pollution on agriculture, highlights farmers' awareness and adaptive capacities, and informs targeted interventions to mitigate pollution effects and enhance farm resilience.

Methodology

Thrissur and Palakkad districts were chosen for this study due to their high concentration of farmers and their significant role in Kerala's production of rice, bananas, and vegetables. The research focuses on these major crops, selecting Puzhakkal Kole Panchayath, in Thrissur and Alathur in Palakkad for rice systems. For vegetables and bananas, the study includes Puthur and Pananchery Panchayaths for bananas and Nadathara and Madakkathara Panchayaths for vegetables, all in Thrissur. Thirty farmers from each Panchayath (15 per Panchayath) and 30 other stakeholders, including administrators, development personnel, local governance members, general public, and NGOs, were interviewed. The total sample size is 120, with farmers randomly selected in consultation with local agricultural officers. This approach ensures a comprehensive analysis of soil pollution impacts and stakeholder perspectives in these key agricultural regions.

Results

The categorization of panchayaths based on soil pollution vulnerability is based on the perceived statements collected from 15 farmers and 5 stakeholders from each panchayath using mean and standard deviation, providing insights into the local perspectives on environmental degradation across different agricultural systems. Table 1 results indicates that the the rice-based agricultural system of Puzhakkal, participants indicated moderate vulnerability to most pollution sources, with the highest concern being slash and burn agricultural practices (SP7) having a pollution index of 86.67. This was followed by concerns over water pollution due to garbage and plastic waste (SP8) with an index of 82.67. The use of chemical fertilizers (SP1) and sewage material (SP3) also contributed moderately to soil pollution based on their perceptions. For the banana-based agricultural system of Alathur, the farmers and stakeholders perceived moderate vulnerability to most pollution sources, with a particularly high concern for water pollution caused by garbage and plastic (SP8), which had an index of 77.33. Indiscriminate pesticide use (SP4) and sewage pollution (SP3) were other significant concerns, while soil-borne pathogens (SP2) were perceived as contributing less to soil pollution with a low index of 49.33.

Table 1: Categorization of panchayaths according to vulnerability of spoil pollution statements (n =120)

Sl. No.	Statements	Rice based agricultural				Banana-based agricultural system				Vegetable-based agricultural system			
		Puzhakkal (n ₁ =20)		Alathur (n ₂ =20)		Puthur (n ₃ =20)		Pananchery (n ₄ =20)		Nadathara (n ₅ =20)		Madakkathara (n ₆ =20)	
		Index	Category	Index	Category	Index	Category	Index	Category	Index	Category	Index	Category
1	SP1	69.33	Moderate	68.00	Moderate	72.00	Moderate	66.66	Moderate	69.33	Moderate	58.66	Moderate
2	SP2	53.33	Low	49.33	Low	42.67	Low	46.66	Low	49.33	Low	49.33	Low
3	SP3	70.67	Moderate	70.67	Moderate	76.00	Moderate	70.66	High	74.66	High	62.66	Moderate
4	SP4	80.00	Moderate	66.67	Moderate	64.00	Moderate	65.33	Moderate	53.33	Moderate	58.66	Moderate
5	SP5	69.33	Moderate	65.33	Moderate	76.00	Moderate	68.00	Moderate	73.33	High	66.66	Moderate
6	SP6	62.67	Moderate	53.33	Low	58.67	Moderate	49.33	Low	48.00	Low	44.00	Low
7	SP7	86.67	High	66.67	Moderate	76.00	Moderate	53.33	Moderate	62.66	Moderate	62.66	Moderate
8	SP8	82.67	High	77.33	High	52.00	Moderate	73.33	High	65.33	Moderate	73.33	High
9	SP9	65.33	Moderate	64.00	Moderate	42.67	Low	46.66	Low	56.00	Moderate	64.00	Moderate

SP1: Soil is polluted due to excess use of chemical fertilizers, SP2: Soil is polluted by soil borne pathogens, SP3: Soil is polluted due to sewage material, SP4: Soil is polluted due to indiscriminate pesticide use, SP5: Soil is polluted due to industrial and urban waste, SP6: Soil is polluted due to use of herbicides, SP7: Soil is polluted due to slash and burn agriculture practice, SP8: Water is polluted due release of garbage/plastic to water bodies and SP9: Soil is polluted due to occurrence of heavy wind and flood

Table 2: Classification of the Panchayaths based on soil pollution (n=120)

Sl. No.	Panchayaths	Index	Extent of water pollution
1	Puzhakkal	71.11	High
2	Alathur	64.59	Moderate
3	Puthur	62.22	Moderate
4	Pananchery	60.00	Low
5	Nadathara	61.33	Moderate
6	Madakkathara	60.00	Low

In Puthur, where vegetable-based agriculture dominates, the participants expressed the highest concern over sewage material pollution (SP3), with a high index of 76.00. Additionally, urban and industrial waste (SP5) and slash and burn practices (SP7) were perceived as moderate pollution contributors. However, soil-borne pathogens (SP2) and the effects of heavy winds and floods (SP9) were seen as lower threats, with indices of around 42.67. In Pananchery,

moderate vulnerability to pollution was reported, with sewage material (SP3) and water pollution (SP8) being the most significant concerns, indicated by indices of 70.66 and 73.33, respectively. The use of chemical fertilizers (SP1) and industrial waste (SP5) were also considered moderate sources of pollution, while herbicide use (SP6) and soil-borne pathogens (SP2) were perceived to have a lower impact. The participants from Nadathara indicated high concern for soil pollution caused by sewage material (SP3) and industrial waste (SP5), with high vulnerability indices of 74.66 and 73.33. Other sources like pesticide use (SP4) and water pollution (SP8) were perceived as moderate threats to soil health. In contrast, Madakkathara showed moderate levels of pollution for most sources, but low concern for herbicide use (SP6) and pathogens (SP2), with indices of 44.00 and 49.33, respectively.

Table 2 explains the overall perceived soil pollution index of six panchayat's. Puzhakkal was observed as having the

highest level of soil pollution with an index of 71.11 perceived by farmers and stakeholders, classified as high. The participants from Alathur (64.59), Puthur (62.22), and Nadathara (61.33) reported moderate levels of perceived soil pollution. In contrast, Pananchery and Madakkathara were classified as having low levels of pollution, each with an index of 60.00.

Discussion

The study's findings, derived from the perceptions of farmers and stakeholders, offer important insights into the vulnerability of soil to pollution across different agricultural systems. As an agricultural extension expert, these results provide a basis for targeted interventions aimed at mitigating soil degradation and enhancing environmental sustainability in the panchayaths. In Puzhakkal's rice-based agricultural system, the highest concern was over slash and burn agriculture (SP7), which had a significant pollution index (86.67). This traditional practice can lead to loss of soil nutrients and increased erosion, highlighting the need for educating farmers about sustainable alternatives. The high concern for water pollution caused by plastic and garbage waste (SP8) also points to improper waste management practices. Extension efforts could focus on promoting better waste disposal systems and introducing organic farming practices to reduce reliance on chemical fertilizers (SP1), which were also seen as moderate contributors to soil pollution.

In Alathur's banana-based system, water pollution (SP8) due to garbage release into water bodies emerged as the primary concern, with an index of 77.33. This indicates the need for water conservation measures and proper garbage management strategies. Pesticide use (SP4) and sewage material (SP3) also contributed significantly, suggesting that extension programs should prioritize the adoption of integrated pest and waste management techniques to minimize pollution risks. For Puthur's vegetable-based agriculture, sewage pollution (SP3) was the most pressing issue (index 76.00), indicating a significant overlap between urban waste and agricultural areas. This calls for stronger policy support and education on sewage treatment and composting to prevent contamination. Similarly, Pananchery and Nadathara face high risks from sewage and industrial waste pollution (SP3 and SP5), with indices exceeding 70. Stakeholders here should be engaged in discussions about waste reduction technologies and the environmental impact of industrial pollution. Madakkathara exhibited low concern for certain pollutants, such as herbicide use (SP6), but moderate levels for other sources. This suggests that although pollution levels are not critical, proactive extension efforts focusing on sustainable land use and reducing reliance on chemical inputs are still crucial to preventing future degradation.

Conclusion

This study provides a comprehensive understanding of soil pollution vulnerability in selected panchayaths of Thrissur and Palakkad, Kerala, based on the perceptions of farmers and stakeholders. The findings indicate varying levels of soil pollution concerns across different agricultural systems, with rice-based, banana-based, and vegetable-based systems showing distinct vulnerabilities. Key pollutants include

sewage material, industrial waste, pesticides, and improper waste disposal. The highest pollution index was observed in Puzhakkal, primarily due to slash and burn agriculture and waste management issues. The study highlights the urgent need for targeted extension programs focusing on sustainable agricultural practices, waste management, and pollution mitigation techniques. By addressing these concerns, farmers can adopt environmentally sustainable practices that improve soil health and productivity, ultimately benefiting both the environment and local communities. These results also call for stronger policy frameworks to support pollution monitoring and the implementation of adaptive measures.

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