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Preliminary assessment of soil quality and heavy-metal contamination in agricultural lands near Orathupalayam Dam, Tamil Nadu, India

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ABSTRACT

Soil degradation by imbalanced nutrient levels and heavy metal contamination poses a significant threat to agricultural productivity and ecosystem health. The physicochemical parameters, heavy metal concentrations and the pollution indices of the soil samples from the contaminated agricultural land near Orathupalayam Dam, Tiruppur, Tamil Nadu were analysed using standard procedures. The soils were alkaline, with low organic carbon and manganese but elevated macronutrients (N, P, K) and the concentrations of various heavy metals, i.e. Cd (1.35 ± 0.16 mg/kg), Cr (20.03 ± 1.07 mg/kg), Pb (14.45 ± 0.50 mg/kg), Ni (37.7 ± 1.15 mg/kg) and Zn (36.18 ± 2.26 mg/kg) were found. The average geo-accumulation index for Cd was 0.16 and for other metals, it was below 1; and the heavy metal pollution index exceeded 100 for all samples. Contamination factor for the heavy metals followed the order Cd > Ni > Zn > Cr > Pb, and all samples had pollution load index above 0.5. Codmium and Ni were identified as moderate-level pollutants, while Zn, Cr and Pb were the baseline pollutants. This study highlights the heavy metal pollution risks, emphasising the need for mitigation strategies and sustainable agricultural practices to reduce heavy metal contamination and improve soil health.

Keywords: Contamination factor, Geo-accumulation index, Heavy metal pollution index, Physico-chemical parameters, Pollution load index

Soil pollution is a significant environmental concern with profound implications on human health, ecosystem sustainability and agricultural productivity. Industrialisation, mining and improper waste disposal are major contributors to soil contamination, particularly through the accumulation of heavy metals (Adepoju *et al.* 2024). Heavy metals such as Cadmium (Cd), Chromium (Cr), Nickel (Ni), Lead (Pb) and Zinc (Zn) are of particular concern due to their persistence, toxicity and ability to accumulate in living organisms (Ahmadi Doabi *et al.* 2019, El-Araby *et al.* 2021).

The analysis of heavy metals in soils is critical for identifying contamination risks and developing mitigation strategies. Various indices, such as Geo-accumulation index, Heavy metal pollution index, Contamination factor and Pollution load index have been widely used to assess soil metal contamination and its ecological impacts (Xia *et al.* 2024).

Many studies in agricultural soils worldwide have documented similar contamination patterns. For instance, a study on heavy metal pollution in the farmland in Ilokun, Nigeria, highlighted significant levels of Pb, Ni and Zn, suggesting anthropogenic influences related to coal combustion, vehicle exhausts and automobile brakes (Oguntuase *et al.* 2024). Despite the global attention on heavy metal pollution in agricultural soils, there is a noticeable research gap in understanding its extent and impact in the agricultural soils of Orathupalayam village, located near the Orathupalayam Dam, Tiruppur, Tamil Nadu. The dam was primarily constructed to provide irrigation water for agriculture. However, the release of untreated effluents from nearby textile industries into the Noyyal river has severely polluted the water, adversely affecting agricultural productivity. The contamination has led to soil degradation, reduced crop yields, and significant economic losses for local farmers. Previous studies in the region have primarily focused on river water quality, but the assessment of soil contamination remains underexplored.

This study aimed to address the research gap by evaluating the soil quality and heavy metal contamination in agricultural fields near Orathupalayam Dam, Tiruppur, Tamil Nadu. The specific objectives are to, assess the physicochemical properties of agricultural soils, including *p*H, electrical conductivity, organic carbon and nutrient levels; quantify the concentration of heavy metals (Cd, Cr, Ni, Pb and Zn) in soil; examine the relationship between soil properties and heavy metal concentrations and; evaluate the level of soil pollution using established indices such

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as Igeo, HPI, Cf and PLI. The findings of this study will provide baseline data on soil quality and heavy metal contamination in the region, offering critical insights for sustainable agricultural practices and pollution mitigation strategies.

MATERIALS AND METHODS

Study area: The Orathupalayam Dam receives water from the Noyyal river, originating from the Velliangiri Hills of Tamil Nadu, flows through the Coimbatore, Tirupur and Erode districts, and serves as a vital water source for agricultural and domestic use. However, rapid industrialisation, particularly the growth of dyeing and bleaching units in Coimbatore and Tiruppur has led to severe pollution of the river. Untreated effluents from these industries have turned the Noyyal river into a dumping site, rendering its water unfit for irrigation and drinking (Jayakumar and Rajagopal 2020, Subramanian and Baskar 2022).

The pollution has not only degraded the water quality but also impacted soil health in the surrounding agricultural areas, leading to significant economic losses for farmers and threatening food security in the region. The study was carried out in agricultural lands near the Orathupalayam Dam, Tiruppur District (11.1087°N, 77.5398°E), Tamil Nadu. The samples were collected in October 2023 during the post-monsoon season. The region experiences a semi-arid climate with moderate rainfall, predominantly during the monsoon season. Agriculture in the area is heavily reliant on irrigation and the choice of crops is primarily maize, legumes and cattle fodder, and is influenced by water availability.

Soil sampling: All sampling tools were sterilised using 80% ethanol to prevent cross-contamination. Soil samples were collected using simple random sampling from the agricultural lands located within a 1 km radius of the Orathupalayam Dam. From each of the three agricultural lands, 20 sub-samples were collected. The sub-samples from each land were then homogenised to form one representative composite sample (Krishnamoorthy *et al.* 2021). Each sampling point was spaced at least 40 m apart and samples were collected from a depth of 15 cm using a sterilised auger. The soil samples were air-dried under shade to preserve soil properties. The samples were sieved through a 2 mm sieve and stored in sterile, labeled plastic bags at 4°C until further analysis (Kurian *et al.* 2024).

Physicochemical parameters: The physicochemical parameters of soil, i.e. colour, *p*H, electrical conductivity (EC), organic carbon (OC), nitrogen (N), potassium (K), phosphorus (P), Iron (Fe), Manganese (Mn) and copper (Cu) were thoroughly examined by standard methods (Table 1).

Heavy metal analysis of soil samples: The concentrations of heavy metals, including Cadmium (Cd), Chromium (Cr), Lead (Pb), Nickel (Ni) and Zinc (Zn) were determined using an Atomic Absorption Spectrophotometer (AAS). Calibration was performed using certified standard solutions of known concentrations for each element. Serial dilutions of the standards were prepared to generate a calibration curve for quantification. A blank correction was applied for background interference and to ensure the accuracy of the instruments. The concentrations of the heavy metals were quantified based on the calibration curve. Quality control measures were conducted to ensure accuracy and precision, including the analysis of certified reference materials and spike recovery tests. The instrument settings and furnace programmes for analysing heavy metals are summarised in Table 2.

Table 1 Physicochemical analysis of soil samples

Parameter	Instrument used/ Method followed	References
*p*H	*p*H meter	BIS (1987)
EC	Conductivity meter	BIS (2000)
OC	Titration method	BIS (1972)
Nitrogen	Kjeldahl method	BIS (1999)
Potassium	Flame photometer	BIS (1980)
Phosphorus	Titration method	BIS (1969)
Iron	Atomic absorption spectrophotometer	Soltanpour and Schwab (1977)
Manganese	Atomic absorption spectrophotometer	Soltanpour and Schwab (1977)
Copper	Atomic absorption spectrophotometer	Soltanpour and Schwab (1977)

EC, Electrical conductivity; OC, Organic carbon.

Pollution assessment of heavy metals: Assessing heavy metal pollution is crucial for preserving healthy ecosystems, implementing efficient water management practices and enforcing environmental policies. To evaluate the contamination levels, this study utilised several indices, including the Geo-accumulation Index (Igeo), Heavy Metal Pollution Index (HPI), Contamination Factor (CF) and Pollution Load Index (PLI). The formulae used and the pollution range categories are provided in Table 3.

Statistical analysis: All the statistical analysis was performed using SPSS software (version 20).

RESULTS AND DISCUSSION

Physicochemical properties of soil: The physicochemical properties of agricultural soil samples near the Orathupalayam Dam are presented in Table 4.

The soil *p*H, a critical factor influencing nutrient availability, ranged from 8.9–9, indicating strongly alkaline conditions. Such high alkalinity can adversely affect crop growth by inducing osmotic and specific ion stresses, as well as by limiting the absorption of essential nutrients (Huang *et al.* 2017, Okorie *et al.* 2024). The EC of the soil samples ranged from 0.50–0.70 dS/m which falls within the non-saline range (Boulding 2017). This suggests that the soil has a low concentration of dissolved salts, reducing the risk of salinity-related stress on crops. The OC content,

Table 2 Test method and instrument settings for heavy metal analysis by AAS

Metal	Test method	Concentration (mg/L)	Method detection limit (mg/kg)	Lamp current (mA)	Acetylene flow rate (L/min)	Wavelength (nm)	Slit (nm)
Cd	AOAC Method 999.11	10	1	4	2	228.8	0.5
Cr	AOAC Method 993.23	10	1	7	3.5	357.9	0.2
Pb	AOAC Method 999.11	10	1	10	2	217	1
Ni	AOAC Method 975.34	10	1	4	2	232	0.2
Zn	AOAC Official Method 973.01	10	0.5	5	2	213.9	1

Cd, Cadmium; Cr, Chromium; Ni, Nickel; Pb, Lead; Zn, Zinc; AAS, Atomic absorption spectrophotometer; AOAC, Association of Official Analytical Chemists.

Table 3 Various indices of pollution assessment and pollution categories

Index	Formula	Definition	Pollution level	Reference
Igeo	$Igeo = \log 2\left[\frac{Cn}{1.5Bn}\right]$	Cn, Measured concentration of heavy metal 1.5, Constant Bn, Background value	>5 (Extremely polluted) 4–5 (Strongly to extremely polluted) 3–4 (Strongly polluted) 2–3 (Moderately to strongly polluted) 1–2 (Moderately polluted) 0–1 (Unpolluted to moderately polluted) <0 (Practically unpolluted)	Muller (1969), Rahman *et al.* (2022)
HPI	$HPI = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi}$ $Wi = \frac{1}{Si}$ $Qi = \sum_{i=1}^{n} \frac{(Mi - Ii)}{Si - Ii} \times 100$	n, Number of parameters considered Wi, Unit weightage Mi, Monitored value of heavy metal Ii, Desirable maximum value Si, Standard value of the ith parameter.	<25 (Excellent) 25–50 (Good) 50–75 (Poor) 75–100 (Very poor) >100 (Unsuitable)	Mohan *et al.* (1996), Singh *et al.* (2019)
CF	$C_f^i = \frac{C^i}{C_n^i}$	C_f^i, Concentration of heavy metal C_n^i, Standard pre-industrial reference level	<1 (Low) 1<CF<3 (Moderate) 3<CF<6 (Considerable) CF<6 (Very high)	Hakanson (1980)
PLI	$PL = \sqrt[n]{CF1 \times CF2 \times CF3 \times \cdots \times CFn}$	CF, Contamination factor n, Quantity of metals in the study	0 (No pollution) 0–1 (Low degree of pollution) 1–2 (Moderate degree of pollution) 2–4 (High degree of pollution) 4–8 (Very high degree of pollution) 8–16 (Extremely high degree of pollution)	Tomlinson *et al.* (1980)

Igeo, Geo-accumulation index; HPI, Heavy metal pollution index; PLI, Pollution Load Index; CF, Contamination factor.

an indicator of soil fertility, was found to be between 0.83% and 0.92 %, which is significantly lower than the typical range of 12–18% for organic soils (Abdulhamid *et al.* 2015). This low OC content may limit soil microbial activity and nutrient cycling, potentially affecting crop productivity.

The nitrogen (N) levels in the soil samples averaged 58 mg/kg, exceeding the standard limit of <50 mg/kg. Nitrogen is a crucial macronutrient for crop growth whose excessive accumulation can lead to nutrient imbalances, reduced crop productivity and environmental issues such as leaching and eutrophication (Mahboob *et al.* 2023). Potassium (K) levels were notably high, ranging 980–990 mg/kg, far exceeding the recommended threshold of <60 mg/kg. Elevated K levels may result from irrigation with wastewater, as potassium has low leachability,

Table 4 Physicochemical properties of the soil samples

Parameters	Unit	BIS	Minimum	Maximum	Average (Mean ± SD)
Colour	-	-	Brown	Brown	Brown
*p*H	-	6.8–8	8.90	9	9.96 ± 0.05
EC	dS/m	0.07–0.6	0.50	0.70	0.63 ± 0.11
OC	%	0.5–7.5	0.83	0.92	0.86 ± 0.04
N	g/kg	<50	39	76	58 ± 18.52
K	mg/kg	<60	980	990	986.66 ± 5.77
P	mg/kg	<2.5	6.80	7.20	7 ± 0.20
Fe	mg/kg	2.9–6.7	3.20	5	3.86 ± 0.98
Mn	mg/kg	3.8–6.9	1.90	2.30	2.03 ± 0.23
Cu	mg/kg	0.3–1.5	0.40	0.80	0.60 ± 0.20

BIS, Bureau of Indian Standards; EC, Electrical conductivity; OC, Organic carbon; N, Nitrogen; K, Potassium; P, Phosphorus; Fe, Iron; Mn, Manganese; Cu, Copper; Standard deviation.

it disrupts soil structure and tends to accumulate soil particles, though potassium is essential for plant growth (Arienzo *et al.* 2009, Wang *et al.* 2013). The phosphorus (P) concentrations ranged from 6.80–7.20 mg/kg, with an average of 7 mg/kg, significantly higher than the recommended threshold of <2.5 mg/kg. Phosphorus is a vital macronutrient for crop growth and microbial activity, but excessive levels can lead to environmental issues such as eutrophication in water bodies due to runoff (Frossard *et al.* 2000, Carpenter 2008, Campdelacreu Rocabruna *et al.* 2024, Ma *et al.* 2024). The high P content in the soil may be attributed to inadequate phosphorus cycling, influenced by biological, chemical and physical factors (Lucas *et al.* 2025).

Micronutrients i.e. Iron (Fe), Manganese (Mn) and Copper (Cu) were also analysed. The Fe content ranged from 3.20–5 mg/kg, within the standard limits for agricultural soils. Iron plays a critical role in soil structure and plant metabolism, but excessive levels can lead to oxidative stress and Fe toxicity, adversely affecting crop yields (Liu *et al.* 2023, Zhu *et al.* 2016). Manganese levels averaged 2.03 mg/kg, below the standard limits, indicating a potential deficiency. This deficiency may be attributed to high soil *p*H and low moisture content, which limit Mn availability (Thapa *et al.* 2021). The Cu levels ranged from 0.4–0.8 mg/kg within permissible limits and did not indicate any toxicity. However, continuous monitoring is essential to prevent potential accumulation.

The soil in the study area was characterised by strong alkalinity, low OC content and elevated levels of N, P and K. These conditions may support certain agricultural practices, but they also pose risks of nutrient imbalances, reduced crop productivity and environmental degradation. Micronutrient analysis revealed adequate Fe and Cu levels but highlighted a potential Mn deficiency, which may require remediation to optimise crop growth.

Heavy metal analysis: The concentrations of Cd, Cr, Ni, Pb and Zn in soil samples, along with their acceptable limits as set by the WHO, are presented in Table 5.

Chromium concentrations ranged from 20.03–22.17 mg/kg, Pb from 14.45–15.46 mg/kg and Zn from 34.5–38.75 mg/kg, all of which are within the WHO threshold levels. These findings indicate that Cr, Pb and Zn do not pose an immediate risk to the agricultural environment in the study area. In contrast, Cd and Ni concentrations exceeded the WHO acceptable limits in all samples. Cadmium levels

Table 5 Observed and certified values of heavy metals in soil

Metal	Acceptable limit (mg/kg) (WHO)	Observed value (mg/kg)			Average (Mean ± SD)
		Sample 1	Sample 2	Sample 3	
Cd	0.8	1.2	1.35	1.52	1.35±0.16
Cr	100	22.17	21	20.03	21.06±1.07
Ni	35	38.05	36.42	38.65	37.7±1.15
Pb	85	14.84	14.45	15.46	14.91±0.5
Zn	50	38.75	34.5	35.29	36.18±2.26

Cd, Cadmium; Cr, Chromium; Ni, Nickel; Pb, Lead; Zn, Zinc; WHO, World Health Organisation; SD, Standard deviation.

Table 6 Pollution assessment indices of heavy metals in soil samples

Sample	Igeo					HPI	Contamination factor					PLI
	Cd	Cr	Pb	Ni	Zn		Cd	Cr	Pb	Ni	Zn	
AS1	0	-2.75	-3.1	-0.46	-0.95	145.85	1.5	0.22	0.17	1.08	0.77	0.546
AS2	0.16	-2.83	-0.52	-3.14	-1.12	163.36	1.68	0.21	0.17	1.04	0.69	0.533
AS3	0.34	-2.90	-0.44	-3.04	-1.08	183.65	1.9	0.2	0.18	1.1	0.7	0.557
Average	0.16	-2.82	-1.35	-2.21	-1.05							

Igeo, Geo-accumulation index; HPI, Heavy metal pollution index; PLI, Pollution load index; Cd, Cadmium; Cr, Chromium; Pb, Lead; Ni, Nickel; Zn, Zinc.

ranged from 1.2–1.52 mg/kg and Ni concentrations ranged from 36.42–38.65 mg/kg, exceeding the WHO limits of 0.8 mg/kg and 35 mg/kg. The elevated levels of Cd and Ni are concerning, as these metals are known to be toxic to both the environment and human health, even at low concentrations. The consistent exceedance of Cd and Ni limits across all samples suggests a potential anthropogenic influence, such as various industrial activities. Further investigation is warranted to identify the specific sources of these metals and to assess their long-term impact on soil quality and agricultural productivity.

Pollution assessment of heavy metals

Geo-accumulation index (Igeo) and heavy metal pollution index (HPI): The Igeo, introduced by Muller (1969), is a widely used tool to assess heavy metal pollution in sediments by comparing current metal concentrations with preindustrial background levels (Mansouri Moghadam *et al.* 2024). The average Igeo values were 0.16, -2.82, -1.35, -2.21 and -1.05 for Cd, Cr, Pb, Ni and Zn, respectively (Table 6). The Igeo values for Cd in samples AS2 and AS3 were 0.16 and 0.34, indicating that these samples fall into class 6 (unpolluted to moderately polluted).

The HPI, calculated using a weighted arithmetic average of concentrations, uses a critical pollution index of 100 (Mohan *et al.* 1996). The HPI of all samples exceeded the pollution index value of 100, with values ranging from 145.85–183.65, indicating significant soil contamination by the studied heavy metals. This poses a considerable risk to the environment and human health, underscoring the need for immediate action to safeguard local ecosystems and agricultural practices.

Contamination factor (CF) and Pollution load index (PLI): Two significant indices, the CF and PLI, were employed to quantify the extent of heavy metal pollution in the study area. The CF was calculated by comparing the measured metal concentrations to pre-industrial reference values, while the PLI provides a comprehensive assessment of overall pollution levels at a given site (Rahman *et al.* 2022). The CF values for the analysed metals ranged from 1.5–1.9 for Cd, 0.20–0.22 for Cr, 1.04–1.10 for Ni, 0.17–0.18 for Pb and 0.69–0.77 for Zn. The order of contamination was Cd>Ni>Zn>Cr>Pb. Cadmium and Ni exhibited moderate contamination (Class 2), while Zn, Cr and Pb showed low contamination (Class 1). The Zn concentrations, despite showing low contamination levels were within permissible limits, indicating no immediate environmental or health risks.

The PLI values for all sampling points were below 1, ranging from 0.533–0.557, indicating that the study area has a low level of pollution for the studied heavy metals. However, continuous monitoring is recommended to detect potential risks earlier, ensuring timely mitigation measures (Rahman *et al.* 2022).

The risk assessment resulted revealed varying levels of heavy metal contamination in the study area. Cadmium and Ni were identified as the primary contaminants with moderate contamination levels based on CF and Igeo values. Chromium and Pb exhibited low contamination levels with Zn concentrations remaining within permissible threshold limits. The HPI exceeding the critical threshold of 100 underscores the cumulative impact of heavy metals on soil quality. Despite the low PLI values, Cd and Ni at moderate contamination levels warrant attention, as these metals can accumulate in the food chain and cause long-term ecological and health hazards.

The study of agricultural soils near Orathupalayam Dam revealed significant challenges due to contamination from heavy metals such as Cd and Ni, alongside alkaline soil conditions, posing environmental and health risks. Pollution indices, including Igeo, HPI, CF and PLI, confirmed moderate pollution for Cd and Ni, with Cr and Pb showing lower contamination levels. Despite baseline pollution levels suggested by PLI, Cd and Ni above acceptable limits render the soil unsuitable for sustainable agriculture. These findings underscore the need for improved water quality management, soil remediation and long-term monitoring to ensure soil health, agricultural sustainability and environmental safety. However, the study focused on a specific region and its limited scope, which does not include assessments of crop yield or human health impacts, presents limitations. Future work should include long-term studies assessing heavy metal contamination's impact on soil health, crop yield and human health, as well as investigating remediation techniques and expanding the geographical scope of research. By integrating proactive measures, effective remediation strategies and continuous monitoring, we may be able to address this pressing issue, ensuring a safer and more sustainable future for agriculture and the environment.

REFERENCES

Abdulhamid Z, Agbaji E, Gimba C and Agbaji A. 2015. Physicochemical parameters and heavy metals content of soil samples from farms in Minna. *International Letters of Chemistry, Physics and Astronomy* **58**: 154–63.

Adepoju A O, Femi-Adepoju A, Jalloh A and Faeflen S. 2024. Soil pollution and management practices. *(In) Environmental Pollution and Public Health*, pp. 187–236. Elsevier, Amsterdam.

Ahmadi Doabi S, Karami M and Afyuni M. 2019. Heavy metal pollution assessment in agricultural soils of Kermanshah province, Iran. *Environmental Earth Sciences* **78**(3): 70.

Arienzo M, Christen E, Quayle W and Kumar A. 2009. A review of the fate of potassium in the soil-plant system after land application of wastewaters. *Journal of Hazardous Materials* **164**(2–3): 415–22.

BIS. 1969. *Indian Standard Method for Volumetric Determination of Phosphorus.* Bureau of Indian Standards, New Delhi.

BIS.1972. *Indian Standard Methods of Test for Soils, Part 22: Determination of Organic Matter*. Bureau of Indian Standards, New Delhi.

BIS.1980. *Indian Standard Method for Determination of Sodium and Potassium (Flame Photometric).* Bureau of Indian Standards, New Delhi.

BIS. 1987. *Indian Standard Method of Test for Soils, Part 26: Determination of pH Value.* Bureau of Indian Standards, New Delhi.

BIS.1999. *Indian Standard Determination of Nitrogen and Nitrogenous Compounds in Soils*. Bureau of Indian Standards, New Delhi.

BIS. 2000. *Indian Standard Determination of the Specific Electrical Conductivity of Soils - Method of Test*. Bureau of Indian Standards, New Delhi.

Boulding J R. 2017. *Description and Sampling of Contaminated Soils: A Field Guide*. CRC Press, Boca Raton.

Campdelacreu Rocabruna P, Domene X, Preece C and Penuelas J. 2024. Relationship among soil biophysicochemical properties, agricultural practices and climate factors influencing soil phosphatase activity in agricultural land. *Agriculture* **14**(2): 288.

Carpenter S R. 2008. Phosphorus control is critical to mitigating eutrophication. *Proceedings of the National Academy of Sciences* **105**(32): 11039–40.

El-Araby E H, Salman K A and Mubarak F. 2021. Human risk due to radon and heavy metals in soil. *Iranian Journal of Public Health* **50**(8): 1624.

Frossard E, Condron L, Oberson A, Sinaj S and Fardeau J. 2000. Processes governing phosphorus availability in temperate soils. *Journal of Environmental Quality* **29**(1): 15–23.

Hakanson L. 1980. An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research* **14**(8): 975–1001.

Huang L, Liu X, Wang Z, Liang Z, Wang M, Liu M and Suarez D L. 2017. Interactive effects of *p*H, EC and nitrogen on yields and nutrient absorption of rice (*Oryza sativ*a L.). *Agricultural Water Management* **194**: 48–57.

Jayakumar N and Rajagopal A. 2020. Noyyal river basin: Water, water everywhere, not a drop to drink. *(In) Water Conflicts in India*, pp. 156–59. Routledge, India.

Krishnamoorthy R, Roy Choudhury A, Arul Jose P, Suganya K, Senthilkumar M, Prabhakaran J, Gopal N O, Choi J, Kim K and Anandham R. 2021. Long-term exposure to azo dyes from textile wastewater causes the abundance of saccharibacteria population. *Applied Sciences* **11**(1): 379.

Kurian E, Rana P and Kesharwani L. 2024. Comparative soil analysis from different crime prone areas of Kottayam and Kollam districts of Kerala for forensic characterisation. *Indian Journal of Forensic Medicine and Toxicology* **18**(1): 50–57.

Liu W, Huo H, Zhou P, Li M and Wang Y. 2023. Research on hyperspectral modeling of total iron content in soil applying LSSVR and CNN based on shannon entropy wavelet packet transform. *Remote Sensing* **15**(19): 4681.

Lucas E R, Nguyen N D, Celi L, Condron L M, Fraser T D, George T S, de La Luz Mora M and Raymond N S. 2025. Organic phosphorus in the terrestrial environment: An update on current research and future directions. *Journal of Soil Science and Plant Nutrition* **25**(1): 393–408.

Ma D, Wang J, Chen K, Lan W, Ye Y, Ma X and Lin K. 2024. Responses of soil phosphorus cycling-related microbial genes to thinning intensity in Cunninghamia lanceolata plantations. *Forests* **15**(3): 440.

Mahboob W, Yang G and Irfan M. 2023. Crop nitrogen (N) utilisation mechanism and strategies to improve N use efficiency. *Acta Physiologiae Plantarum* **45**(4): 52.

Mansouri Moghadam S, Payandeh K, Koushafar A, Goosheh M and Mohammadi Rouzbahani M. 2024. Level of heavy metals and environmental pollution index in Ahvaz, Southwest Iran. *Scientific Reports* **14**(1): 14754.

Mohan S V, Nithila P and Reddy S J. 1996. Estimation of heavy metals in drinking water and development of heavy metal pollution index. *Journal of Environmental Science and Health Part A* **31**(2): 283–89.

Muller G. 1969. Index of geoaccumulation in sediments of the Rhine River. *GeoJournal* **2**: 108–18.

Oguntuase M A, Oyebamiji A O, Ayeni O M and Adeyanju O T. 2024. A comprehensive environmental analysis of heavy metal contamination, ecological risks and health impacts in Ilokun area, Ado-Ekiti, Nigeria. *Environmental Pollution and Management* **1**: 118–27.

Okorie M N, Okechukwu V U and Omokpariola D O. 2024. Physicochemical properties and health risk assessment of selected heavy metals from soil and borehole water in Ifite-Awka, Anambra State, Nigeria. *Discover Applied Sciences* **6**(3): 108.

Rahman M S, Ahmed Z, Seefat S M, Alam R, Islam A R M T, Choudhury T R, Begum B A and Idris A M. 2022. Assessment of heavy metal contamination in sediment at the newly established tannery industrial estate in Bangladesh: A case study. *Environmental Chemistry and Ecotoxicology* **4**: 1–12.

Singh D D, Thind P S, Sharma M, Sahoo S and John S. 2019. Environmentally sensitive elements in groundwater of an industrial town in India: Spatial distribution and human health risk. *Water* **11**(11): 2350.

Soltanpour P and Schwab A. 1977. A new soil test for simultaneous extraction of macro-and micro-nutrients in alkaline soils. *Communications in Soil Science and Plant Analysis* **8**(3): 195–207.

Subramanian A and Baskar S. 2022. Water quality assessment of Noyyal river using water quality index (WQI) and multivariate statistical techniques. *Water Science* **36**(1): 85–98.

Thapa S, Bhandari A, Ghimire R, Xue Q, Kidwaro F, Ghatrehsamani S, Maharjan B and Goodwin M. 2021. Managing micronutrients for improving soil fertility, health and soybean yield. *Sustainability* **13**(21): 11766.

Tomlinson D L, Wilson J G, Harris C and Jeffrey D. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgolander Meeresuntersuchungen* **33**: 566–75.

Wang M, Zheng Q, Shen Q and Guo S. 2013. The critical role of potassium in plant stress response. *International Journal of Molecular Sciences* **14**(4): 7370–90.

Xia F, Zhao Z, Niu X and Wang Z. 2024. Integrated pollution analysis, pollution area identification and source apportionment of heavy metal contamination in agricultural soil. *Journal of Hazardous Materials* **465**: 133215.

Zhu F, Li Y, Xue S, Hartley W and Wu H. 2016. Effects of iron-aluminium oxides and organic carbon on aggregate stability of bauxite residues. *Environmental Science and Pollution Research* **23**(9): 9073–81.