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Integrated Analysis of Soil Properties for Health Monitoring in the Yamuna Watershed

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Abstract

Soil analysis, which determines the inputs required for lucrative and productive operations, is a helpful tool for farms. A thorough soil test may help guarantee that the right amount of fertilizer is applied to satisfy crop needs while using the nutrients already present in the soil. The objectives of soil analysis are to ascertain the level of nutrient availability or the need for its input. Since fertilization does not always increase yields in poor soils owing to a number of limiting variables, it is helpful to predict the profitability of fertilization and the increase in output. It also helps to save money and energy by just applying the appropriate quantity of fertilizer. Fourteen representative soil samples were gathered for physico-chemical examination from several villages in the current study: Kalesar, Gumthala Rao, Garhi Birbal, Gharaunda, Rana Majra, Hathawala, Budanpur, Jakauli, Palla, Badarpur, Lalpur, Jawan, Kulena, and Hasanpur.The soil conditions were found to be mildly to moderately alkaline, as indicated by the pH values, which varied from 8.3 to 8.8. The EC ranged from 0.41 to 1.10 dS m^{-1}, at different locations indicating that the soils were not saline. With an organic carbon level ranging from 0.46 to 0.70 percent, the reproductive status was low to moderate. P ranged from 2.11 to 3.42 kg ha^{-1}, Na ranged from 44.5 to 96.7 kg ha^{-1}, while K^+ ranged from 122 to 356 kg ha^{-1}. Manganese Mn varied from 1.79 to 3.02 ppm, Fe from 2.10 to 4.46 ppm, Cu from 0.69 to 1.47 ppm, and Zn from 0.69 to 1.82 ppm, according to the micronutrient amounts that were measured. Overall, the findings show that the soils have a reasonable amount of organic matter and nutrients, making them slightly alkaline and appropriate for most crops when fertilizer management is managed. The requirement for site-specific nutrient management to preserve soil fertility and raise agricultural output is highlighted by the differences in nutrient availability among settlements.

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Introduction

Northern India's agricultural and natural environment is greatly influenced by the Yamuna River, one of the country's principal rivers and the main tributary of the Ganges.[1] Soil quality along its banks is of significant interest due to its impact on agriculture, ecosystem health, and as an indicator of pollution levels.[2] Physical and chemical parameters of soil quality in the Yamuna River basin include: physical parameters like Bulk texture, Porosity, Water holding capacity, Soil texture and chemical parameters like EC, organic matter content, nutrient levels, pH, heavy metal concentrations. These variables change as the river flows and are impacted by things like urban pollution, industrial discharge, and agricultural runoff.[3] Found significant variations in soil texture and nutrient content along different stretches of the Yamuna.[4] However, some researchers have found higher concentrations of heavy metals in soils close to industrial areas.[5] Assessing the health of the river, agricultural production, and any pollution problems requires an understanding of these soil properties.[6] Recent research has shown that to guarantee sustainable farming methods and ecosystem preservation, the Yamuna basin's soil quality has to be continuously monitored and managed.[7] Riverbed soil, also known as alluvial soil, is often fertile and perfect for agriculture due to the slow deposition of nutrient-rich silt brought by rivers.[8] The thin layer of material that covers the earth's surface is called soil, and it is created when rocks weather. It is mostly composed of slowly yet gradually interacting mineral particles, organic materials, water, air, and living things. Thus, most of the terrestrial life depends on soil to survive.[9] The quantity of plant nutrients that are accessible in the soil, as well as the chemical, physical, and biological characteristics of the soil that are crucial for plant nutrition, or "soil health," are all determined by a series of chemical procedures known as soil analysis. Chemical soil analysis is used to assess the basic plant nutrients, including P, N,K, humus content, total $CaCO_3$, pH, organic matter, trace elements, accessible lime, and other physical properties. Organic matter, including agricultural waste and animal manure, is broken down by soil microbes. They aid in the adhesion of soil particles into stable aggregates during this process. Additionally, they create humus, an organic material that doesn't decompose further and aids in soil retention of water and nutrients, creating the ideal conditions for plant development.[10] The roots are held in place by the soil, which also allows plants to rise above the ground and absorb the light they require to survive. The world's natural and human systems are still considered to be seriously threatened by climate change. Researchers focused mostly on studies related to changing environmental conditions and conducted numerous studies for vegetation monitoring, air and water quality, agricultural area changes, land surface temperature variations, and waste management during COVID-19.[11] Agriculture is greatly impacted by changes in soil, temperature, precipitation, solar radiation, and long-term climatic patterns. Based on the history of climate change over the past 30 years, predictable and possible changes in rainfall and temperature can reduce agricultural outputs and yields.[12] These consequences include changes to ecosystems and the loss of species, interruptions to the supply of food and water, and threats to food security and well-being.[13] One of the primary sources of plant nutrients is the decomposed debris. Many soils have varied nutritional profiles, and some are deficient in nutrients required to support plant species.[14] For these reasons, a soil test is crucial. Certain soils may have formerly had an abundance of nutrients, but once the crops were harvested, the reserves were exhausted.[15] Before planting crops, those who cultivate crops for a living must evaluate the soil's nutritional profile; otherwise, all their labor may be in vain. Additional justifications include maximizing crop yield, shielding the environment from pollution, runoff from soil and fertilizers leaching, improving the nutritional balance of the growing media, helping to diagnose plant culture problems, and energy by applying the required number of fertilizers. The ability of soil to continue being a living, breathing ecosystem that supports people, animals, and plants is known as soil health.[16] Low crop yields in most nations have been caused by degraded and infertile soils brought on by ongoing monoculture, inadequate organic matter recycling, rainfall unpredictability and frequent dry spells. These factors have also made poverty, food insecurity, and child malnutrition worse.[17] The quantity of organic matter in the soil is often associated with its properties. Climate change adaptation strategies include soil conservation techniques like cover crops and minimal or no tillage. The decision to use soil conservation measures is heavily influenced by the climate.[18] An appropriate climate and healthy soil may help any nation produce more crops. Several causes, including population increase, industrialization, and shifting lifestyles, contribute to soil pollution.[19] We must look at the soil's physico-chemical properties to assess its quality. Fourteen typical soil samples were collected from various sites and put through physico-chemical analysis to ascertain the various qualities.The physico-chemical properties of the soil in the Yamuna riverbed have not been extensively studied.The Yamuna watershed, which originates at a height of around 6,387 meters in the Lower Himalayas near the Yamunotri Glacier in Uttarkashi district of Uttarakhand, spans a vast drainage area of over 366,000 km². Before joining the Ganga at Triveni Sangam, Prayagraj, it passes through the states of Himachal Pradesh, Haryana, Delhi, and Uttar Pradesh. Millions of people rely on the watershed for home, industrial, drinking, and irrigation needs. However, the Yamuna has seen significant pollution and ecological degradation as a result of the fast industrialization and urbanization that has occurred, particularly in the Delhi and Haryana areas. This basin's soils are mostly alluvial, with silt deposits enriching them. However, pollutants from industrial, agricultural, and municipal sources are becoming more and more prevalent. This study looked at the physico-chemical properties of soil in the Yamuna riverbed to assess soil fertility, pollution levels, and total nutritional status. Fourteen typical soil samples were gathered from different places along the Yamuna riverbanks in Haryana and Delhi. To identify their salient characteristics and evaluate the geographical diversity throughout the watershed, these samples were methodically examined.

Materials and Methods

Experimental Site

Soil samples from fourteen sites along the Yamuna River in Delhi and Haryana were used for the experiment. A variety of riverfront settings and land-use circumstances can be found in these places, including Kalesar, Gunthala Rao, Garhi Birbal, Gharaunda, Rana Majra, Hathawala, Budanpur, Jakhouli, Palla, Badarpur, Lalpur, Jawan, Kulena, and Hasanpur. Standardized and generally accepted soil analysis techniques were used for all soil processing and laboratory studies, which were carried out in a controlled laboratory setting. This guaranteed the precision and dependability of the physico-chemical measurements derived from the samples that were gathered.

Study Area

The Yamuna River basin in Delhi's National Capital Territory (NCT) and Haryana was the site of the study. Haryana is around 44,212 km² in size and is located between latitudes 27.39°–30.35°N and longitudes 74.28°–77.36°E. The study was carried out in the Yamuna River basin in Delhi's National Capital Territory (NCT) and Haryana. Haryana spans over 44,212 km² and is located between latitudes 27.39°–30.35°N and longitudes 74.28°–77.36°E. At an elevation of around 6,387 meters, the Yamuna River rises from the Yamunotri Glacier in Uttarakhand. It flows for around 1,376 kilometers across Uttarakhand, Himachal Pradesh, Haryana, Delhi, and Uttar Pradesh until joining the Ganga at Prayagraj. The river enters Haryana close to Yamuna Nagar and passes through the main districts of Sonipat, Panipat, Karnal, and Yamuna Nagar. It travels from Sonipat into Delhi, where it is crucial for providing water and sustaining urban and agricultural systems. Along the middle Yamuna stretch, a variety of geomorphological and environmental circumstances are represented by the chosen sample villages and riverfront sites. Soil quality evaluation is essential for watershed management because of the region's problems, which include increasing pollution, agricultural runoff, soil deterioration, and varying water levels.

Sample Collection

Fourteen composite surface soil samples (S1–S14) were methodically gathered from several communities along the Yamuna River shown in table 1. Kalesar, Gunthala Rao, Garhi Birbal, Gharaunda, Rana Majra, Hathawala, Budanpur, Jakhouli, Palla, Badarpur, Lalpur, Jawan, Kulena, and Hasanpur were among the locations chosen. Stones, trash, and plant residues were removed from the sampling area at each site. Next, a soil auger was used to gather soil from a depth of 0–15 cm. A composite sample was created by carefully mixing two to three kg of dirt from each site on a clean plastic sheet. Before the soil was transferred into labeled polybags with the sample number and location, roots and small plant pieces were manually removed. All materials were allowed to air dry in the lab before being gently crushed with a wooden mallet and sieved through a 2 mm screen. One kilogram of the subsample was kept for examination. The samples were examined for important physico-chemical characteristics, such as: pH and EC, as determined by digital meters; organic carbon, determined using conventional titration techniques; Using photometry and other conventional methods for the analysis of macronutrients (K, P, and Na); Micronutrients (Mn, Fe, Cu, and Zn) were measured using accepted laboratory techniques.

Table 1: Physico-chemical parameters of different sampling locations

District	Location	Sample code	GPS Coordinated	Description
Yamuna Nagar	Kalesar	S-1	Latitude: 30.3444° N Longitude: 77.5352° E	The Indian state of Haryana's Yamuna Nagar district is home to Kalesar village. Although it is not located on the Yamuna River's banks directly, it is near the river and is a component of the greater ecosystem that is impacted by the river's flow and related activities.
	Gumthala Rao	S-2	Latitude:30.0836°N Longitude: 77.3217° E	Gumthala Rao is located relatively close to the Yamuna River, which plays a significant role in the village's ecosystem and economy. Terrain and Soil: The soil in the area is fertile, benefiting from the alluvial deposits brought by the river, making it suitable for agriculture
Karnal	Garhi Birbal	S-3	Latitude:29.7536°N Longitude: 77.0335° E	Agriculture: Much like other villages in the vicinity of the Yamuna, GarhiBirbal's economy is predominantly agrarian. The fertile soil supports the cultivation of crops such as wheat, rice, sugarcane, and various vegetables. Irrigation: The Yamuna River is a crucial source of irrigation for the village. Even though the village is not on the riverbank, irrigation channels and canals sourced from the Yamuna help in watering the fields, ensuring productive farming cycles.
	Gharaunda	S-4	Latitude: 29.5362° N Longitude: 76.9712° E	Gharaundaisislocated in the Karnal district, which is near the Yamuna River in the rich northern Indian plains.The nature and crops of Gharaunda are impacted by the river. Terrain & Soil: The Yamuna River's alluvial soil, which is extremely rich and ideal for intensive agriculture, helps the region surrounding Gharaunda.
Panipat	Rana Majra	S-5	Latitude: 29.4108° N Longitude: 76.9126° E	The Yamuna River is comparatively close to Rana Majra, which has an impact on the ecology and agriculture of the hamlet.

				Terrain and Soil: The village lies in the fertile plains of northern India, with soil that benefits from the alluvial deposits of the Yamuna, making it highly suitable for agriculture.
	Hathawala	S-6	Latitude: 29.5071° N Longitude: 76.7502° E	The Yamuna River, which is important to the area's biological system and agricultural techniques, is comparatively close to Hathwala. Farming is the main employment of the people who live in Hathwala. Numerous crops, including wheat, rice, sugarcane, and vegetables, may be grown in the rich soil that is enhanced by the nutrients that the Yamuna River carries.
Sonipat	Budanpur	S-7	Latitude: 29.0019° N Longitude: 77.0521° E	In the northern region of Haryana, in the Sonipat district, is Budanpur. The hamlet is in northern India's rich plains. Many different types of plants and animals may be found in Budanpur's agricultural setting. The Yamuna River's biological influence enhances the region's biodiversity.
	Jakauli	S-8	Latitude: 28.9694° N Longitude: 77.0403° E	Jakauliis in the Sonipat district of the Haryana state in northern India. The community is tucked away in northern India's lush plains. The agricultural landscape, which sustains a variety of plant and animal life, enhances the environment surrounding Jakauli. The Yamuna River's biological influence enhances the region's biodiversity.
Delhi	Palla	S-9	Latitude: 28.8639° N Longitude: 77.1471° E	Palla is situated near the Haryana border in Delhi's northern outskirts. One of the region's most distinctive geographical features is the Yamuna River's floodplains, where it is located. Yamuna River proximity: The village's location near the Yamuna River has an immediate effect on its everyday life, agriculture, and ecology.
	Badarpur	S-10	Latitude: 28.4958° N Longitude: 77.3023° E	The hamlet of Badarpur, located in southeast Delhi, is greatly impacted by its closeness to the Yamuna River. The river helps with agriculture by improving the soil and supplying necessary irrigation. Festivalsand ceremonies are frequently held on the river's banks, reflecting the village's close ties to the river in both culture and religion. However, the

				Yamuna River's pollution and the village's fast development present problems.
Faridabad	Lalpur	S-11	Latitude: 22.1907°N Longitude: 69.9635°E	The district of Faridabad, in the southern region of Haryana, is where Lalpur is located. It is situated close to the Yamuna River's banks, which is an important local topographical feature. The Yamuna River's proximity to the hamlet has an impact on everyday living, the ecology, and agriculture.
	Jawan	S-12	Latitude: 28.4203° N Longitude: 77.2501° E	Jawan is located in India's Haryana state's Faridabad district. It is situated in the district's northern region, encircled by rural communities and agricultural areas. The settlement is distinguished by its farming-suitable soil, which is characteristic of the alluvial plains in this area.
Palwal	Kulena	S-13	Latitude: 28.5126° N Longitude: 77.7501° E	KulenaVillageislocated close to the Yamuna River's banks in Haryana's Palwal district.
	Hasanpur	S-14	Latitude: 28.1123° N Longitude: 77.2844° E	Hasanpur is located close to the Yamuna River in Haryana's Palwal district. The village's ecology and economy are shaped by the river, a notable geographical feature. Village life revolves around agriculture, cultural celebrations, and environmental sustainability. Hasanpur provides prospects for community development and economic growth despite obstacles like water management and environmental preservation, guaranteeing a balance between tradition and advancement.

Statistical Analysis

Descriptive statistics, such as mean, minimum, maximum, range, and standard deviation for each measured parameter, were used to examine the physico-chemical data from fourteen sample sites (S1–S14) in order to evaluate the spatial variation in soil quality along the Yamuna River. The pH of the soil had a low standard deviation (0.15), a mean of 8.49, and a narrow range (8.3–8.8), indicating consistently alkaline conditions at all locations. With higher values at S13 and S14 indicating greater soluble salts in certain areas, electrical conductivity showed substantial variability, ranging from 0.41 to 1.01 dS/m (mean 0.70 dS/m). Due to variations in plant cover and organic matter inputs, organic carbon varied significantly between sites S4 and s11 exhibiting the greatest quantities (0.29–0.71%, mean 0.53%). Available potassium showed the most diversity (122–356 kg/ha, mean 239.14 kg/ha)with the highest values at S3 and S4 and the lowest at S7 and S14, probably due to parent material, clay content, and fertilizer treatments. Similar mineralization and fertilizer histories throughout the riverbanks are indicated by the relatively constant availability of phosphorus (2.18–3.58 kg/ha, mean 3.05 kg/ha). Differential salt buildup was reflected in the vast range of sodium levels (43.6–96.72 kg/ha, mean 75.07 kg/ha), with higher concentrations seen at downstream locations (S11–S14). Micronutrient concentrations varied geographically as well: manganese ranged from 1.76 to 3.02 ppm (mean 2.23 ppm), iron ranged from 1.83 to 4.40 ppm (mean 3.22 ppm), copper ranged from 0.66 to 1.47 ppm (mean 0.92 ppm), and zinc ranged from 0.69 to 1.94 ppm (mean 1.33 ppm). Several sites had significantly higher concentrations because of things like soil aeration, organic matter decomposition, and pH levels. Overall, these statistical indices show that the Yamuna River's soil qualities exhibit considerable geographical variation, which is influenced by hydrological, land-use, and natural processes.

Results

Soils from fourteen sampling sites (S1–S14) along the Yamuna River showed clear geographical differences in their physico-chemical properties. The soil at S1has a pH of 8.4, moderate EC, low organic carbon, low potassium, and sufficient levels of micronutrients. S2 had a reduced salt level, intermediate K and P, and a somewhat higher pH (8.5) and organic carbon. Although sodium was still low, S3had the greatest potassium content (356 kg/ha) and the highest pH (8.6); micronutrients like Fe and Mn were moderate. S4 had high levels of potassium (341 kg/ha) and organic carbon (0.70%), moderately high levels of Fe, and comparatively low levels of Zn. With a peak Fe value of 4.40 ppm, S5 had the highest alkalinity (pH 8.8), high organic carbon, high potassium, and the lowest sodium level. S6had intermediate levels of potassium, phosphorus, and micronutrients, a somewhat lower pH (8.3), and a high organic carbon content. Zn level peaked at 1.94 ppm in S7, which contained high organic carbon but extremely low potassium and the greatest phosphorus. S8 had high amounts of Fe and Zn together with low potassium and high sodium, indicating moderate alkalinity. While organic carbon and potassium remained modest and Fe concentrations remained high, EC and sodium grew even more at S9. High pH (8.8), elevated EC (0.84 dS/m), moderate nutrient levels, and high sodium (88.04 kg/ha) were observed in S10 (Badarpur). High EC (0.96 dS/m), intermediate organic carbon, high sodium, the greatest Cu content (1.32 ppm), and high Mn were all found in S11. S12had minimal organic carbon, the greatest amounts of Cu (1.47 ppm) and Mn (3.01 ppm), and the highest EC (1.30 dS/m) and sodium (96.72 kg/ha). High EC (1.10 dS/m), low potassium, the lowest phosphorus (2.11 kg/ha), extremely high sodium, and highest Mn (3.02 ppm) were all present in S13. Lastly, S14 exhibited moderate alkalinity (pH 8.3), high EC (1.0 dS/m), little organic carbon, low K and P, and exceptionally high salt (96.7 kg/ha), with moderate amounts of micronutrients.

Table 2: Physical-chemical parameter results from several sample stations

Sample No.	Village names	pH	EC (dSm^1)	Organic carbon (%)	K+ ($Kgha^1$)	P ($Kgha^1$)	Na ($Kgha^1$)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)'
S1	Kalesar	8.4	.57	.46	122	3.42	74.2	2.20	3.42	0.89	1.09
S2	Gumthala Rao	8.5	.55	.52	223	3.30	57.3	2.10	2.67	0.90	1.12
S3	Garhi Birbal	8.6	.53	.53	356	2.96	45.2	1.85	2.49	0.92	1.18
S4	Gharaunda	8.4	.49	.70	341	2.87	44.5	1.87	3.59	0.87	0.77
S5	Rana Majra	8.8	.41	.69	334	2.80	43.6	1.91	4.40	0.73	0.69
S6	Hathawala	8.3	.62	.68	260	3.11	68.7	1.89	3.91	0.71	1.24
S7	Budanpur	8.6	.67	.69	146	3.58	84.24	1.76	3.67	0.66	1.94
S8	Jakauli	8.4	.69	.67	157	2.96	83.23	1.79	4.01	0.69	1.82
S9	Palla	8.5	.72	.66	240	2.80	81.12	1.84	4.03	0.75	1.61
S10	Badarpur	8.8	.84	.65	242	3.07	88.04	2.13	3.12	0.89	1.69
S11	Lalpur	8.6	.96	.57	252	2.81	91.71	2.81	3.01	1.32	1.74
S12	Jawan	8.4	1.3	.49	248	3.27	96.72	3.01	2.93	1.47	1.72
S13	Kulena	8.5	1.1	.48	130	2.11	95.81	3.02	2.97	1.22	1.03
S14	Hasanpur	8.3	1.0	.47	132	2.18	96.7	2.72	3.06	1.18	1.02

pH

pH value of samples found to be in the range between 8.1 to 8.8, which is alkaline in nature as shown in Figure 1.

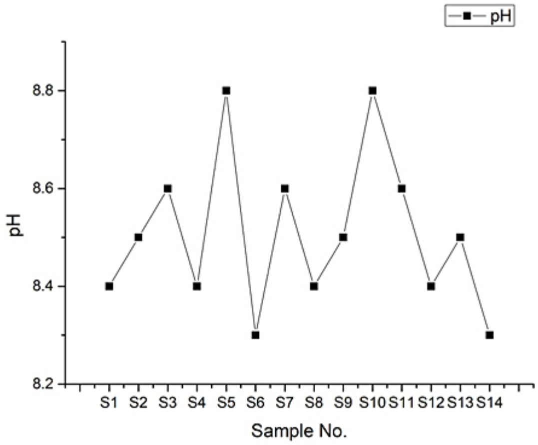

Fig. 1: pH readings taken throughout the Yamuna River at several sample sites.

Electrical Conductivity (EC)

EC values ranged in the soil samples from 0.41 to 1.3, as shown in Figure 2.

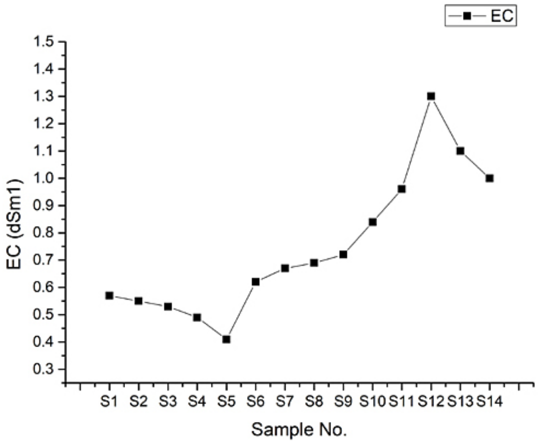

Fig. 2: Electrical conductivity levels were measured throughout the Yamuna River at several sample.

Organic Carbon

Fourteen distinct samples had C contents ranging from 0.46 to 0.70% as shown in Figure 3.

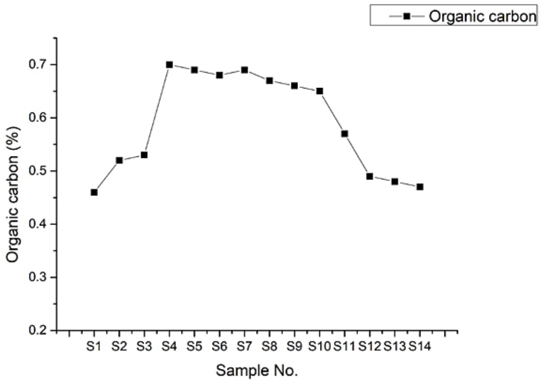

Fig. 3: Levels of organic carbon were measured throughout the Yamuna River at several sample locations.

Potassium

In the collected samples potassium ranged from 122 to 356 $kgha^{-1}$ shown in Figure 4.

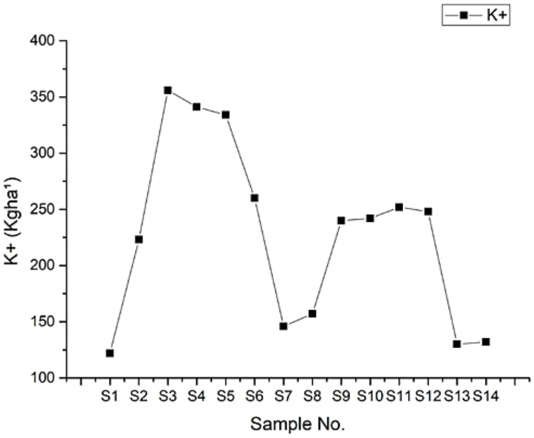

Fig. 4: Potassium levels were measured throughout the Yamuna River at several sample points.

Phosphorous

The values for phosphorus from the collected soil samples are in the range between 2.11-3.58 kg ha^{-1}, as shown in Figure 5.

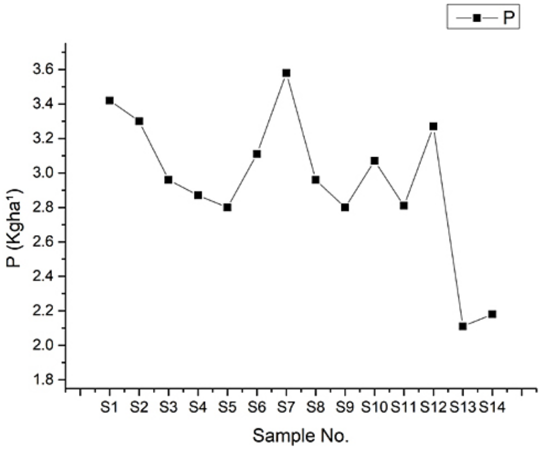

Fig. 5: Phosphorus levels were measured throughout the Yamuna River at several sample locations.

Sodium

Sodium levels ranged from 43.6 to 96.72 kg ha-1 as shown in Figure 6.

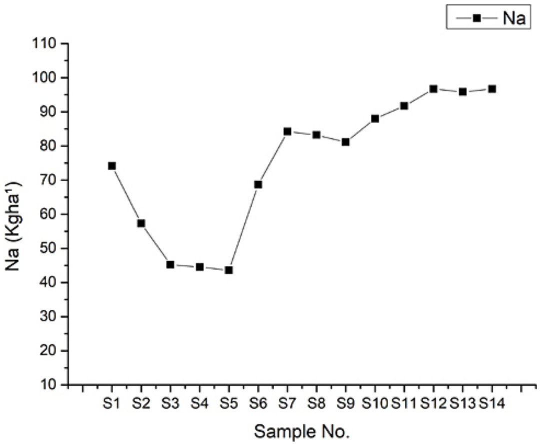

Fig. 6: Sodium concentrations were measured throughout the Yamuna River at several sample locations.

Manganese

Manganese concentrations vary from 1.76 to 3.02 ppm, as shown in Figure 7.

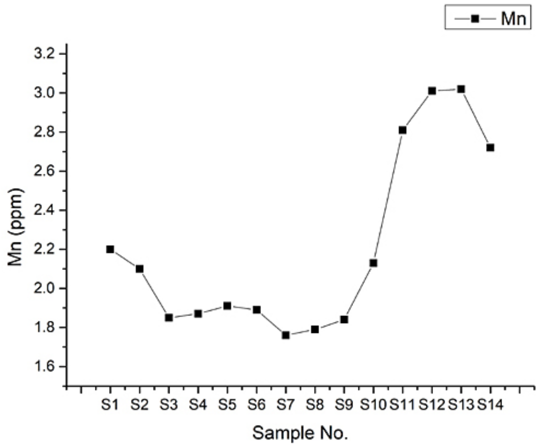

Fig. 7: Manganese concentrations were measured throughout the Yamuna River at several sample points.

Zinc

Zn levels range from 0.69 to 1.94ppm as shown in Figure 8.

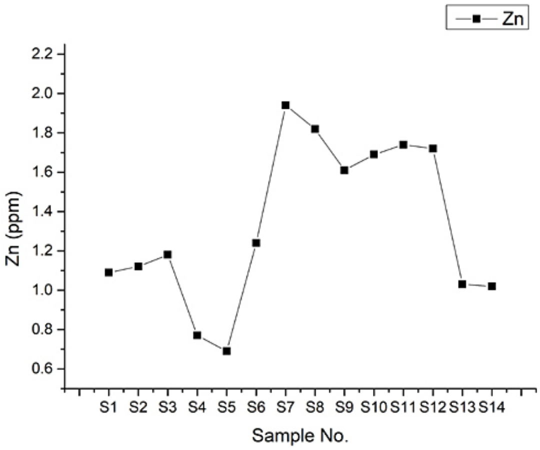

Fig. 8: Zinc levels along the Yamuna River were measured at several sample points.

Copper

The range of copper for the selected samples is in the range of 0.66 to 1.47 ppm, as shown in Figure 9.

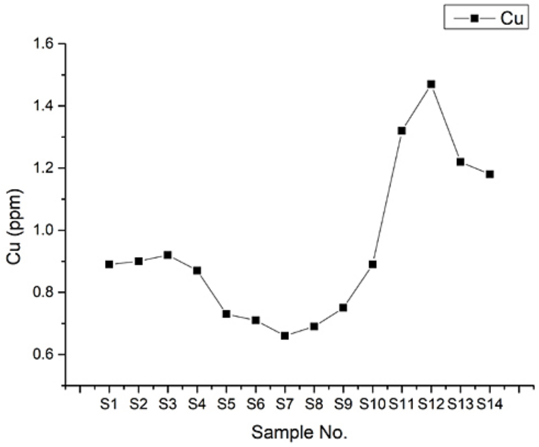

Fig. 9: The amount of copper measured at several sample locations along the Yamuna River.

Iron

Different soil samples had high and low proportions of Fe, ranging from 2.49 to 4.40 ppm, as shown in Figure 10.

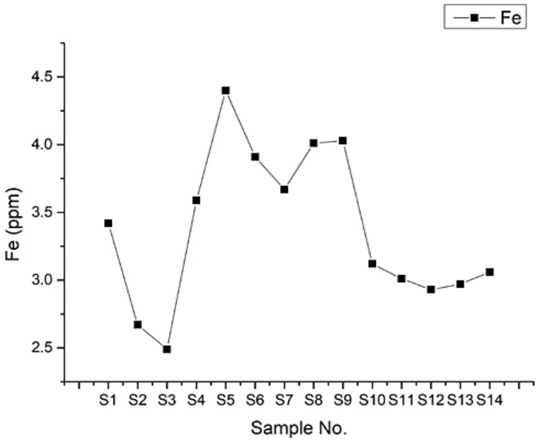

Fig. 10: Iron levels were measured throughout the Yamuna River at several sample locations.

Discussion

The current study emphasizes how important regional variability is influencing the physico-chemical properties of soil, which have a direct impact on crop yield and fertility status. Soil quality is greatly impacted by location-specific factors such as land use, irrigation techniques, and human activities, as evidenced by variations in soil texture, pH, organic carbon, and nutrient availability among test locations.20,21 Therefore, soil analysis is a crucial diagnostic tool for figuring out the exact inputs needed for sustainable agricultural techniques, evaluating fertility, and finding nutrient shortages.[22] Applying compost, green manure, and crop wastes to maintain ideal amounts of organic matter improves soil structure, microbial activity, and nutrient retention ability.[23] Balanced N-P-K fertilizers, liming materials, and biofertilizers are used sparingly to help restore soil health and long-term production.[24] Also, it has been demonstrated that applying micronutrients like zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) correctly greatly increases crop production, root growth, and nutrient efficiency.[25] All things considered, the best method for enhancing soil fertility, protecting natural resources, and encouraging sustainable agricultural growth in the Yamuna basin is integrated nutrient management (INM), which blends organic and inorganic nutrient sources with crop-specific management and scientific irrigation.[26,27] In keeping with previous observations that alluvial soils of the Indo-Gangetic Plains frequently display alkalinity due to carbonate-rich parent material, the pH of the soil varied narrowly between 8.3 and 8.8, indicating consistently alkaline conditions across all areas.[28] Higher EC at S13 and S14 indicated localized salt deposition, a pattern commonly associated with inadequate drainage and sporadic floods in riparian zones. Electrical conductivity (0.41–1.01 dS/m) shown significant variance.[29] with lower levels at S8 and S9 and relatively greater concentrations at S4 and S11, organic carbon varied greatly (0.29–0.71%), suggesting variations in plant cover and organic matter turnover. This kind of OC fluctuation is characteristic of intensively farmed alluvial soils.30 With the greatest values at S3 and S4, available potassium (122–356 kg/ha) demonstrated significant geographical diversity, indicating heterogeneity in parent material and fertilizer inputs. This is consistent with studies that K distribution in alluvial soils frequently depends on clay minerals and agricultural methods.[31] According to Olsen *et al*., constant fertilizer usage and the high fixing of P under alkaline circumstances may be responsible for the rather equal availability of phosphorus (2.18–3.58 kg/ha).[32] Sodium contents (43.6–96.72 kg/ha) varied significantly, with increased Na at downstream locations (S11–S14), suggesting potential salt buildup through seasonal waterlogging or capillary rise—processes frequently seen in agricultural fields near to rivers.[33] Due to variations in soil aeration and redox conditions, Mn levels (1.76–3.02 ppm) fluctuated somewhat because Mn becomes more accessible in reduced or wet environments.[34] Variations in alluvial sediment deposition and pH–redox interactions that affect Fe solubility in riverbank soils are reflected in Fe variability (1.83–4.40 ppm).[35] Cu aggressively combines with organic residues, Cu variation (0.66–1.47 ppm) is mostly governed by organic matter interactions.36 Soil alkalinity, organic carbon, and unequal fertilizer application are some factors that are known to impact Zn availability(0.69–1.94 ppm)in alluvial soils.[34]

Conclusion

It was found that the physico-chemical properties of the soil varied depending on the location of the soil. Preserving organic matter is essential for controlling fertilizer supply. However, for sustainable management and enhancing the soils' fertility condition, Liming materials, more labile organic inputs, and appropriate inorganic fertilizers (N-P-K) would all be used.In order to regulate agricultural nutrients, to maximize crop yields and preserve soil health, elements such as crop type, irrigation, residue control, application schedules, N source, Zn, Cu, Feand Mn placement strategies are essential. In the field, bio fertilizers and artificial fertilizers should be used in conjunction with unscientific irrigation techniques to achieve sustainable agricultural development. While applying these minerals won't damage the soil, it will increase its fertility. More organic fertilizers must be applied to the soil to increase production and enhance soil health.

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This statement does not apply to this article.

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This research did not involve human participants, animal subjects, or any material that requires ethical approval Informed Consent Statement This study did not involve human participants, and therefore, informed consent was not required.

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Permission to Reproduce Material from other Sources

Not Applicable

Author Contributions

- **Pooja Malik:** Data Collection, Analysis, Drafting, Writing – Review & Editing.
- **Nisha Kumari:** Conceptualization, Visualization, Supervision

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