RESEARCH PAPER

A Quantitative Assessment of Soil: Heavy Metal Contaminated Soils with Various Soil Properties

Sandhya Chaudhary[1]

*[*1]Professor, Department of Chemistry, N.R.E.C. College, Khurja, Bulandshahr-203131*
Email:sandhyachaudhary162023@gamil.com.

ABSTRACT
The recent emergence of heavy metal poisoning of soil into limelight has been categorized as a critical environmental issue due to the persistence, toxicity, and possible effect on human health and environmental stability. In an attempt to know more about the near-control variables that mediate the behavior of contamination and its causation, hence, this paper quantitatively establishes the relationshipbetween the levels of heavymetal andimportant soil physico-chemical attributes. The atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectrometry (ICP-MS) were used to determine the amount of lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), and nickel (Ni) by analyzing the soil samples collected in the polluted areas. We also tested the pH of the soil, the percentage of the organic matter, and the soil texture. The results demonstrated that there is a negative significant correlation between the pH and the metal concentration with a high negative value showing an upward progress in the mobility of the metal in the acid environment, and organic matter and clay content is positively correlated and it insinuates that they help in the adsorption and stabilization of the metal. These findings demonstrate the relevance of soil chemical and physical properties as factors shaping the conduct of heavy metals and incorporating them as key factors in the design of successful cleanup and management protocols of soils ..
Keywords: *Heavy metal contamination, Soil properties, pH, Organic matter, Soil texture, Correlation analysis, Environmental remediation, Soil pollution*
How to cite this article: Chaudhary S, A Quantitative Assessment Of Soil: Heavy Metal Contaminated Soils With Various Soil Properties .Int J Drug Deliv Technol. 2026;16(3s): 145-150; DOI: 10.25258/ijddt.16. 145-150
Source of support: Nil.
Conflict of interest: None

INTRODUCTION

The contamination of soil with heavy metals has also emerged as one of the most pressing environmental issues in the world today, mainly because of the high rate of industrialization, urbanization, mining and haphazard application of chemical fertilizers and pesticides in agriculture. These man-made operations contribute to the resulting amassing of poisonous metals like Pb, Cd, Cu, Zn as well as Ni in the soil. Unlike organic pollutants, heavy metals are not subject to biodegradation; therefore, theycan remain in soils for decades before being taken up by plants and entering the food web, causing acute harm to humans and other animals. The chronic exposure to heavy metals is linked to various undesirable outcomes, such as neurological conditions, kidney damages, metabolic and reproductive disturbances.

The soil's physicochemical characteristics adversely affect the capacity of heavy metals to move, distribute, and retain, since heavy metals are not uniformly distributed in soils. However, pH, organic matter content, cation exchange capacity, and soil texture are essential factors that all affect the solubility, adsorption, and bioavailability of metals. As an example, the acidic soils are expected to increase the solubility of metals, whereas the alkaline and those containing organic matters are expected to accelerate the immobilization of metals by metal complexation and adsorption. In the same way, the capacity of clay soils to hold metals can be greater because this type of soil canhave a great surface area and a high binding potential with electrostatic interactions, but the sandy soils tend to have more leaching and dispersing potentials.

The measurement of the contamination level, determination of the environmental hazards, and the development of effective remediation and soil management programs require the examination of the intricate interrelations between soil characteristics and heavy metal concentrations. Despite the substantial amount of literature performed on the subject of metal contamination, the individuals have to conduct quantitative study which integrates the chemical analysis with the description of the properties of the soil to formulate clear correlations and predictive trends. This is the reason why, the present study, will analyze the relationship between heavy metal concentration and the soil physicochemical properties however, in the different locations that are affected. By applying advanced methods of analysis and statistics, the paper will target to present a better concept of the contamination dynamics and this will be adopted in developing specific and sustainable recycling steps of soil and environmental protection.

MATERIALS AND METHODS

This section will describe the methodology that will be utilized to collect, analyze, and interpret soil samples in order to assess the level of heavy metal contamination in

**Author for Correspondence:*
sandhyachaudhary162023@gamil.com

relation to the soil's physicochemical qualities. The methodology would include site selection, sampling procedure, soil and metal analysis methods, and statistical analyses used to interpret data.

Soil Sampling

Five different sites (S1-S5) in the study area were prepared with soil samples systematically chosen on different levels of industrial and agricultural impact on the soil.

S1 and S2 were close to industrial discharge areas where effluents of small-scale units in manufacturing and metal processing are discharged.

S3 was a farmland where irrigation was by irrigable water sources that had the potential of being contaminated.

The mixed anthropogenic activities were manifested by the fact that S4 was located near a waste disposal area.

S5 was chosen in an urban run-off/roadside location that was prone to vehicular emissions and run off.

All the sites were located after considering observable environmental stress factors and the proximity to the potential sources of pollution like effluent channels, mining sites, and dumping sites. Composite soil samples were made by combining subsamples taken at five random spots of a site; this was done by mixing the topsoil layer (020 cm) that was most affected by contamination. To make the samples homogenous, the samples were air-dried, crushed gently and sieved using a 2 mm mesh. All the processed samples were placed in clean and labeled poly ethylene containers and kept under airtight conditions until analysis.

Heavy Metal Analysis

The examination was carried out using traditional analytical procedures to reliably and accurately identify the level of heavy metal. The US Environmental Protection Agency's Method 3050B was followed to digest approximately 1 gram of soil by adding concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). The filtered digested extracts were diluted to a known volume using deionized water. Measuring Pb, Cd, and Cu was performed using AAS (PerkinElmer Analyst series).

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is utilized fordetection of Zn and Ni concentrationsbecause this method has high sensitivity and can detect trace elements.

For the construction of the calibration curves, we relied on the certified reference standards for calibration. To guarantee quality, we analyzed blank samples, duplicates, and reference soil standards. All the concentrations were in milligrams of kilogram (mg/kg) of dry soil.

Soil Property Analysis

Laboratory methods (physicochemical parameters of the soil samples obtained) were measured by the following methods:

pH: A calibrated digital pH meter was used in one of the soil-to-water solutions of 1: 2.5 in accordance with the standard protocol described in ISO 10390 (2005).

Organic Matter Content: The determination of this was done by using the dichromate oxidation process that was developed by Walkley and black (1934) which is an acceptablemethod usedto determinethe quantityof organic carbon in soils.

Soli Texture: The hydrometer was used in the procedure followed by Bouyoucos (1962) to determine the texture of the soil. The soils were then typed as sandy loam, loam or clay loam depending on the relative quantities of sands and silt and clay as shown in USDA Soil Texture Triangle.

Statistical Analysis

Descriptive statistics that included the mean, standard deviation, and range for the data were calculated. The Pearson correlation coefficient (r) was used to establish significantcorrelationsbetween heavy metal concentrations and the physicochemical properties of the soils through correlationof heavymetalwith physicochemicalproperties. We determined significance at both 0.05 and 0.01 for p-values. Microsoft Excel 2021 was used to generate graphs, and SPSS 25.0 (IBM Corp., USA) was used to analyze all data. Trends were visually reviewed using these graphs.

RESULTS

Heavy metal concentrations in soil samples, changes to soil physicochemical qualities, and correlations between these variables as measured by statistical methods are all detailed in this section of the study.

Concentrations of Heavy Metals in Soil Samples

The results obtained can be summarized as shown in Table 1 that gives the means and standard deviations of the measured concentrations of the heavy metals in the soil samples collected.

Table 1: Concentrations of Heavy Metals in Soil Samples

Site Code	Pb (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ni (mg/kg)
S1	118.4	3.6	54.2	102.3	29.8
S2	142.5	4.2	62.8	110.6	34.1
S3	95.7	2.8	49.5	98.4	27.5
S4	161.2	4.8	68.9	124.2	36.9
S5	133.9	3.9	60.1	112.7	33.4
Mean ± SD	130.3 ± 24.3	3.9 ± 0.8	59.1 ± 7.2	109.6 ± 9.3	32.3 ± 3.8

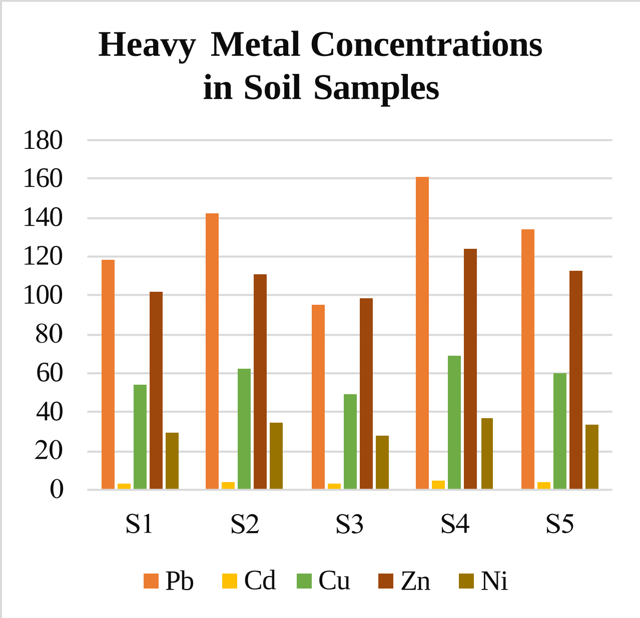

Figure 1: Graphical Representation of Concentrations of Heavy Metals in Soil Samples

Table 1 indicates that the concentrations of heavy metal are significantly different across sites of sampling. The highest concentration was found in lead (Pb) and zinc (Zn) with mean concentration of 130.3mg/kg and 109.6mg/kg respectively, which shows the high impact of anthropogenic factors, most probably through industrial discharge, vehicular emission, and waste deposition. Most of the sites had concentrations of Pb exceeding the permissible limit of 100 mg/kg by the world health organization, which showed possible ecological and health risks. Though in lesser amounts (mean 3.9 mg/kg), cadmium (Cd) is of great concern to the environment because it is toxic even at low levels. Median values of copper (Cu) and nickel (Ni) were moderate, and it could be explained by natural soil composition and secondary sources of pollution. The evident difference (large standard deviation) across sites implies non-homogenous patterns of contamination due to specific local soil factors, pH change, and source of pollutants. The overall results indicate that the frequent points of concern in the study sites are Pb and Zn.

Physicochemical Properties of Soil

The pH of the soil was between 5.2 and 7.4 as shown in Table 2 implying slightly acidic to slightly near-neutral soil conditions in both locations.

Table 2: Soil Samples' Physicochemical Properties

Site Code	pH	Organic Matter	Sand	Silt	Clay	Soil Texture
S1	5.6	2.4	52	28	20	Sandy Loam
S2	6.2	3.1	45	30	25	Loam
S3	7.4	4.3	40	32	28	Clay Loam
S4	5.2	2.1	58	26	16	Sandy Loam
S5	6.8	3.7	42	34	24	Loam
Mean ± SD	6.2 ± 0.8	3.1 ± 0.8	47.4 ± 7.3	30 ± 3.2	22.6 ± 4.6	—

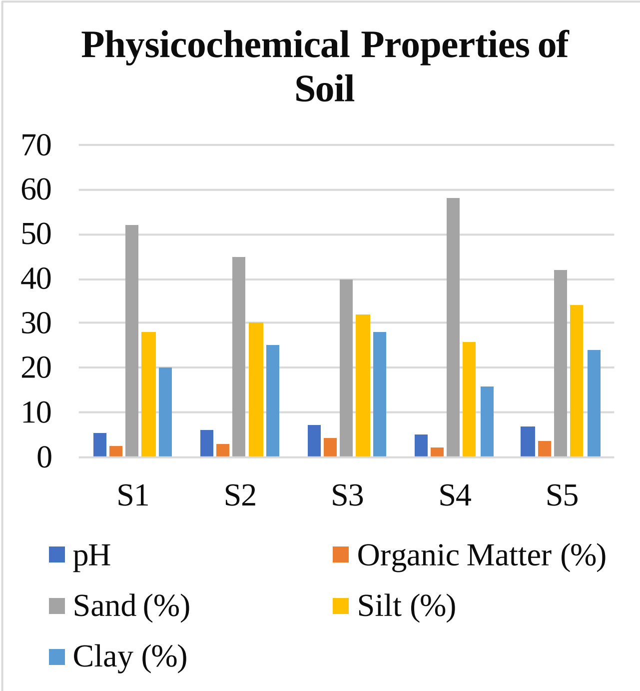

Figure 2: Graphical Representation of Soil Samples' Physicochemical Properties

This PH oscillation influences the heavy metal solubility and mobility; hence soils with a high acidity level (S1 and S4) probably will affect the two processes more. Loamy soils (S3) and Clay loam soils (S5) were found to have higher percentages of organic matter whose values were ranging between 2.1-4.3. This tendency may be used to improve adsorption and immobilization of heavy metals, including Pb and Zn, promoting a higher organic retention capacity. The average sand level in the soils of sandy loam to clay loam was 47.4 percent. The increased concentration of sand in some samples such as S1 and S4 shows that the sample has a reduced ability to hold nutrients and in other samples such as S3 and S5 there is an increase in clay and silt which leads to improved binding of heavy metals.

Correlation Between Soil Properties and Heavy Metals

The patterns of association of heavy metal concentrations and soil qualities, are observed in Table 3.

Table 3: Correlations

Soil Property	Pb	Cd	Cu	Zn	Ni
pH	-0.82**	-0.75*	-0.68*	-0.73*	-0.64*
Organic Matter (%)	+0.71*	+0.68*	+0.74**	+0.70*	+0.66*

Clay (%)	+0.63*	+0.58*	+0.61*	+0.59*	+0.55

*Significant at $p < 0.05$, **Highly significant at $p < 0.01$*

All of the metals tested showed a strong negative correlation with soil pH; in particular, metals are more bioavailable when their solubility and mobility are enhanced at lower pH (high acidity). On the other hand, the positive correlation of all metals with the organic matter content was strong, which means that organic matter is a significant constituent of the soils to immobilize metals in terms of adsorption and metal complexation. Also there is a moderate positive relationship between clay content and heavy metal content in soils implying that soils that contain a high level of clay content (finer textured soils) are more effective in retaining the metals by virtue of the large surface area and the cation exchange capacity. Such connections show the interactive nature of soil chemistry and soil texture in reference to heavy metals, and how important it is to control pH and organic matter in order to minimize contamination.

DISCUSSION

The section also makes interpretations of the research findings with specific consideration of the role that the soil characteristics play in the contamination of the heavy metals as well as the implications of achieving the successful soil remediation and control.

Relationship Between Heavy Metal Contamination and Soil Properties

This research demonstrates how soil physicochemical parameters, including the pH, the level of organic matter and the texture, influence the distribution and reaction of metal contaminants in contaminated soil. Soil acidity increases metals' solubility and mobility, increasing the potential biological and environmental hazard posed by heavy metals. There is a significant negative correlation between soil pH and heavy metals (Pb, Cd, and Zn) in addition to these physicochemical properties of soil. As the pH level declines, the level of metals increases and is easily carried away by groundwater or absorbed by plants thereby aggravating the effects of contamination.

Conversely, positive relation between organic matter and metals content indicates that organic carbon is therefore a key component in the retention of metal via complexation and chelation mechanisms. The sites that have a high organic matter content (like S3 and S5) have a high adsorption capacity, and hence less free forms of ionic metals are available in the soils, and also, the migration of ionic metals is restricted in the soils. This shows that organic matter can be considered a stabilizing factor, which attaches heavy metals effectively reducing their bioavailability.

In addition, the middle positive association between hex fluoric content of soil and metal accumulation is a strong under liner of the role of soil texture in moderating metal dynamics. The clay soils have a greater surface area and a large cation exchange capacity and thus have a higher capacity of adsorbing and retaining metal ions than the sands soils. Consequently, soils that are rich in clays and organic matter are used as natural barriers and have buffering capacity that decreases the possibility of heavy metal mobility and the potential of environmental risks.

Implications for Soil Remediation and Management

The developed correlations between the characteristics of the soil and the metal content are significant in terms of developing site-specific remediation plans. Liming or alkaline amendments to increase soils pH and, through this, reduce metal solubility and bioavailability can be utilized in acidic soils (including S1 and S4). In the caseof low organic matter soils, organic amendments like compost, manure or biochar could be used to promote adsorption and stabilization of heavy metals by increasing soil structure and cation exchange capacity.

Furthermore, metal-accumulating plant species phytoremediation might be a good method in sites with moderate pollution where soil properties (neutral pH and sufficient levels of organic matter) are favorable to plant assimilation. The methods of biological and chemical remediation would also be combined, which would increase the effectiveness of decontamination.

In management regard, routinely monitoring the soil pH, organic matters and soil texture is a significant practice that can be used to anticipate contamination behavior and determine the potential effectiveness of remediation. The present paper implies that a complex strategy should be implemented where the proper comprehension of the soil chemistry is combined with the sustainable management strategies that will help eliminate the threat of the metal pollution without disturbing the agricultural activities and the ecosystem of health.

CONCLUSION

The physicochemical propertiesof soils suchas pH, organic matter content and the percentage of clay are widely applicable in the study in determining the mobility, retention, and distribution of heavy metals in the contaminated soils. Negative relationships are strong between the pH and the metals concentrations, owing to the fact that the metals are believed to be more soluble and possibly more bioavailable in acidic conditions thereby posing more environmental hazard. On the other hand, positive correlations of heavy metals with organic matter and clay content suggest their importance in the adsorption and stabilization of elements that cause the metals to be on the move less. These findings demonstrate that the dynamics of interactions between the soil chemistry and contamination need to be investigated in order to develop effective remediation initiatives. These measures include soil pH management, organic inputs and constant monitoring, which are all part of an overall management plan that can enhance the quality of soil andreduce thelevel of heavy metal contamination of the water bodies and human health.

FUTURE DIRECTIONS

More research is necessary to gain more insights into the understanding of complex relationships between heavy metal contamination and physicochemical properties of soils in various environmental conditions. It is viable to integrate the application of advanced techniques of modeling such as Geographic Information Systems (GIS) and predictive statistical models to map the gradients of contamination at various regions. Additionally, the bioavailability studies will be needed to examine how plants take in and translocation of heavy metals, and speciation and their relationship to the soil chemistry. Sustainable remediation should also be taken into consideration or biochar, addition of microbes, and green nanotechnology to makethe restoration of thecontaminated soils more environmentally friendly. It will require the integrated and site remediation strategies to restore healthy and sustainable soils and environmental conditions in the long run.

REFERENCE

1. Askari, M. S., Alamdari, P., Chahardoli, S., & Afshari, A. (2020). Quantification of heavy metal pollution for environmental assessment of soil condition. Environmental monitoring and Assessment, 192(3), 162.
2. Hamzenejhad, R. (2020). Quantitative assessment of soil heavy metals pollution. Applied Soil Research, 8(2), 37-52.
3. He, Z. (2015). Heavy metal contamination of soils: sources, indicators and assessment.
4. Huang, J., Guo, S., Zeng, G. M., Li, F., Gu, Y., Shi, Y., ... & Peng, S. (2018). A new exploration of health risk assessment quantificationfrom sources of soil heavy metals under different land use. Environmental Pollution, 243, 49-58.
5. Jiang, B., Adebayo, A., Jia, J., Xing, Y., Deng, S., Guo, L., ... & Zhang, D. (2019). Impacts of heavy metals and soil properties at a Nigerian e-waste site on soil microbial community. Journal of hazardous materials, 362, 187-195.
6. Kaur, M., Kumar, A., Mehra, R., & Kaur, I. (2020). Quantitative assessment of exposure of heavy metals in groundwater and soil on human health in Reasi district, Jammu and Kashmir. Environmental geochemistry and health, 42(1), 77-94.
7. Lu, Q., Wang, S., Bai, X., Liu, F., Li, C., Deng, Y., & Tian, S. (2021). Quantitative assessment of human health risks under different land uses based on soil heavy metal pollution sources. Human and Ecological Risk Assessment: An International Journal, 27(2), 327-343.
8. Lv, J., & Liu, Y. (2019). An integrated approach to identify quantitative sources and hazardous areas of heavy metals in soils. Science of the Total Environment, 646, 19-28.
9. Mohamed, E. S., Saleh, A. M., Belal, A. B., & Gad, A. (2018). Application of near-infrared reflectance for quantitative assessment of soil properties. The Egyptian Journal of Remote Sensing and Space Science, 21(1), 1-14.
10. Pan, F., Yu, Y., Yu, L., Lin, H., Wang, Y., Zhang, L., ... & Zhu, R. (2020). Quantitative assessment on soil concentration of heavy metal–contaminated soil with various sample pretreatment techniques and detection methods. Environmental Monitoring and Assessment, 192(12), 800.
11. Xian, Y., Wang, M., & Chen, W. (2015). Quantitative assessment on soil enzyme activities of heavy metal contaminated soils with various soil properties. Chemosphere, 139, 604-608.
12. Xiang, M., Li, Y., Yang, J., Lei, K., Li, Y., Li, F., ... & Cao, Y. (2021). Heavy metal contamination risk assessment and correlation analysis of heavy metal contents in soil and crops. Environmental Pollution, 278, 116911.
13. Zeng, L., Wang, Y., Jing, L., & Cheng, Q. (2021). Quantitative determination of auxiliary information for mapping soil heavy metals and soil contamination risk assessment. Applied Geochemistry, 130, 104964.
14.Zhang, J., Liu, Z., Tian, B., Li, J., Luo, J., Wang, X., ... & Wang, X. (2023). Assessment of soil heavy metal pollution in provinces of China based on different soil types: From normalization to soil quality criteria and ecological risk assessment. Journal of Hazardous Materials, 441, 129891.
15. Zhao, H., Wu, Y., Lan, X., Yang, Y., Wu, X., & Du, L. (2022). Comprehensive assessment of harmful heavy metals in contaminatedsoil in order to score pollution level. Scientific Reports, 12(1), 3552.
16. Chaudhary, S. and Kumar, A. (2012). Monitoring of Benzene, Toluene, Ethyl benzene and Xylene (BTEX) Concentration In ambient Air of Firozabad, India. International Archive of Applied Science & Technology, Vol. 3(2), 92-96.
17. Chaudhary, S. and Kumar, A. (2012). Study on Refuelling pump stations caused by BTEX Compounds in Firozabad city. International Archive of Applied Science & Technology, Vol. 3(2),75-79.
18. Chaudhary, S. and Sisodia, N. (2015). Analysis of Ketoconazole and Piribedil using Ion Selective Electrodes. IOSR Journal of Applied Chemistry, Vol. 8(1), Ver.II, 1-4.
19.Chaudhary, S. (2016). Effect of benzene and Xylene concentration on Public health in Ambient Air In City of Firozabad, India. PARIPEX – Indian Journal of Research,Vol. 5(11), 504-505.
20. Singh, V. and Chaudhary, S. (2019). Study of groundwater quality in Khurja city and adjoining areas of Khurja Borewell And hand-pump water. International Journal of Geography, Geology and Environment, 1(1), 95-9 9.
21. Chaudhary, S. and Singh, V. (2021). Toluene concentration at commercial site in ambient air of Firozabad and its Impact on human health, International

journal of humanities, Law and Social Sciences, Vol. 8(1), 71-76.
22. Chaudhary, S. (2022). Benzene and Toluene concentration at different Traffic intersection during Pre-mid-post winter season, in ambient air of Aligarh and its impact on Human Health, PARIPEX - Indian Journal of Research, vol.11(8), 42-45.
23. Chaudhary, S. (2022). Effect of BTEX Concentrations on human health, in ambient air at different refuelling pump stations in Firozabad, Journal of Socio-Economic Review, Vol. 9(2), 34-41.
24. Chaudhary, S. (2023). Photo electrochemical (PEC) Study of The Dye Sensitized High Band Gap Structure of ZnO Semiconductor electrodes Prepared by the SOL-Gel Method, PARIPEX- Indian journal of Research, Vol. 12(9), 94-96.
25. Chaudhary, S. (2024). An Assessment of released Industrial Effluent and its impact on Water Quality, PARIPEX- Indian journal of Research, Vol. 13(8), 55-58.
26.Chaudhary, S. (2024). Role of Native plant Species in Phytoremediation of Heavy Metals from Contaminated Soil at Atrauli and Panethi, PARIPEX- Indian journal of Research, Vol. 13(8), 59-62.
27. Singh, Y., Chaudhary, S., Ravikant (2024). An Exhaustive examination of the models, methods, histories and viewpoints related to water quality Indexes (WQIs). AIRO journals, Vol. 3(1), 210-226.
28. Geeta, Chaudhary, S., Ravikant (2024). Heavy metals in Aligarg's urban soil: An overview of health risks and pollution assessment, AIRO journals, Vol. 3(1), 228-244.
29.Chaudhary, S., Singh, V., Singh, S. K. (2024). A Stud.y of New Approaches to Statistical Analysis of research data, JSIANE,Vol. 4(4), 24-29.
30. Chaudhary, S. (2024) Role of Nano Catalysts in Green Chemistry, JSIANE,Vol. 4(4), 08-11.
31. Geeta, Chaudhary, S. (2024). A Comprehensive Study on Native Plant Species for Phytoremediation of Heavy Metals Contaminated in Soil, JSIANE,Vol. 4(4), 15-19.
32.Kumar, Y., Chaudhary, S. (2024). A Study of Innovative Approaches to Water Pollution Control: Emerging Strategies and Technologies, JSIANE,Vol. 4(4), 47-51.
33.Chaudhary, S. (2025). AStudy of Toxic Heavy Metals In Released Treated/Untreated Waste water from Slaughterhouses of Khurja, Uttar Predesh. JSIANE, 5(1), ISSN:2583-2093, 5(1). 9-11.
34. Singh, Y., Chaudhary, S. (2025). Heavy Metal Concentration in Contaminated Water Caused by a Release of Industrial pollutants and City Waste. JSIANE, 5(1), ISSN:2583-2093, 5(1), 38-40.
35. Geeta, Chaudhary, S. (2025). Soil Quality Degradation Due to Heavy Metal Concentration in Contaminated Soil and its Remediation. JSIANE, 5(1), ISSN:2583-2093, 5(1), 43-45.
36. Geeta, Chaudhary, S. Kant, R. (2024). Assessment of human health risks from the distribution and concentration of heavy metals in soil, ground water amd vegetables in Aligarh, Uttar Pradesh, Frontiers in Health Informatics, ISSN:2676-7104, Vo;. 13(5), 1104-1116.
37. Singh, Y., Chaudhary, S. Kant, R. (2024). Physiochemical indicators of emerging pollutants in Aligarh's urban water system.Frontiers in Health Informatics, ISSN:2676-7104, Vo;. 13(5), 1117-1131.