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Soil Quality Degradation Due To Heavy Metal Concentration in Contaminated Soil and Its Remediation

Geeta[1] and Dr. Sandhya Chaudhary[2]

[1]Research Scholar, Department of Chemistry, Mangalayatan University, Aligarh, Uttar Pradesh, India

[2]Associate Professor, Department of Chemistry, N.R.E.C. College, Khurja-Bulandshahr Affiliated To Ch. Charan Singh University, Meerut, Uttar Pradesh, India

Corresponding Author E-mail: sandhyachaudhary162023@gmail.com

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Abstract

Heavy metals are important soil pollutants that have a major impact on soil quality and plant health. These elements include cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn). These naturally occurring metals can build up in soils as a result of a variety of human activities, such as industrial operations, agricultural practices, and inappropriate waste disposal. Heavy actions raise the amounts of heavy metals in the soil, which hinder plant growth by interfering with physiological and biochemical processes. The study examines several heavy metal contamination sources and highlights how soil metal accumulation is affected by the continuous application of inorganic fertilizers and other agricultural inputs. One effective and affordable way to mitigate soil contamination is through the use of phytoremediation. This research integrates information from several sources, such as books, internet databases, and national and international periodicals. It offers a thorough understanding of the fundamental chemistry of heavy metals, their origins, and their effects on soil and plant health. With an emphasis on sustainable agricultural practices and cutting-edge remediation techniques, the findings highlight the need for efficient remediation strategies to manage and reduce heavy metal contamination in soils.

Keywords*:* Soil Quality, Heavy Metal Concentration, Contaminated Soil, Remediation techniques, Phytoremediation.

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Introduction

Degradation of soil quality caused by heavy metal pollution has become a major environmental concern worldwide, especially in areas with high industrial and agricultural activity. Although heavy metals are naturally occurring elements, human activities like mining, industrial emissions, improper waste disposal, using contaminated sewage sludge, and excessive chemical fertilizer application can cause a drastic increase in the concentration of these elements in soils. Due to their non-biodegradable nature, environmental persistence, and soil accumulation. Heavy metals change the physicochemical characteristics of soil, hinder the growth of soil microbes, and decrease the amount of vital nutrients that are available. Because of this, the fertility of the soil is decreased and harmful metals bioaccumulate in plants, which can enter the food chain and seriously endanger human health. The depletion of soil quality is an increasing concern, and remediation methods that may successfully remove or neutralize these harmful metals from polluted soils need to be given immediate attention. Many remediation techniques have demonstrated promise in reducing heavy metal contamination, including soil washing, phytoremediation, and the application of organic amendments. These techniques seek to protect the environment, improve soil productivity, and restore soil quality. This introduction prepares the reader for a thorough examination of the factors that lead to the degradation of soil quality caused by heavy metals, as well as their effects and remediation strategies.

Sources and Effects of Contamination with Heavy Metals

The main causes of heavy metal contamination in soils include mining, industrial processes, and overuse of chemical pesticides and fertilizers in agriculture. These metals damage soil structure, lower fertility, and alter microbial diversity as they build up in the soil. These hurtful metals can possibly be consumed by plants over the long run, which could bring about bioaccumulation in the natural pecking order and serious wellbeing dangers for the two individuals and creatures. The inclination of weighty metals like cadmium, lead, and chromium to immobilize indispensable minerals alongside their determination compounds soil crumbling and decreases rural creation.

Methods of Remediation for Soils Contaminated with Heavy Metals

Physical and biological techniques are needed for heavy metal-contaminated soil cleanup that is effective. Using plants to extract or stabilize heavy metals is a technique known as phytoremediation, which is both economical and environmentally benign. In order to improve soil health and lower the danger of contamination, other methods including soil cleaning, chemical stabilization, and the addition of organic amendments (such compost or biochar) try to either remove or neutralize hazardous metals. The primary objective of remediation is to restore soil quality for sustainable agricultural use, and the choice of remediation approach is contingent upon the type of metal, the degree of pollution, and the soil conditions.

Literature Review

Azhar, U., et.al.,(2022).All around the world, contaminated soil that contains hazardous metals and metalloids is prevalent. Metals are relatively fixed in subsurface frameworks because of precipitation and adsorption processes. Thusly, the strong stage wellsprings of metals, like mucks, trash, polluted soils, or squanders, have been the focal point of remediation methodologies in such defiled locales. These harmful compounds have been building up in the soil for the past thirty years, endangering both human health and the ecosystem. Heavy metal pollution has serious negative effects on people and the environment, which has led to industrial unrest in many nations. The use of cutting-edge technology, timekeeping, planning difficulties, and expense are a few disadvantages that must be appropriately managed. The most effective way to remove metals from soil is now thought to be through biological techniques, plant regeneration, and in situ metal immobilization. These recent developments have altered the dynamics. Rajendran, S., et.al., (2022).centers around the general condition of soil defilement by weighty metals, especially the unbalanced degrees of weighty metals in crops. Future issues as well as the assessment of current state of the art innovations were analyzed. The atomic and hereditary pathways that microorganisms and plants use to aggregate and endure weighty metals have been explained. The need for remediation methodology, levels of soil defilement, site conditions, far and wide selections, and various conceivable outcomes happening at various phases of cleanup are portrayed exhaustively. Massive efforts to rehabilitate polluted soils have caused significant problems. Wang, L., et.al., (2021).explains these environmentally friendly remediation techniques as well as the cutting-edge soil additives used in these eco-friendly methods. Because iron-based additions have the best stabilization performances for both metallic cations and oxyanions and cause very little disturbance to the soil, they are the most promising options for green remediation. Conversely, regardless of whether squander determined materials are cheap, they have a more drawn-out term hazard of delivering pollutants, which brings down their general supportability. The "greenest" remediation procedures have been demonstrated to be phytoremediation and green revision-based S/S; regardless, judicious decisions ought to be founded on the results of case-explicit manageability evaluations. Lastly, it is suggested that combining a number of green remediation strategies could improve remediation effectiveness in a complementary way. Xu, D. M., et.al., (2021).examined the state of heavy metal pollution in the soils close to Chinese nonferrous metal smelters. After that, a thorough discussion of their primary source methodologies and the health risk concerns for soil remediation was held. It should be mentioned that incomplete risk assessments might lead to expensive corrective actions and inadvertent changes. Additionally, the main focus was on the most current developments in the cleanup of damaged smelting sites. In contrast, stakeholders now have access to a restricted number of innovative remedial options. In order to draw attention to research deficiencies, significant considerations about site cleanup technologies were also made. Therefore, more creative research has to be done to improve smelter site rehabilitation. The assessment came to a close with a forecast for future research directions, which should be very beneficial to the wide range of researchers working in this area. Zhang, H., et.al., (2020).looks at the utilization of bioremediation for blend pesticide and weighty metal-defiled soil. The bioremediation of weighty metals and pesticides can be affected by both biotic and abiotic boundaries, like pH, temperature, the bioavailability of toxins, the connections between contaminations, natural intensity, and organic state. The current review, meantime, provides an overview of the processes by which microbes and plants bioremediate pesticides and heavy metals. A review is also conducted of the techniques used to assess the efficacy of soil remediation. In light of the aforementioned, this review suggests the further research needed in this area.

Research Methodology

Research Design- In order to methodically assess the long-term effects of different inorganic fertilizers and organic manure on heavy metal buildup in Vertisols, the study used an experimental design. In order to examine the impact of fertilizer and organic input combinations and doses on soil contamination and nutrient availability, this strategy incorporates numerous treatments. The project is to ascertain the impact of long-term fertilizer use on both hazardous and important heavy metals by comparing the effects of various treatments. This will provide insights into soil management techniques that minimize contamination while increasing soil health.

Study Location- Vertisols, which are distinguished by a high clay concentration that influences nutrient availability and water retention, were the subject of the study. The suitability of the experimental site for soybean-wheat cropping sequences—a typical agricultural practice in the area—led to its selection. This site is perfect for the study since it has had fertilizer applied continuously for more than 35 years, enabling a thorough assessment of the combined effects of these inputs on fertility and soil metal concentration. Applying fertilizers over an extended period of time offers a pertinent setting for researching the persistence and effects of heavy metals in soil.

Soil Sampling- A standard depth of 0–15 cm was used to gather soil samples from each treatment plot in order to evaluate surface soil contamination. Throughout the cropping cycle, sampling was done several times to record changes in metal concentrations over time. To guarantee that the data appropriately depict the average soil conditions of every treatment plot, composite samples were collected. Samples were collected, air-dried, crushed, and sieved through a 2 mm mesh screen in order to get them ready for analysis. Samples were handled and stored properly to avoid contamination and guarantee accurate results.

Heavy Metal Analysis- The standard method for detecting metal content, atomic absorption spectrophotometry (AAS), was used to examine the amounts of heavy metals in the soil. The elements that were the subject of the analysis were zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and dangerous metals (cadmium (Cd), lead (Pb), nickel (Ni), and chromium (Cr)). To precisely assess each metal's concentration, mg/kg was used. A statistical study was performed to assess the effects of different treatments on metal buildup and compare metal concentrations across treatments. CD (P = 0.05) was used to identify significant differences.

Table 1: Sources of heavy metals

Heavy Metal	Sources
Cadmium	Geological origins, human activity, the smelting and refining of metals, burning fossil fuels, the use of phosphate fertilizers, and sewage sludge
Chromium	tanneries, sludge, solid waste, and the electroplating industry
Lead	Mining and refining metalliferous ore, incineration of lead-contaminated gasoline, urban sewage, Pb-enriched industrial effluent, and paints
Nickel	Landfill collapses, wildfires, oceanic bubble bursts and gas exchanges, as well as the weathering of soils and geological materials

Figure 1: Heavy metals can come from both natural and manmade sources.

Lead, nickel, cadmium, and chromium are examples of heavy metals that come from different sources and contribute to environmental contamination in different ways. The main ways that cadmium enters the environment are through natural geogenic processes and human activity. These activities include burning fossil fuels, applying phosphate fertilizer, smelting metal, and disposing of sewage sludge. Industrial operations include electroplating, the disposal of sludge and solid waste, and tannery operations are frequently the source of chromium contamination. On the other hand, natural occurrences like forest fires and volcanic eruptions, as well as man-made sources like landfills and oceanic gas exchanges, emit nickel. Understanding these sources is essential for managing and reducing heavy metal pollution and protecting the environment and public health.

Data Collection and Analysis

The process of gathering data included determining the amounts of dangerous and necessary heavy metals in soil samples from various treatments. ANOVA was used in the statistical analysis to evaluate the variations in metal concentrations among treatments. Post-hoc analyses were used to pinpoint certain noteworthy variations and trends in the accumulation of metals. The goal of the analysis was to ascertain how various applications of manure and fertilizer affect the levels of heavy metals and the availability of nutrients in the soil.

Phytoremediation Potential- The possibility of phytoremediation, a method that employs plants to absorb and extract heavy metals from contaminated soils, was also investigated in this study. The capacity of a variety of plant species to withstand and accumulate heavy metals was assessed, with an emphasis on choosing plants that are both practical for large-scale application and efficient at eliminating pollutants. The study evaluated the potential of several species for managing soil contamination and their efficacy in lowering metal concentrations in the soil.

Sustainability Evaluation- By contrasting the measured quantities of heavy metals in the soil with the safe thresholds suggested for agricultural soils, the sustainability of fertilizing techniques was assessed. The study looked at how FYM can improve soil fertility and lower the buildup of dangerous metals. The study sought to find a balanced strategy that avoids metal contamination while maximizing nutrient availability by combining FYM with chemical fertilizers. Making sure that fertilizer techniques support long-term soil health and productivity was the main goal of the sustainability evaluation.

Data Analysis

Basic Chemistry of Heavy Metals- The accompanying weighty metals are available in contaminated soils arranged by overflow: Pb, Cr, As, Zn, Album, and Cu. Due to the chance of bioaccumulation in the pecking order, these metals can possibly bring down crop efficiency. Since the destiny and science in soil are vigorously reliant upon the substance type of the weighty metals, essential science is expected to grasp the bioavailability and restorative prospects of these weighty metals in the dirt (Table 1). Weighty metals are reallocated into a few synthetic structures with variable bioavailability, portability, and poisonousness after they are adsorbed on soil colloids. Notwithstanding, it is imagined that the appropriation is constrained by how weighty metals respond in soil, including particle trade, mineral precipitation and disintegration, adsorption and desorption, fluid complexation, natural immobilization and activation, and plant retention.

Table 2: Basic chemistry of the heavy metals

Heavy Metals	Atomic Number	Atomic Weight	Density (g/cm³)	Melting Point (°C)	Boiling Point (°C)
Chromium (Cr)	24.0	52.0	7.19	1875.0	2665.0
Nickel (Ni)	28.0	58.7	8.90	1455.0	2913.0
Copper (Cu)	29.0	63.5	8.96	1083.0	2595.0
Zinc (Zn)	30.0	65.4	7.14	419.5	906.0
Arsenic (As)	33.0	75.0	5.72	817.0	613.0
Mercury (Hg)	80.0	200.6	13.6	-38.8	357.0
Cadmium (Cd)	48.0	112.4	8.65	320.9	765.0
Lead (Pb)	82.0	207.2	11.40	327.4	1725.0

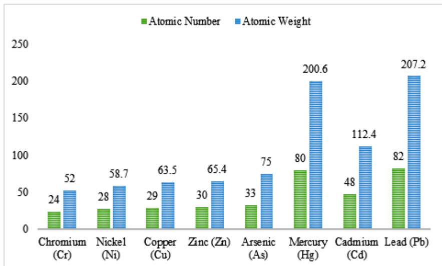

Figure 2: Basic chemistry of the heavy metals

Effects of continuous inorganic fertilizer application on heavy metal buildup in vertisols- The consequences of the drawn-out compost try utilizing a soybean-wheat editing grouping in a Vertisol are displayed in tables 3 and 4. It was found that the consistent use of different rural sources of info (inorganic composts and natural excrements) to the dirt caused the items in dangerous weighty metals (Disc, Pb, Ni, and Cr) and fundamental weighty metals (Zn, Fe, Mn, and Cu) to essentially collect. Besides, the treatment getting very ideal portion manures (150% NPK through urea, SSP, and MOP, individually) had the best groupings of Cd, Pb, and Ni, though the control plot had the least qualities. By the by, even following 35 years of serious editing with consistent uses of various inorganic composts and natural excrement, the basic weighty metals (Zn, Cu, Fe, and Mn) are not restricting variables. The 100 percent NPK+15 t FYM ha-1treatment plots had the most noteworthy items in fundamental weighty metals, which is plainly on the grounds that ranch yard excrement speeds up the accessibility of these fundamental weighty metals yearly. 150% NPK medicines came in second, and the control plot had the most reduced values.

Table 3: Content of Hazardous Heavy Metals (mg/kg)

Treatments	Cd	Pb	Ni	Cr
50% NPK	0.032	1.733	0.357	0.134
100% NPK	0.034	1.809	0.388	0.156
150% NPK	0.042	1.886	0.405	0.180
100% NP	0.026	1.630	0.327	0.052
100% N	0.020	1.764	0.514	0.143
100% NPK + FYM	0.018	1.591	0.296	Trace
100% NPK – S	0.017	1.742	0.327	0.047
Control	0.018	1.425	0.195	Trace
CD (P = 0.05)	0.01	0.15	0.05	0.01

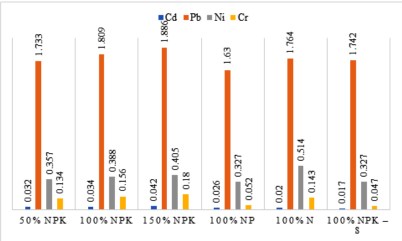

Figure 3:Content of Hazardous Heavy Metals (mg/kg)

Table 4: Content of Essential Heavy Metals (mg/kg)

Treatments	Zn	Fe	Mn	Cu
50% NPK	0.47	20.64	17.20	1.58
100% NPK	0.48	21.81	17.91	1.40
150% NPK	0.75	26.05	16.84	1.64
100% NP	0.53	28.73	19.65	1.46
100% N	0.50	19.71	12.56	1.25
100% NPK + FYM	0.92	31.04	16.58	1.82
100% NPK – S	0.49	26.89	15.00	1.32
Control	0.42	17.04	14.19	1.18
CD (P = 0.05)	0.09	2.32	1.60	0.18

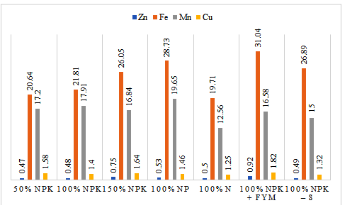

Figure 4: Content of Essential Heavy Metals (mg/kg)

Higher doses of NPK fertilizers, especially at 150%, result in an increased buildup of hazardous metals like cadmium (Cd), lead (Pb), nickel (Ni), and chromium (Cr), posing possible contamination issues, according to an analysis of the heavy metals content in soils under different treatments. Nevertheless, this accumulation is much decreased when farmyard manure (FYM) is added to the 100% NPK + FYM treatment, indicating that FYM may help lessen the harmful consequences of overuse of fertilizers. On the other hand, treatments containing FYM were found to have higher concentrations of important heavy elements as zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu), suggesting improved soil fertility and nutrient availability. Therefore, mixing FYM with chemical fertilizers offers a balanced approach that promotes healthier and more sustainable soil management by minimizing the accumulation of harmful metals and increasing the availability of vital nutrients.

Conclusion

The study emphasizes the substantial influence of numerous man-made and natural sources on heavy metal pollution in soils. Metals like nickel, cadmium, chromium, and lead are introduced through industrial processes, waste disposal, and natural processes like weathering and volcanic eruptions. The persistent use of inorganic fertilizers, especially in excess, leads to the build-up of dangerous heavy metals in agricultural soils, which can be detrimental to crop yield and soil health. But adding organic inputs, such as farmyard manure (FYM), turns out to be a smart way to lessen these risks because it not only keeps dangerous metals from building up but also increases the availability of important heavy metals like zinc, iron, manganese, and copper, which are critical for plant growth. This study emphasizes how crucial it is to incorporate sustainable soil management techniques, such as the sensible use of chemical and organic fertilizers, in order to maintain soil fertility over the long run and reduce the negative consequences of heavy metal contamination.

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