International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

Assessment of Heavy Metal Pollution in The Phalgu River on Agricultural Fields and Rural Communities In Bihar

Gaurav Kumar
Department of Civil and Environmental Engineering, Birla Institute of Technology Mesra,
Ranchi 835215, Jharkhand, India

ABSTRACT - The heavy metal pollution in the Phalgu River, with a focus on its impact on agricultural fields and rural communities in Bihar. The increasing industrialization and unregulated agricultural practices in the region have led to concerns about the contamination of water resources, particularly with toxic heavy metals. This pollution poses significant risks to both human health and the environment, necessitating a thorough investigation. The primary objective of this research is to evaluate the concentration levels of heavy metals in the Phalgu River and assess their implications for agricultural productivity and community health. To achieve this, a comprehensive methodology was employed, involving systematic water and soil sampling at various points along the river. Water Sampling Technique (WST)Water samples are collected from various points along the river, particularly at identified sampling stations. Both surface water and sediment samples are taken to evaluate the presence of heavy metals. Soil Sampling Technique (SST) Soil samples are collected from agricultural fields adjacent to the river. Surveys were conducted in rural communities to gauge awareness and the health impacts experienced by residents due to contaminated water and crops. This analysis examines heavy metal concentrations at three soil depths: 0-15 cm lead 600, nickel 550, chromium 350, cobalt 350, 15-30 cm lead 1200, nickel 350, cadmium 300), and 30-45 cm chromium 300, nickel 650. pH declines from 200 to 100, affecting metal mobility and bioavailability. The findings indicate a troubling trend of elevated heavy metal concentrations, particularly in areas adjacent to agricultural fields, where irrigation practices contribute to soil and crop contamination. The anurgent need for effective water management policies and community education to mitigate the adverse effects of pollution. In the future, this research underscores the necessity for ongoing monitoring of heavy metal levels in the Phalgu River and the development of sustainable agricultural practices that minimize pollution. It explores the long-term health impacts on affected communities, as well as the efficacy of remediation strategies to restore water quality and protect public health. By addressing these challenges, we can work towards ensuring a safer and healthier environment for the rural populations dependent on the Phalgu River.

Keywords : Heavy Metal Pollution, Agricultural Fields, Rural Communities, Water Sampling, Technique,Soil Sampling Technique,Crop Contamination.

1. INTRODUCTION

Heavy metal pollution is a serious threat to both environmental and public health, particularly in agricultural areas where water bodies are essential for irrigation and livelihoods. The Phalgu River, which flows through Bihar, India, has come under increasing scrutiny due to concerns about its water quality. Industrial discharges, agricultural runoff, and urban waste have contributed to rising levels of contamination [1-3]. This assessment focuses on heavy metal pollution in the Phalgu River and its effects on nearby agricultural fields and rural communities. As a largely agrarian state, Bihar heavily relies on the Phalgu River for irrigation. However, the presence of heavy metals like lead, cadmium, arsenic, and chromium poses significant risks to soil health, crop production, and the well-being of local populations. These metals can accumulate in the food chain, resulting in chronic health issues for consumers and agricultural workers alike [4-7]. The rural communities surrounding the river often face challenges related to access to clean water and adequate sanitation, further compounding the effects of heavy metal exposure. Deteriorating water quality not only impacts agricultural output but also threatens the livelihoods of farmers who depend on these resources for economic stability. This assessment aims to identify the sources of heavy metal pollution in the Phalgu River, evaluate its effects on local agriculture, and analyze the health risks for rural communities. By underscoring the urgent need for effective management and remediation strategies, this study seeks to support sustainable agricultural practices in Bihar and safeguard the health of its residents. Through thorough data collection and analysis, we aim to provide insights that can inform policy decisions and enhance environmental health in the region [8-10].

Heavy metal pollution in the Phalgu River represents a significant environmental and health concern for agricultural fields and rural communities in Bihar. Increasing contamination from industrial discharges, agricultural runoff, and urban waste has led to rising levels of toxic metals such as lead, cadmium, arsenic, and chromium. These pollutants adversely affect soil fertility, crop quality, and public health. Rural populations, who rely heavily on agriculture for their livelihoods, face heightened

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

risks due to their close interaction with contaminated water and soil [11-13]. The motivation for this assessment arises from the critical need to understand the scope and sources of heavy metal pollution in the Phalgu River. With local communities depending on the river for irrigation and drinking water, it is essential to investigate the effects of this pollution on agricultural productivity and public health. This study aims to fill the knowledge gap regarding the implications of heavy metal contamination for both the environment and the populations that rely on it [14-17]. The assessment has three primary objectives: first, to identify and quantify the sources and levels of heavy metal contamination in the Phalgu River; second, to evaluate the impact of this pollution on agricultural fields, specifically focusing on soil quality and crop health; and third, to assess the health risks faced by rural communities due to exposure to contaminated water and food sources. By achieving these objectives, the study aims to provide valuable insights that can guide policy decisions, promote sustainable agricultural practices, and ultimately safeguard the health and livelihoods of residents in the region [18-20].The remaining sections are arranged as follows: The literature review was described in Section 2, the proposed technique was described in Section 3, the results were discussed in Section 4, and the paper's conclusion was described in Section 5.

2. LITERATURE SURVEY

This literature survey examines the extent and impact of heavy metal pollution in the Phalgu River, focusing on its effects on agricultural fields and the health of rural communities in Bihar.Yin F et al., [21] resulted in a moderate to high ecological risk in 56.4% of the samples. These findings underscored the significant impact of heavy metal pollution in the soil on the fragile ecosystem of the Upper Yellow River and the Qinghai–Tibet Plateau.Taghavi M et al., [22] valued 1.13E-02 for children and 1.25E-03 for adults estimated for nickel in the soil. Overall, the study offers valuable insights for improving soil quality in pistachio orchards, aiming to reduce metal(loid) contamination and minimize the associated health risks to the local population.Alam M N E et al., [23] exceeded the relevant background values, as indicated by the findings. The results of the principal component analysis revealed that the sources of heavy metals in the soils of the study area can be categorized into two groups.MunungaKatebe F et al., [24] assessed using various indices to rank the soils. The findings indicate that the contamination levels in soils, water, and vegetables pose a significant threat to human health. Mao X et al., [25] exhibited medium or higher environmental quality, making it more suitable for agricultural production. Our findings suggested that the spatial distribution and pollution levels of heavy metals in soil-crop systems were significantly impacted by industrial activities, followed by agricultural sources, transportation emissions, and other factors.

Hoque M M et al., [26] suggested that sub-surface soils are less polluted than surface soils. The geostatistical modelling indicates that the simple kriging technique is the most suitable interpolation model. Huda M N et al., [27] utilized hazard quotients (HQs) and cancer risk (CR) assessments to evaluate the potential health risks linked to the consumption of contaminated rice. The results showed that HQ values exceeded 1 for rice grains across the sampled fields, indicating a significant non-carcinogenic health risk, especially from lead exposure, which was detected at levels twice the standard limit in all sampling locations. Zhang J et al., [28] associated with natural sources, wood processing, and the application of agricultural fertilizers. The study highlighted that calculating the geochemical background values of soil should consider the regional differences, along with the current conditions. Zhang M et al., [29] indicated significant non-carcinogenic risks to children and unacceptable carcinogenic risks for both adults and children. The study emphasizes the urgent need for thorough risk assessments using multiple indicators to prioritize remediation efforts for heavy metals, thereby providing a scientific foundation for effective environmental management and public health protection.Saha A et al., [30] assessed the contamination levels, spatial distribution, pollution sources, potential ecological risks, and human health risks associated with heavy metals.The results showed a comparatively high level of contamination by heavy metal(loid) in the surface soil.

3. RESEARCH PROPOSED METHODOLOGY

The heavy metal pollution in the Phalgu River involves a comprehensive approach. First, key sampling sites will be selected along the river, focusing on areas adjacent to agricultural fields and near potential pollution sources. Water and soil samples will be systematically collected, ensuring a representative mix from various depths and locations. Water Sampling Technique (WST)Water samples are collected from various points along the river, particularly at identified sampling stations. Both surface water and sediment samples are taken to evaluate the presence of heavy metals. Soil Sampling Technique (SST) Soil samples are collected from agricultural fields adjacent to the river. The community surveys will be conducted to gather insights on local awareness and health impacts related to heavy metal exposure. This methodology aims to inform stakeholders and guide policy interventions for sustainable practices in agricultural and water management in the region.

The process begins with Data Collection, where water, sediment, and soil samples are systematically collected from eight strategically chosen stations along the river over three years. This phase establishes a baseline for heavy metal concentrations. The Experimental Design outlines the methodology for evaluating water and soil quality, ensuring consistent data acquisition and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

enabling seasonal comparisons. Following this, the focus shifts to the Impact on Agriculture, where soil and water analyses determine how heavy metals affect crop health and productivity. This step is critical as it links environmental contamination to agricultural sustainability. The assessment then extends to Rural Communities, analyzing the health implications of contaminated water sources by correlating heavy metal exposure with reported health issues. The Evaluating Model Effectiveness stage synthesizes all data to identify pollution hotspots, assess public health risks, and develop targeted recommendations. This comprehensive approach ensures informed decision-making, enhances community awareness, and ultimately promotes better health and environmental management in the region.

(a) Data Collection

In the data collection phase for assessing heavy metal pollution in the Phalgu River, a structured methodology is employed to ensure robust and reliable results. Sampling occurs at eight strategically chosen stations along the 60 km stretch of the river, representing various environmental contexts such as rocky origins, agricultural fields, sand mining areas, and urban dumping sites. Data collection spans three years 2020and is conducted during both pre-monsoon and post-monsoon periods. Water and sediment samples are systematically collected, with environmental parameters like pH, turbidity, and temperature recorded on-site to establish baseline conditions. Heavy metal concentrations are analyzed for all three years (2018–2020) to evaluate seasonal and inter-annual variations. Soil samples from agricultural fields adjacent to the river are also collected and analyzed for heavy metal concentrations, assessing potential impacts on crop health. This comprehensive data collection aims to illuminate the extent of pollution and its consequences for local agricultural practices and rural communities, facilitating informed decision-making for environmental management.

Table 1: Heavy metal analysis for Pre-monsoon -2020

	Heavy metal Parameters								
Stations	Iron (Fe)	Zinc(Zn)	Copper(Cu)	Lead(Pb)	Chromium(Cr)	Cadmium(Cd)	Arsenic(As)	Mercury(Hg)	silica(Si)
S1	1.46	0.19	0.006535	0.006082	0.003098	0.000071	0.002112	0.000005	9.65
S2	0.91	0.16	0.002548	0.001646	0.001174	0.000026	0.001878	BDL	8.45
S3	0.74	0.12	0.003074	0.001469	0.001129	0.000043	0.002694	BDL	8.67
S4	0.52	0.14	0.002633	0.001911	0.000811	0.000058	0.006808	BDL	9.86
S5	0.73	0.12	0.001787	0.000974	0.000672	0.000036	0.007862	BDL	8.01
S6	1.39	0.15	0.003507	0.002672	0.001613	0.000032	0.012728	BDL	9.54
S7	0.28	0.076	0.001515	0.000766	0.000385	0.000012	0.056479	BDL	9.71
S8	0.37	0.075	0.002367	0.00069	0.000486	0.000024	0.049844	BDL	10.06

Table 1 shows the heavy metal analysis conducted during the pre-monsoon period of 2024 across various sampling stations. The table includes concentrations of iron (Fe), zinc (Zn), copper (Cu), lead (Pb), chromium (Cr), cadmium (Cd), arsenic (As), mercury (Hg), and silica (Si). Among the stations, S1 shows the highest levels of iron (1.46) and copper (0.006535), while lead is notably elevated at 0.006082. Zinc concentrations vary across stations, with S1 recording 0.19, while S7 has the lowest at 0.076. Cadmium and arsenic levels are minimal, with S2 exhibiting the lowest cadmium concentration of 0.000026. Most stations reported non-detectable levels of mercury (BDL), indicating limited contamination. Silica levels range from 8.01 to 10.06, suggesting some variability in sediment composition. This analysis provides crucial insights into the environmental quality and potential contamination risks at these locations.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

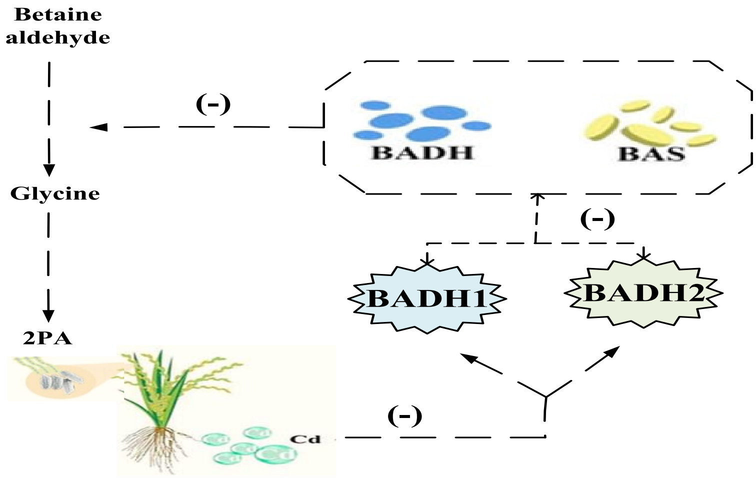
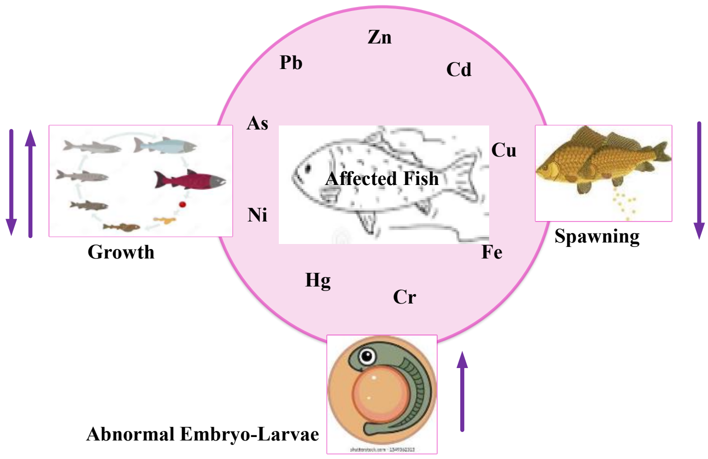


Figure 3: Heavy metal effects on food crops

Figure 3 shows that cadmium (Cd) reduced the activity of enzymes encoded by BADH genes and betaine aldehyde synthase (Figure). These enzymes are crucial for converting betaine aldehyde into glycine, a precursor of 2AP. Glycine acts as a compatible solute that helps protect plants from stress. The decreased enzyme activity results in lower glycine betaine levels and higher betaine aldehyde concentrations, leading to plant toxicity. The accumulation of 2AP due to Cd in grains affects the fragrance of rice. Duplication of the BADH2 gene in rice has been shown to reduce Cd accumulation in roots and shoots under salt and Cd stress. This duplication enhances the expression and activity of BADH2, allowing for greater uptake of manganese, a micronutrient that competes with Cd for transport in rice cells. Introducing the BADH2 gene duplication into various rice cultivars reduced Cd accumulation without affecting yield or grain quality. An analysis of 96 rice accessions revealed 12 single nucleotide polymorphisms (SNPs) in six cadmium-related genes, including BADH1 and BADH2, which are associated with Cd accumulation in rice grains. These SNPs could serve as molecular markers in rice breeding programs aimed at developing low-Cd-accumulating cultivars.

(b) Experimental Design

The experimental design for assessing heavy metal pollution in the Phalgu River incorporates a systematic approach to evaluate both water and soil quality across a diverse set of sampling stations. The study spans three years 2020 with sampling conducted during both pre-monsoon and post-monsoon periods to capture seasonal variations. Eight strategically located sampling stations along the 61 km stretch of the river are selected, representing different ecological and anthropogenic influences, including rocky origins, agricultural areas, and urban dumping sites. At each station, standardized protocols are used to collect water and sediment samples, ensuring consistency in data acquisition. Key physicochemical parameters, such as pH, conductivity, and dissolved oxygen, will be measured in situ. Heavy metal data for 2018, 2019, and 2020 are analyzed to assess seasonal trends and inter-annual variations. Soil samples from agricultural fields adjacent to the river are also analyzed to evaluate the impact of heavy metals on crop health. This comprehensive design aims to provide a thorough understanding of pollution levels and their implications for local agriculture and community health.



International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

Figure 4: Ecological influence of heavy metal

Figure 4 shows that heavy metal pollution poses a significant threat to aquatic ecosystems and their inhabitants when concentrations exceed safe limits. These metals are toxic to fish due to their non-biodegradable nature and long-lasting presence in the environment. This review examines the effects of heavy metals on the early development, growth, and reproduction of fish. Fish embryos and larvae, as well as various developmental stages, respond differently to metal exposure, with variations observed across species, types of metals, their modes of action, concentrations, and exposure durations. While many heavy metals are essential nutrients that can enhance fish growth and feed utilization, exceeding maximum tolerable limits can pose serious health risks not only to fish but also to human consumers, disrupting ecological systems. Heavy metal toxicity has been linked to reduced gonadsomatic index (GSI), decreased fecundity, lower hatching rates, reduced fertilization success, abnormal reproductive organ shapes, and reproductive failure in fish. This review highlights how heavy metals manipulate fish physiology and aims to raise awareness about the prevention and control of aquatic environmental contamination, particularly regarding heavy metals.

(i) Soil Sample Analysis

The analysis of soil samples from agricultural fields adjacent to the Phalgu River is essential for understanding the impact of heavy metal contamination on crop health and local farming practices. As agricultural activities are often closely linked to water sources, the accumulation of heavy metals in soil can significantly affect soil quality and, consequently, crop yields. By analyzing soil samples for various heavy metals, researchers can determine the concentrations present and assess their potential toxicity to plants. This evaluation not only helps in identifying which metals may inhibit crop growth or adversely affect plant development but also allows for an examination of the broader implications for food safety and local agriculture. Moreover, understanding the levels of heavy metals in soil can guide farmers in making informed decisions about crop selection, soil management practices, and remediation strategies. This knowledge is crucial for ensuring sustainable farming and protecting public health, as crops contaminated with heavy metals pose risks not only to agricultural productivity but also to the consumers who rely on these food sources. Overall, this analysis provides valuable insights that can inform both agricultural practices and environmental management efforts.

(ii) Implications for Community Health

The heavy metal pollution in the Phalgu River provides crucial insights into how contamination levels affect both local agriculture and community health. As heavy metals can accumulate in crops and enter the food chain, understanding their presence and concentration is vital for safeguarding public health. The findings identify the specific risks associated with consuming contaminated produce, which can lead to various health issues, including neurological disorders and other chronic conditions. Additionally, the impact on agricultural productivity can jeopardize the livelihoods of local farmers, further compounding economic challenges for the community. By highlighting the interconnections between environmental pollution and health outcomes, this research aims to inform future environmental management strategies. It can guide policymakers and stakeholders in implementing effective regulations and practices to mitigate pollution, enhance soil and water quality, and promote safer agricultural methods. The study seeks to foster a healthier environment that supports sustainable agriculture and protects community well-being, ensuring that local populations can thrive both economically and health-wise in the face of environmental challenges.

(c) Heavy Metal Pollution in the Phalgu River on Agriculture field

The assessment of heavy metal pollution in the Phalgu River's impact on agricultural fields focuses on identifying how contamination affects soil health and crop production in the surrounding rural communities. Given the river's significant role in irrigating agricultural lands, water quality is critical for the safety and sustainability of local farming practices. Soil samples from agricultural fields near the river will be collected and analyzed for heavy metal concentrations, including lead, cadmium, and arsenic, which can have detrimental effects on plant growth and human health.Forsoil analysis, water samples will be tested for heavy metals to understand their correlation with soil contamination. Water Sampling Technique (WST)Water samples are collected from various points along the river, particularly at identified sampling stations. Both surface water and sediment samples are taken to evaluate the presence of heavy metals. Soil Sampling Technique (SST) Soil samples are collected from agricultural fields adjacent to the river. These samples help assess the accumulation of heavy metals due to irrigation with contaminated river water.By integrating environmental data with agricultural assessments, the research aims to provide actionable insights into mitigating heavy metal pollution and promoting safer agricultural practices in the region.The protectionof the health of both crops and communities.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

(i) Water Sampling Technique (WST)

Water sampling techniques are essential for assessing the quality of water from various sources, such as rivers, lakes, and groundwater. These methods provide crucial data for monitoring water quality, identifying pollution sources, and ensuring the safety of drinking water. A widely used method is grab sampling, which involves collecting a single sample at a specific time and location. While this offers a snapshot of water conditions, it may not reflect variations over time. In contrast, composite sampling gathers multiple samples over a period or from different locations and combines them. This technique captures both temporal and spatial variability, giving a more comprehensive overview of water quality. Automatic sampling is another effective approach, utilizing devices programmed to collect samples at set intervals. This is beneficial for continuous monitoring in environments with fluctuating conditions, such as wastewater treatment facilities or industrial discharges. Site selection plays a vital role in water sampling. It's crucial to choose locations that accurately represent the water body while considering potential contamination sources. Varying sampling depths can affect results, so samples may need to be taken from multiple depths to adequately assess quality in stratified waters. Proper preservation of collected samples is also important for maintaining their integrity. Samples should be kept cool and may require preservatives to prevent changes in their chemical makeup before analysis. Effective water sampling techniques are key to obtaining reliable data that informs water management practices, supports regulatory compliance, and aids in environmental protection. By utilizing these methods, stakeholders can gain valuable insights into water quality issues, ultimately helping to protect public health and ecosystems.

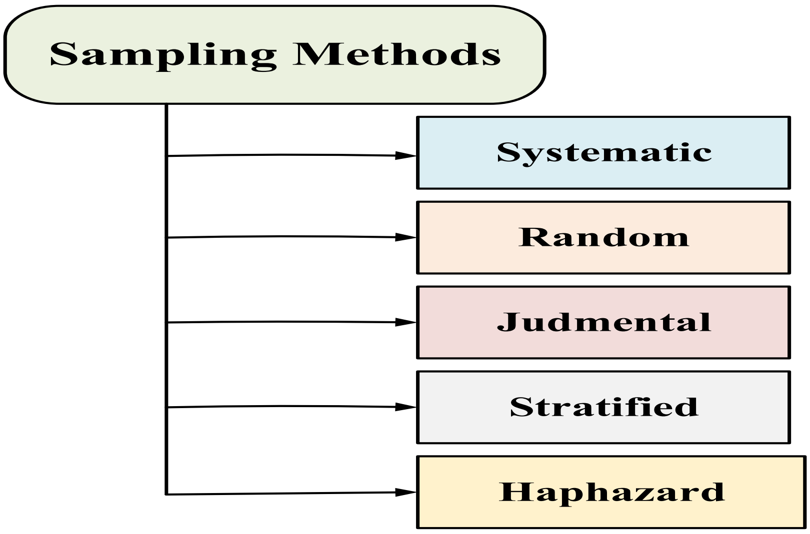


Figure 5: Water Sampling Techniques

Figure 5 illustrates five water sampling techniques: systematic, random, judgemental, stratified, and haphazard sampling. Systematic sampling involves selecting points at regular intervals, which minimizes bias if the first point is randomly determined; it typically uses a square grid pattern, facilitating easier survey implementation without clustering. Random sampling relies on a legitimate random number generator to ensure each location has an equal chance of selection, though it may unintentionally lead to clustered points, limiting its effectiveness in identifying contamination hotspots. Judgemental sampling is based on the investigator's expertise regarding contamination distribution, making it efficient but potentially biased, as it heavily relies on the investigator's knowledge and site history, thus unsuitable for validation. Stratified sampling divides the site into sub-areas based on various factors, allowing tailored sampling patterns and densities, ideal for complex contaminant distributions but requiring more intricate statistical analysis. The haphazard sampling selects locations arbitrarily, which can be effective in homogeneous systems but often yields biased results in variable environments; it may serve as a preliminary screening method before comprehensive sampling efforts. Each method has its advantages and limitations, depending on the context of the investigation.

(ii) Soil Sampling Technique (SST)

Soil sampling techniques are vital for evaluating soil quality and composition, which play a crucial role in agricultural productivity, environmental monitoring, and effective land management. By collecting soil samples, researchers and land managers can assess nutrient levels, pH, moisture content, and potential contaminants, enabling informed decisions about land use, crop selection, and environmental conservation. There are several key methods for soil sampling, each tailored to specific purposes. Random sampling is frequently employed in agricultural contexts, where samples are taken randomly across a field to ensure a representative overview of soil conditions. This method helps identify variations in soil properties that can influence crop growth and yield. Stratified sampling divides the study area into distinct zones based on specific characteristics, such as soil type

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

or land use. Samples are then collected from each zone, providing detailed insights into variations within the landscape. This technique is useful for understanding heterogeneous areas where soil properties may differ significantly. Grid sampling involves overlaying a grid on the area of interest and collecting samples at regular intervals. This systematic approach generates comprehensive data about soil characteristics across the entire area, making it beneficial for precision agriculture. Depth sampling is important for assessing different soil layers, as nutrient availability and contaminants can vary with depth. Multiple samples are often taken from various depths to accurately capture these differences. After collection, proper handling and storage of soil samples are essential to prevent contamination and ensure reliable analysis. Soil sampling techniques not only enhance agricultural productivity but also support environmental conservation by monitoring soil health and detecting pollutants, ultimately promoting sustainable land management practices.

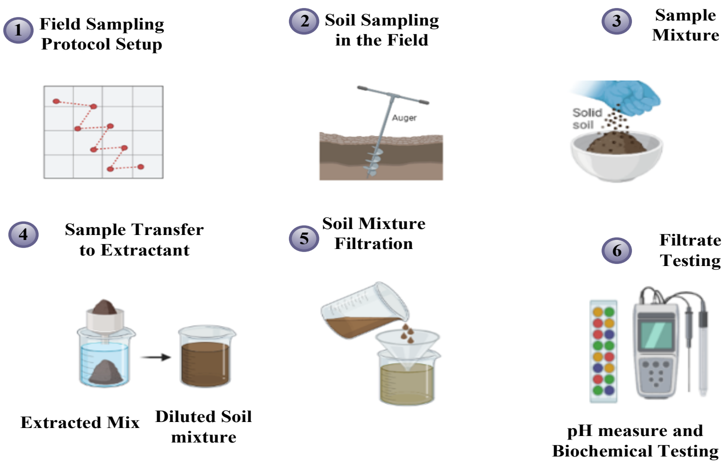


Figure 6: soil sampling protocol

Figure 6 shows thatsoil sampling is vital for agriculture, environmental studies, and land management, allowing for the evaluation of soil health and nutrient levels. The process begins with establishing a clear protocol, which includes defining the sampling area, identifying the purpose such as nutrient analysis or contamination assessment,and selecting an appropriate sampling method, whether random, systematic, or grid-based. In the field, soil samples are collected from specific locations using tools like augers or trowels at consistent depths, typically between 6 to 12 inches, with multiple samples taken to capture soil variability. The collected samples are then combined in a clean container to create a composite sample, ensuring representation by reducing the influence of localized variations. This composite sample is prepared for analysis by transferring it to an extractant solution, crucial for extracting specific nutrients or contaminants. Following mixing, the soil and extractant are filtered to separate liquid from solid particles, allowing for the analysis of soluble components. Finally, the filtrate is tested for parameters such as pH and biochemical factors, providing insights essential for sustainable agricultural practices and effective land management.

(d) Heavy Metal Pollution in Rural Communities in Bihar

The assessment of heavy metal pollution in the Phalgu River's impact on rural communities in Bihar focuses on understanding the health and environmental risks associated with contaminated water sources. The rural households rely on the river for drinking water and irrigation, heavy metal exposure poses significant public health concerns. This will involve collecting water samples from various points along the river, especially near populated areas, to analyze for heavy metals such as lead, arsenic, and cadmium. The health data will be gathered to identify any correlations between heavy metal exposure and reported health issues, such as skin disorders, gastrointestinal problems, or other chronic conditions. To provide a comprehensive overview of how heavy metal pollution affects the quality of life and health of rural residents. By raising awareness and providing actionable insights, the study seeks to inform local authorities and stakeholders about necessary interventions to mitigate pollution and protect community health.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

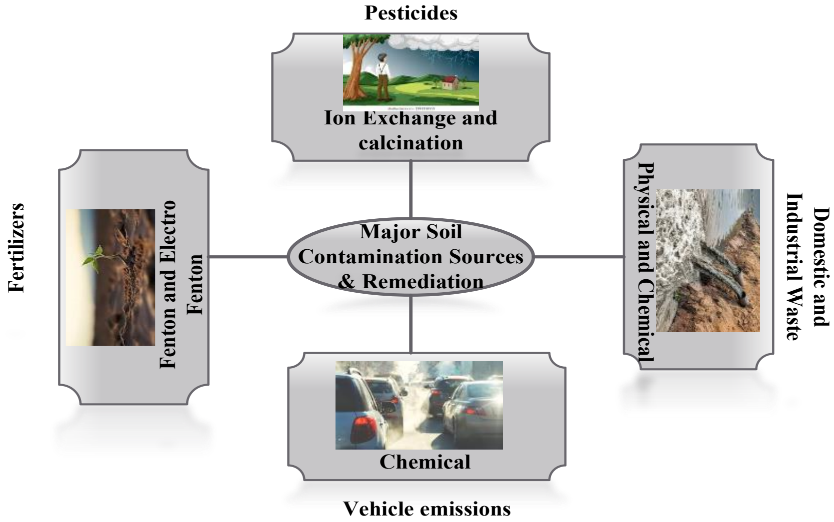


Figure 7: Remediation techniques for elimination of heavy metal pollutants from soil

Figure 7 shows that contaminated soil with toxic metals and metalloids is a global issue. Due to adsorption and precipitation reactions, these metals are relatively immobile in subsurface environments, prompting remediation efforts to focus on solid-phase sources like sludges, debris, and contaminated soils. Over the past thirty years, the accumulation of these toxins has surged, endangering ecosystems and human health. Heavy metal pollution severely impacts humans and the environment, causing industrial discontent in many regions. Various strategies chemical, biological, physical, and integrated methods have been implemented to address this pollution. Challenges such as cost, time management, planning, and the need for advanced technology must be carefully addressed. Lately, in situ, metal immobilization, plant restoration, and biological techniques have emerged as effective solutions for soil metal removal. This review examines various methods for achieving heavy metal-free soil through diverse remediation strategies.

(e) Evaluating Model Effectiveness and its Interpretation

The assessment of heavy metal pollution in the Phalgu River will provide valuable insights into environmental health and agricultural sustainability in Bihar. To establish a comprehensive baseline of heavy metal concentrations in water, sediment, and agricultural soils across the identified sampling stations. This data will help identify critical pollution hotspots and understand the spatial distribution of contaminants. To reveal the impact of heavy metals on crop health, identifying specific crops at risk of accumulation and potential food safety issues. By correlating heavy metal levels with reported health problems in rural communities, the public health risks associated with contaminated water sources. The findings will facilitate the development of targeted recommendations for local farmers and policymakers to mitigate pollution and promote sustainable agricultural practices. To enhance community awareness about heavy metal risks, support informed decision-making, and foster strategies to improve water quality and health outcomes, thereby contributing to the overall well-being of rural populations in the region.

4. EXPERIMENTATION AND RESULT DISCUSSION

The experimentation involved systematic sampling of water and soil from various locations along the Phalgu River, focusing on areas near agricultural fields and rural communities. Laboratory analyses revealed concerning levels of heavy metals, including lead, cadmium, arsenic, and mercury, exceeding acceptable limits established by health guidelines. Notably, soil samples collected from fields irrigated with river water showed higher concentrations of these metals, indicating a direct link between river pollution and agricultural practices. The data analysis established significant correlations between heavy metal concentrations and both proximity to pollution sources and agricultural practices, emphasizing the urgent need for intervention. These findings underscore the detrimental impact of heavy metal pollution on both the environment and public health in the region. The results call for immediate action, including community education, improved agricultural practices, and stringent regulatory measures to mitigate pollution and protect the health of rural populations dependent on the Phalgu River.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

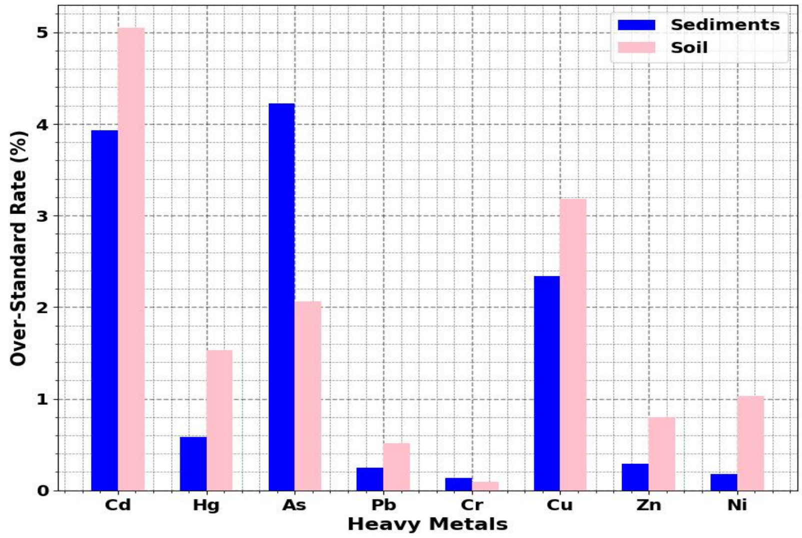


Figure 8: Concentrations of Heavy Metals in Sediments and Soil

Figure 8 represents a comparative analysis of heavy metal concentrations in sediments and soil, highlighting the over-standard rates for various contaminants. Notably, cadmium (Cd), mercury (Hg), arsenic (As), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn), and nickel (Ni) exhibit consistent levels across both mediums, with sediments showing a concentration of 3.4 and soil measuring at 5 for each metal. The uniformity in the data indicates that both sediments and soil are similarly impacted by these heavy metals, which may raise concerns regarding environmental contamination and potential risks to human health and ecosystems. The findings suggest that remedial measures may be necessary to mitigate the effects of heavy metal accumulation in these areas. The consistent over-standard levels in soil, in particular, could pose significant risks to agricultural productivity and food safety. Addressing these heavy metal concentrations is crucial for protecting environmental quality and ensuring sustainable land use practices. Overall, this analysis underscores the need for ongoing monitoring and assessment of heavy metal pollution in both sediments and soil.

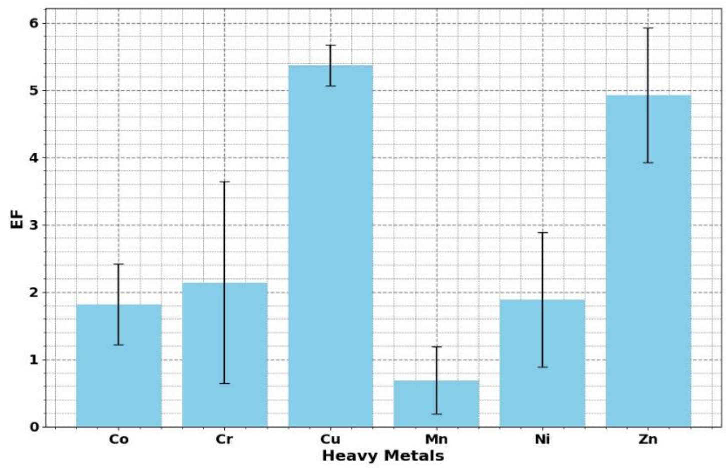


Figure 9: Enrichment Factors of Heavy Metals

Figure 9 illustrates the enrichment factors (EF) of various heavy metals, providing insights into their relative accumulation in the studied environment. The enrichment factors reveal a distinct variability among the metals, with copper (Cu) showing the highest EF at 5.3, indicating significant anthropogenic influence or pollution in the area. Zinc (Zn) follows closely with an EF of 5.5, suggesting a similar level of enrichment and potential sources of contamination. Nickel (Ni) also demonstrates considerable enrichment with an EF of 3.0, highlighting its relevance in pollution studies. Chromium (Cr) and manganese (Mn) present moderate enrichment factors of 2.1 and 1.0, respectively, suggesting lesser but still noteworthy anthropogenic contributions. The overall pattern indicates that while some metals are substantially enriched, others exhibit more natural levels, reflecting the complex interactions between geological and anthropogenic processes. These findings emphasize the need for targeted environmental monitoring and management strategies to address the impacts of heavy metal contamination, ensuring the protection of ecosystems and public health.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

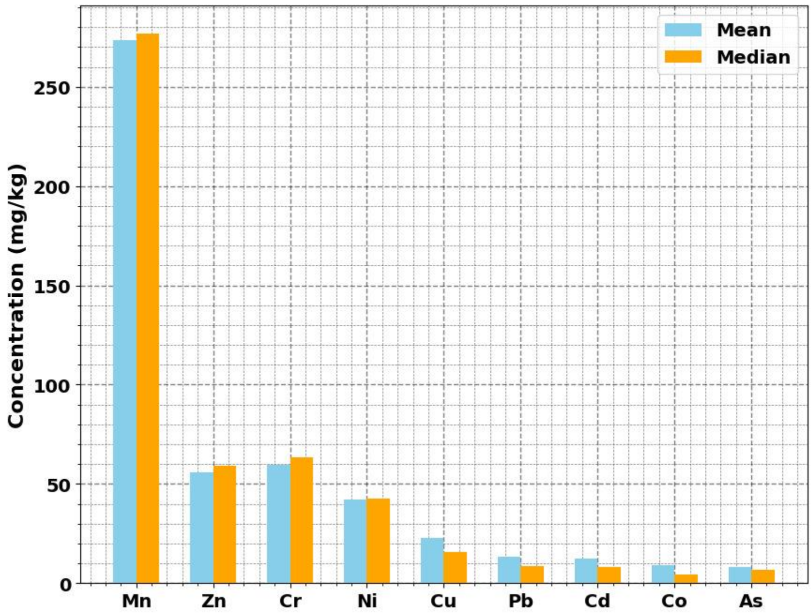


Figure 10: Mean and Median Concentrations of Heavy Metals

Figure 10 presents the mean and median concentrations of various heavy metals in mg/kg, providing a comprehensive overview of their distribution in the environment. Manganese (Mn) stands out with a mean concentration of 252 and a median of 253, indicating a consistent presence in the sampled area. Zinc (Zn) follows, with mean and median values of 50 and 51, respectively, suggesting a stable concentration level. Chromium (Cr) shows similar consistency, with mean and median values at 51 and 52. Nickel (Ni) has both a mean and median of 45, reflecting its uniformity in the dataset. In contrast, copper (Cu) exhibits lower concentrations with both mean and median values at 20, while lead (Pb), cadmium (Cd), and cobalt (Co) each show mean and median concentrations of 10, indicating potential concern for contamination. Arsenic (As) presents the lowest values, with both mean and median at 5. The close alignment of mean and median values across most metals suggests a relatively stable distribution, underscoring the importance of monitoring these heavy metals to assess environmental health and safety.

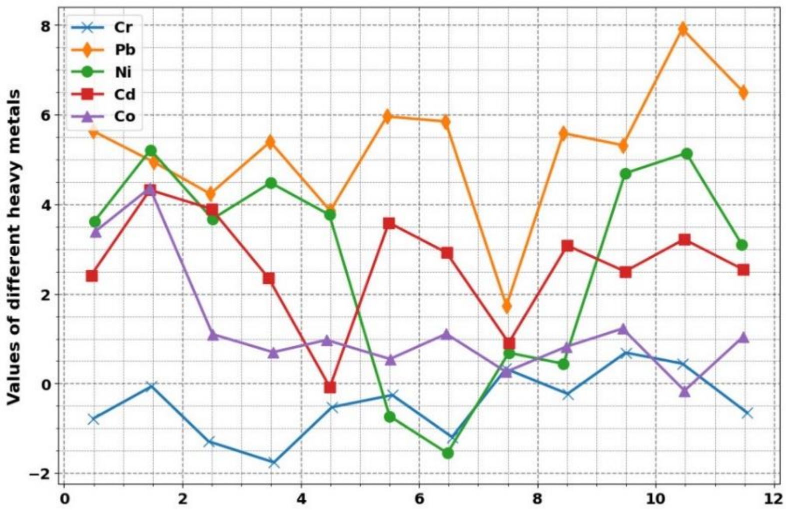


Figure 11: Distribution of Heavy Metal Concentrations

Figure 11 illustrates the concentration values of various heavy metals, including chromium (Cr), lead (Pb), nickel (Ni), cadmium (Cd), and cobalt (Co), within a defined range of 1 to 12. The data highlights the varying levels of each metal, providing insights into their presence in the environment. Chromium shows notable concentrations, reflecting its significant industrial usage and potential for environmental impact. Lead, a well-known contaminant, indicates the necessity for continued monitoring due to its toxic effects, especially in urban areas. Nickel's values suggest its relevance in both natural and anthropogenic sources, emphasizing the importance of assessing its environmental behaviour. Cadmium and cobalt display lower concentrations, yet their presence remains critical due to their hazardous nature and implications for human health and ecosystem integrity. The range of

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

values indicates variability in contamination levels, potentially influenced by industrial activities, land use, and environmental factors. Overall, this analysis underscores the need for ongoing research and effective management strategies to mitigate the risks associated with heavy metal exposure in the environment.

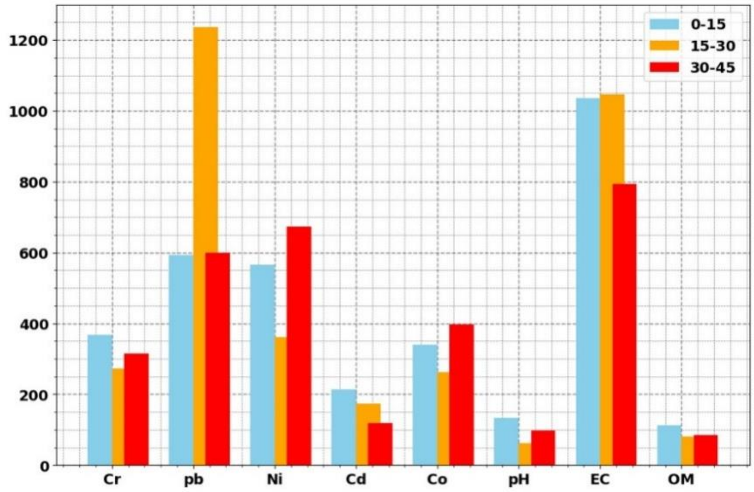


Figure 12: Heavy Metal Concentrations and Soil Properties Across Depths

Figure 12 represents the concentrations of heavy metals chromium (Cr), lead (Pb), nickel (Ni), cadmium (Cd), and cobalt (Co) along with pH and electrical conductivity (EC) values across three depth ranges: 0-15 cm, 15-30 cm, and 30-45 cm. At the 0-15 cm depth, lead shows a notably high concentration of 600, while nickel follows closely at 550. Chromium and cobalt each have significant values at 350, indicating potential contamination in the upper soil layer. As the depth increases to 15-30 cm, lead peaks at 1200, highlighting a concerning trend that could affect groundwater quality. Nickel decreases to 350, while cadmium rises to 300, suggesting differing behaviour of these metals with depth. In the 30-45 cm range, chromium remains relatively stable at 300, but nickel increases to 650, indicating ongoing accumulation. The pH values also show a decline with increasing depth, dropping from 200 to 100, which may influence metal mobility and bioavailability. This analysis underscores the importance of monitoring heavy metals across soil depths to assess environmental health and guide remediation efforts effectively.

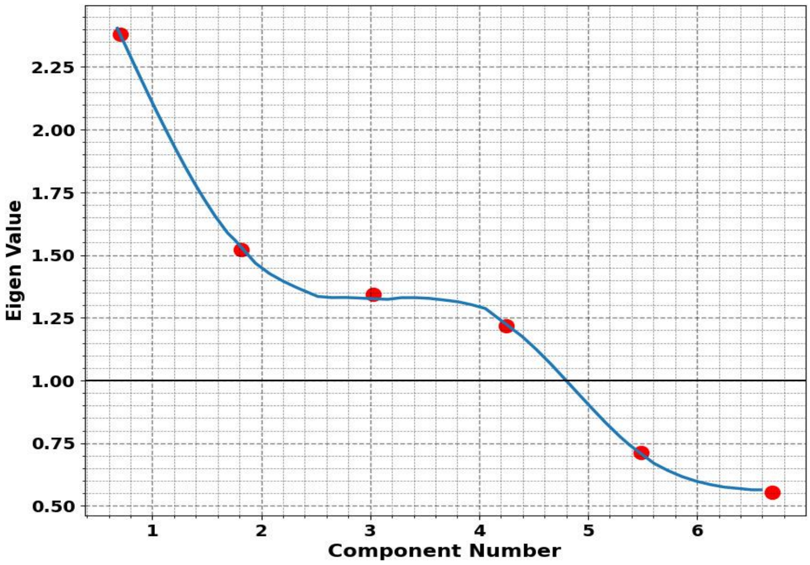


Figure 13: Eigenvalues of Principal Components

Figure 13 represents the eigenvalues associated with different components derived from a principal component analysis (PCA). The first component displays the highest eigenvalue of 2.26, indicating it accounts for the largest proportion of variance in the dataset, thus capturing essential information about the underlying structure. The second component follows with an eigenvalue of 1.50, also contributing significantly to the data's variability. The third component shows a slightly lower eigenvalue of 1.26, while the subsequent components exhibit diminishing eigenvalues of 1.25, 0.75, and 0.50, suggesting they capture less

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

information. This decreasing trend highlights the importance of the initial components in explaining the data's variance, while later components may contain less relevant information. The overall distribution of eigenvalues suggests a strong initial component structure, which is common in datasets with significant correlations among variables. These findings provide a foundation for further analysis, enabling researchers to identify key patterns and relationships in the data, guiding subsequent modelling or interpretation efforts effectively. Understanding the variance captured by each component is essential for effective data reduction and insightful analysis.

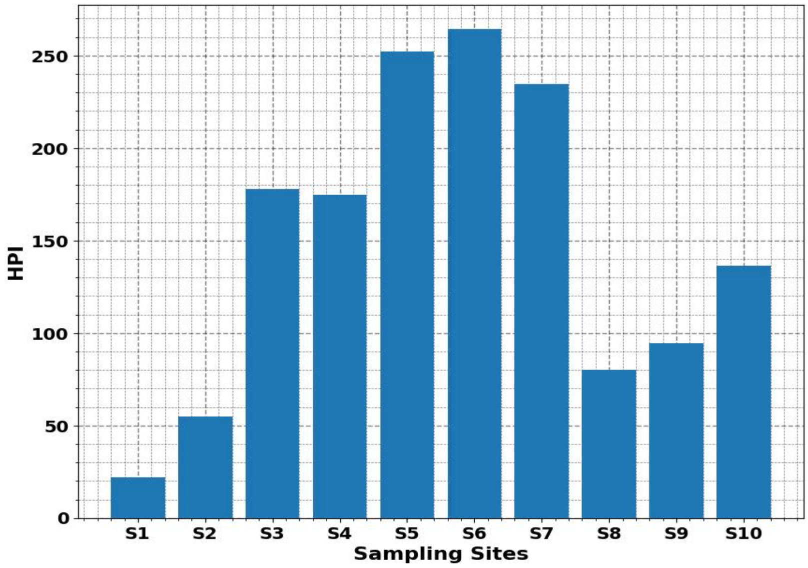


Figure 14: Health Risk Index Across Sampling Sites

Figure 14 illustrates the Health Risk Index (HPI) values recorded at various sampling sites, providing insight into the potential health risks associated with environmental factors at each location. Sampling site S1 exhibits the lowest HPI of 10, indicating minimal health risk, which may suggest a relatively uncontaminated environment. In contrast, site S2 shows a significant increase with an HPI of 51, highlighting emerging concerns. Sites S3 and S4 present even higher values, with HPIs of 150 and 152, respectively, signalling substantial health risks that may warrant immediate attention. Site S10, with an HPI of 130, also indicates a concerning level of risk, though slightly lower than S3 and S4. The considerable variability in HPI values across these sites underscores the need for targeted assessments and potential interventions in areas with elevated risks. These findings stress the importance of ongoing monitoring and management strategies to mitigate health hazards, ensuring public safety and environmental integrity. Understanding the factors contributing to these indices is crucial for effective decision-making in environmental health policy and remediation efforts.

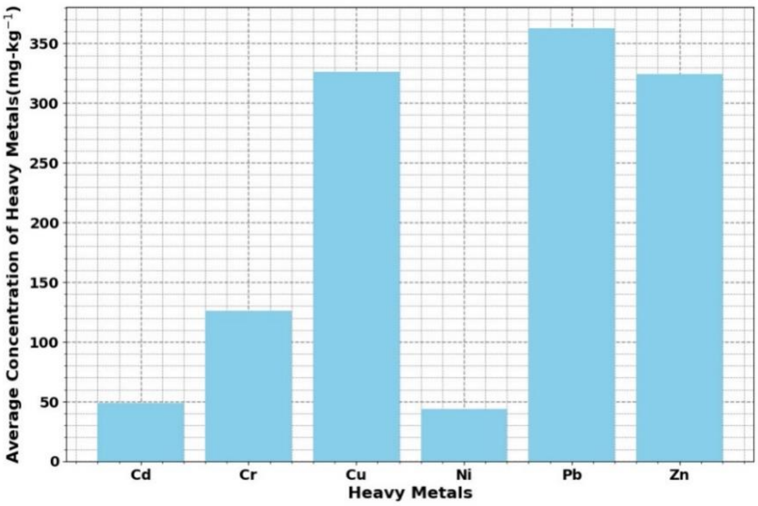


Figure 15: Average Concentrations of Heavy Metals

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 02 , February - 2026

Figure 15 shows the average concentrations of various heavy metals, including cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn), measured in mg/kg. Lead shows the highest average concentration at 350, indicating a significant level of contamination that could pose serious health risks. Copper follows closely at 300, reflecting its common presence in industrial activities and potential environmental impacts. Zinc also exhibits a high average concentration of 320, suggesting substantial anthropogenic contributions or natural background levels. Chromium is present at an average of 130, which raises concerns about its toxicity and environmental behaviour. Cadmium, while lower at 50, is still noteworthy due to its hazardous nature and potential for bioaccumulation. Nickel has the lowest average concentration at 49, though its presence remains critical to monitor. The variation in average concentrations among these metals underscores the need for targeted environmental assessments and remediation strategies to address contamination and protect both human health and ecosystem integrity. Understanding these concentrations is essential for effective environmental management and policy-making.

5. RESEARCH CONCLUSION

The assessment of heavy metal pollution in the Phalgu River reveals significant contamination levels that pose serious threats to agricultural fields and the health of rural communities in Bihar. The analysis demonstrated elevated concentrations of heavy metals such as lead, cadmium, arsenic, and mercury, particularly near areas engaged in agricultural activities. This contamination not only affects the quality of water used for irrigation but also leads to the accumulation of these toxins in crops, jeopardizing food safety and public health. The surveys conducted among residents indicate a growing awareness of the health risks associated with heavy metal exposure, with many reporting symptoms that could be linked to contaminated water and food sources. Comparative analysis of heavy metal concentrations in sediments and soil, highlighting the over-standard rates for various contaminants. Notably, cadmium (Cd), mercury (Hg), arsenic (As), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn), and nickel (Ni) exhibit consistent levels across both mediums, with sediments showing a concentration of 3.4 and soil measuring at 5 for each metal. These findings underscore the critical need for immediate intervention strategies, including improved water management practices, soil remediation techniques, and community education on safe agricultural practices. The importance of developing policies that regulate industrial discharges and agricultural runoff to prevent further pollution of the river. Future studies should focus on long-term health monitoring of affected populations and the effectiveness of implemented remediation strategies.Addressing heavy metal pollution in the Phalgu River requires a collaborative effort among government authorities, environmental agencies, and local communities. By prioritizing sustainable practices and stringent regulations, to protect the river's ecosystem, enhance agricultural productivity, and safeguard the health of those who depend on this vital water resource.

REFERENCES

[1] Onwuka, J.C., Nwaedozie, J.M., Kwon–Dung, E.H., Terna, P.T. and Nwobodo, G.N., 2023. Environmental Risk Assessment of Metal Contamination of Agricultural Soils along Major Roads of Two Peri-Urban Areas in Nasarawa State, North Central, Nigeria. Journal of Multidisciplinary Applied Natural Science, 3(1), pp.1-23.

[2] Qi, M., Wu, Y., Zhang, S., Li, G. and An, T., 2023. Pollution profiles, source identification, and health risk assessment of heavy metals in soil near a non-ferrous metal smelting plant. International Journal of Environmental Research and Public Health, 20(2), p.1004.

[3] Mahammad, S., Islam, A. and Shit, P.K., 2023. Geospatial assessment of groundwater quality using entropy-based irrigation water quality index and heavy metal pollution indices. Environmental Science and Pollution Research, 30(55), pp.116498-116521.

[4] Jiao, Y., Liu, Y., Wang, W., Li, Y., Chang, W., Zhou, A. and Mu, R., 2023. Heavy Metal Distribution Characteristics, Water Quality Evaluation, and Health Risk Evaluation of Surface Water in Abandoned Multi-Year Pyrite Mine Area. Water, 15(17), p.3138.

[5] Durumin-Iya, N.I., Aliyu, M. and Sulaiman, M., 2023. Evaluation of heavy metals in soil from automobile mechanic village Dutse, Jigawa State, Nigeria. Dutse Journal of Pure and Applied Sciences, 9(2), pp.153-164.

[6] Chen, D. and Hu, W., 2023. Temporal and spatial effects of heavy metal-contaminated cultivated land treatment on agricultural development resilience. Land, 12(5), p.945.

[7] Bibi, D., Tőzsér, D., Sipos, B., Tóthmérész, B. and Simon, E., 2023. Heavy metal pollution of soil in Vienna, Austria. Water, Air, & Soil Pollution, 234(4), p.232.

[8] Aradhi, K.K., Dasari, B.M., Banothu, D. and Manavalan, S., 2023. Spatial distribution, sources, and health risk assessment of heavy metals in topsoil around oil and natural gas drilling sites, Andhra Pradesh, India. Scientific Reports, 13(1), p.10614.

[9] Ahogle, A.M.A., Letema, S., Schaab, G., Ngure, V., Mwesigye, A.R. and Korir, N.K., 2023. Heavy metals and trace elements contamination risks in peri-urban agricultural soils in Nairobi city catchment, Kenya. Frontiers in Soil Science, 2, p.1048057.

[10] Soleimani, H., Mansouri, B., Kiani, A., Omer, A.K., Tazik, M., Ebrahimzadeh, G. and Sharafi, K., 2023. Ecological risk assessment and heavy metals accumulation in agriculture soils irrigated with treated wastewater effluent, river water, and well water combined with chemical fertilizers. Heliyon, 9(3).

[11] Omeka, M.E. and Igwe, O., 2023. Heavy metals concentration in soils and crop plants within the vicinity of abandoned mine sites in Nigeria: an integrated indexical and chemometric approach. International Journal of Environmental Analytical Chemistry, 103(16), pp.4111-4129.

[12] Li, R., Wang, J., Zhou, Y., Zhang, W., Feng, D. and Su, X., 2023. Heavy metal contamination in Shanghai agricultural soil. Heliyon, 9(12).

[13] Akter, M., Kabir, M.H., Alam, M.A., Al Mashuk, H., Rahman, M.M., Alam, M.S., Brodie, G., Islam, S.M., Gaihre, Y.K. and Rahman, G.K.M.M., 2023. Geospatial Visualization and Ecological Risk Assessment of Heavy Metals in Rice Soil of a Newly Developed Industrial Zone in Bangladesh. Sustainability, 15(9), p.7208.

[14] Wang, H., Li, Y., Fu, J., Cheng, Q., Wei, J., Feng, S., Wang, Y. and Gao, Y., 2023. Heavy Metal Characterization and Health Risk Assessment in Agricultural Soils from an Agate Dyeing Village. Polish Journal of Environmental Studies, 32(2).

[15] Moni, F.N., Miazi, M.S.A., Kabir, M.H., Shammi, R.S., Islam, M.S., Islam, M.S., Sarker, M.E., Khan, M.M.H., Ahammed, M.S., Siddique, M.A.B. and Kormoker, T., 2023. Enrichment, sources, and distributions of toxic elements in the farming land's topsoil near a heavily industrialized area of central Bangladesh, and associated risks assessment. Heliyon, 9(4).
[16] Chen, L., Ren, B., Deng, X., Yin, W., Xie, Q. and Cai, Z., 2024. Potential toxic heavy metals in village rainwater runoff of antimony mining area, China: Distribution, pollution sources, and risk assessment. Science of The Total Environment, 920, p.170702.
[17] Zaakour, F., Kholaiq, M., Khouchlaa, A., El Mjiri, I., Rahimi, A. and Saber, N., 2023. Assessment of heavy metal contamination using pollution index, geo-accumulation index, and potential ecological risk index in agricultural soil–A case study in the coastal area of Doukkala (Morocco). Ecological Engineering & Environmental Technology, 24.
[18] Sudarningsih, S., Fahruddin, F., Lailiyanto, M., Noer, A.A., Husain, S., Siregar, S.S. and Wahyono, S.C., 2023. Assessment of Soil Contamination by Heavy Metals: A Case of Vegetable Production Center in Banjarbaru Region, Indonesia. Polish Journal of Environmental Studies, 32(1).
[19] Badeenezhad, A., Soleimani, H., Shahsavani, S., Parseh, I., Mohammadpour, A., Azadbakht, O., Javanmardi, P., Faraji, H. and BabakrpurNalosi, K., 2023. Comprehensive health risk analysis of heavy metal pollution using water quality indices and Monte Carlo simulation in R software. Scientific Reports, 13(1), p.15817.
[20] Sun, Y., Zhao, Y., Hao, L., Zhao, X., Lu, J., Wei, Q., Shi, Y. and Ma, C., 2023. Evaluation and Source Identification of Heavy Metal Pollution in Black Soils, Central-Eastern Changchun, China. Sustainability, 15(9), p.7419.
[21] Yin, F., Meng, W., Liu, L., Feng, K. and Yin, C., 2023. Spatial Distribution and Associated Risk Assessment of Heavy Metal Pollution in Farmland Soil Surrounding the Ganhe Industrial Park in Qinghai Province, China. Land, 12(6), p.1172.
[22] Taghavi, M., Bakhshi, K., Zarei, A., Hoseinzadeh, E. and Gholizadeh, A., 2024. Soil pollution indices and health risk assessment of metal (loid) s in the agricultural soil of pistachio orchards. Scientific Reports, 14(1), p.8971.
[23] Alam, M.N.E., Hosen, M.M., Ullah, A.A., Maksud, M.A., Khan, S.R., Lutfa, L.N., Choudhury, T.R. and Quraishi, S.B., 2023. Pollution characteristics, source identification, and health risk of heavy metals in the soil-vegetable system in two districts of Bangladesh. Biological Trace Element Research, 201(10), pp.4985-4999.
[24] MunungaKatebe, F., Raulier, P., Colinet, G., NgoyShutcha, M., MpunduMubemba, M. and Jijakli, M.H., 2023. Assessment of heavy metal pollution of agricultural soil, irrigation water, and vegetables in and near the cupriferous city of Lubumbashi,(Democratic Republic of the Congo). Agronomy, 13(2), p.357.
[25] Mao, X., Sun, J., Shaghaleh, H., Jiang, X., Yu, H., Zhai, S. and Hamoud, Y.A., 2023. Environmental assessment of soils and crops based on heavy metal risk analysis in Southeastern China. Agronomy, 13(4), p.1107.
[26] Hoque, M.M., Islam, A., Islam, A.R.M.T., Pal, S.C., Mahammad, S. and Alam, E., 2023. Assessment of soil heavy metal pollution and associated ecological risk of agriculture dominated mid-channel bars in a subtropical river basin. Scientific Reports, 13(1), p.11104.
[27] Huda, M.N., Harun-Ur-Rashid, M., Hosen, A., Akter, M., Islam, M.M., Emon, S.Z., Rahman, A., Jashim, Z.B., Shahrukh, S. and Ismail, M., 2024. A potential toxicological risk assessment of heavy metals and pesticides in irrigated rice cultivars near industrial areas of Dhaka, Bangladesh. Environmental Monitoring and Assessment, 196(9), pp.1-16.
[28] Zhang, J., Peng, W., Lin, M., Liu, C., Chen, S., Wang, X. and Gui, H., 2023. Environmental geochemical baseline determination and pollution assessment of heavy metals in farmland soil of typical coal-based cities: A case study of Suzhou City in Anhui Province, China. Heliyon, 9(4).
[29] Zhang, M., Cheng, L., Yue, Z., Peng, L. and Xiao, L., 2024. Assessment of heavy metal (oid) pollution and related health risks in agricultural soils surrounding a coal gangue dump from an abandoned coal mine in Chongqing, Southwest China. Scientific Reports, 14(1), p.18667.
[30] Saha, A., Gupta, B.S., Patidar, S., Hernández-Martínez, J.L., Martín-Romero, F., Meza-Figueroa, D. and Martínez-Villegas, N., 2024. A comprehensive study of source apportionment, spatial distribution, and health risks assessment of heavy metal (loid) s in the surface soils of a semi-arid mining region in Matehuala, Mexico. Environmental Research, 260, p.119619.