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Study on Agricultural Runoff Causing Heavy Metal Contamination in Surface Waters

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Abstract: In recent years, the detrimental effects of agricultural practices on water quality have gained increasing attention. Heavy metal contamination stemming from agricultural runoff has emerged as a significant factor contributing to the degradation of surface water. This comprehensive study takes a deep dive into ecqualogy in surface waters resulting from agricultural runoff. It not only evaluates the extent of contamination but also assesses its profound impact on water quality. Furthermore, the research diligently identifies the sources of pollution, shedding light on the origins of heavy metal contamination in agricultural areas. It employs meticulous data collection and laboratory analysis, ensuring a robust foundation for its findings. Notably, the research doesn't stop at ecological implications but delves into the potential human health effects. Through analysis, it uncovers the health implications associated with heavy metal contamination, underscoring the interconnectedness of environmental and public health concerns. One key finding highlighted in this study is to pollutigate the season efficacy. Ultimately, the analysis reinforces the imperative for continuous monitoring and proactive measures to safeguard our precious water resources. It underscores the need for ongoing efforts to protect against the multifaceted challenges posed by heavy metal contamination in agricultural areas.

Keywords: Heavy metal contamination, Surface water quality, Agricultural runoff, Human health implications, Multifaceted challenges

1. Introduction

Water pollution has become an increasingly pressing issue, affecting approximately 71% of surface water, with a growing portion contaminated by heavy metal pollutants. Inorganic contaminants, including lead, arsenic, antimony, radium, soil sediments, salt, and pathogens, have been classified by researchers as significant contributors to this environmental concern[1]. Water is vital to life and serves a major part in many biological processes. It also serves for an array of economic uses, such living use, transportation, hydropower generation, agriculture, manufacturing, and tourist and commercial activities. The assessment of water quality relies on the use of various standard physicochemical parameters. Table 1 has shown the parameters and their standards as per BIS 10500:2012.
The global concern of water pollution has intensified, and India is grappling with an alarming level of water contamination. Rivers, lakes, ponds, and even groundwater sources in our country have experienced a significant increase in pollution [41]. The preservation of ample water resources for future generations is no longer a local issue but a pressing global dilemma.

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India's freshwater reserves face imminent threats from both natural and human-induced factors [42]. The term "heavy metals" denotes metallic elements with high density, exceeding 4 g/cm3, which are environmentally persistent, non-biodegradable, and prone to accumulating in plants and animals, thereby posing long-term health risks to humans [43].

Table 1: List of parameters and their standards (BIS 10500:2012)

Parameters	**Standards**
Chromium (Cr)	0.05 mg/l
Manganese (Mn)	0.1 mg/l
Iron (Fe)	0.3 mg/l
Nickel (Ni)	0.05 mg/l
Zinc (Zn)	0.05 mg/l

Heavy metals can find their way into the environment through both natural processes and human activities [44]. These sources encompass the natural breakdown of the Earth's crust, mining operations, soil erosion, industrial discharges, urban runoff, sewage effluents, and the application of pest or disease control agents in agriculture[12]. Air pollution fallout also contributes to heavy metal contamination [4]. Over recent decades, there has been increasing concern regarding the impact of various pollutants, including trace metals, pesticides, oil, and fertilizers on environmental components such as soil, plants, and water bodies. In particular, the contamination of aquatic ecosystems has emerged as a significant global issue[46].Figure 1 depicts a visual representation of the complexity of water quality issues related to agriculture of heavy metals [33].

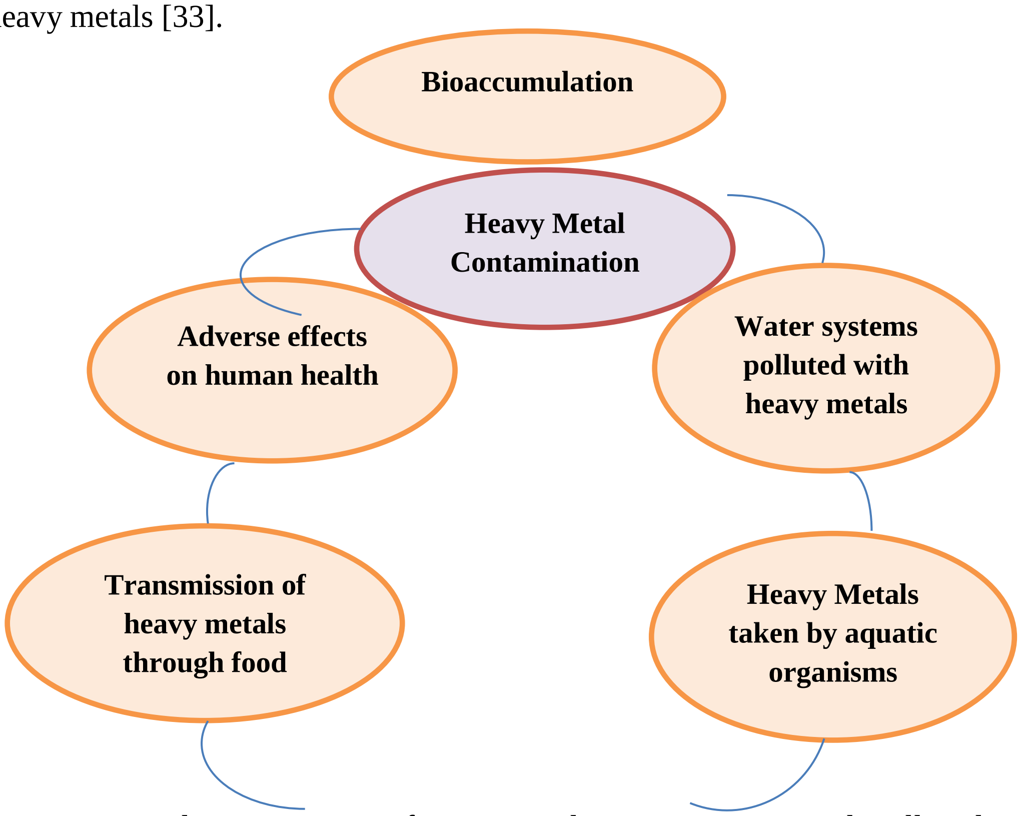

Fig. 1: Pictorial representation of Sources and Transmission agriculturally-related water quality problems of Heavy Metals through food chain

Agriculture undeniably plays a pivotal role in the dissemination of heavy metals into our ecosystems, but a concerted effort is underway to champion Catchment Sensitive Farming practices [14]. These practices are designed to transform the agricultural landscape, ensuring that land management respects and safeguards the ecological well-being of our water environments[10]. However, it is crucial to acknowledge that agriculture doesn't stand alone as the sole perpetrator of this predicament[21].

Indeed, heavy metal contamination extends its reach beyond the agricultural sector. Urban development, transportation systems, and construction activities collectively constitute substantial sources of pollution[9]. Their detrimental impact is far-reaching, affecting the ecology and water quality of various catchment areas. As we endeavour to promote sustainable land use and protect the delicate balance of our water ecosystems, addressing these multiple contributors to heavy metal contamination is paramount[23]. It calls for a holistic and collaborative approach, where all sectors recognize their responsibility in preserving the health of our water environments [45]. The table 2 provides a sources and effects of heavy metals.

Table 2: Sources and Effects of Heavy metals

Heavy Metals	Sources	Effects
Cr	Industrialprocesses-Tanneries,Electroplating,Steel production	Carcinogenic(Hexavalent Chromium),Skin irritation,Respiratory issues,Groundwater contamination
Mn	Naturaloccurrence,Industrial discharge,Mining activities, Fertilizers	Neurological effects, Impaired cognitive development in children, Respiratory problems, Water contamination
Fe	Natural mineral deposits, Industrial discharges, Run off from corroding iron structures	Essential nutrient in small amounts, Excessive iron causes discoloration and taste issues in water, Non-toxic in most cases
Ni	Industrial processes, Stainless steel production, Nickel, cadmium batteries, Mining operations	Dermatitis, Allergic reactions, Carcinogenic (in certain forms), Soil and water contamination
Zn	Galvanization, Metal plating, Mining, Wastewater discharge, Fertilizers	Essential nutrient in small amounts, Excessive zinc can lead to gastrointestinal issues, Toxic to aquatic life in high concentrations, Water contamination

2. Literature survey:

In a study conducted by Dimowo [8], While the assessment of River Ogun revealed significant deviations in various physicochemical parameters, it is noteworthy that heavy metal contamination was not explicitly addressed in this study. However, the findings concerning other key parameters emphasized the unsuitability of the water for domestic use and the pressing need for stringent regulations to safeguard aquatic life from the risk of mass extinction due to anoxic conditions.

Meliga and Salifu [23] While the study primarily focused on variations in physicochemical and biological parameters across monitoring stations and months, the specific presence or impact of heavy metals in the ecosystem was not explicitly addressed. However, the results did highlight the complex dynamics between biological and physicochemical parameters, suggesting a potential for further investigations into heavy metal contamination in the region.
In their study, Iyama and Edori [17] The study on Imonite Creek's water quality in Ndoni, Rivers State, Nigeria, primarily indicated lower concentrations of heavy metals and total dissolved solids, suggesting limited contamination by organic and inorganic pollutants. However, it underscored concerns related to turbidity and the presence of trace amounts of elements like manganese (Mn) in the creek, which warrant further investigation to ensure the safety of the aquatic ecosystem.
Cosmas, et al. [6] The study on seasonal variations in physiochemical and bacteriological parameters of rivers highlighted challenges related to the Njaba River, specifically in terms of slow increases in contaminant loads. While heavy metals were not explicitly mentioned, these findings emphasize the need for comprehensive water quality assessments, which should include an examination of heavy metal contamination and measures for remediation, in addition to pH adjustment and microbial assay improvements.

3. Objectives of the study:

- To quantify and characterize the presence of heavy metals in surface waters affected by agricultural runoff
- To investigate the ecological and human health implications of heavy metal contamination
- To pinpoint the primary sources of heavy metal contamination in agricultural runoff and to evaluate the effectiveness of strategies and practices aimed at reducing heavy metal contamination.

4. Scope of the study:

The central focus of this study is an extensive investigation into heavy metal contamination within surface waters stemming from agricultural runoff. This research is specifically carried out in the Kakinada region of Andhra Pradesh, which was selected for its representation of diverse agricultural practices, including the potential for heavy metal pollution. The data collection process involves a comprehensive approach, encompassing the sampling of water, meticulous analysis of meteorological data, and laboratory assessments of critical parameters, with a particular emphasis on detecting heavy metal contamination. To enhance the understanding of pollutant dynamics, the study employs hydrological modelling to predict the transport of heavy metals. Additionally, the research includes an ecological impact assessment to evaluate water quality and the overall health of aquatic ecosystems, with specific regard to the presence of heavy metals. Furthermore, the study investigates potential implications for human health, particularly concerning drinking water sources and the risks associated with heavy metal exposure. The application of robust statistical analysis aids in identifying trends and correlations within the collected data, thus contributing to a comprehensive understanding of heavy metal contamination. Ultimately, the study's findings serve as a valuable resource for making well-informed land management decisions and shaping policies geared towards mitigating the adverse effects of agricultural runoff, with a specific focus on addressing heavy metal contamination issues.

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5. Methodology:

Study Area Selection:

The initial and primary step in any environmental studies is selecting the study region. Identifying a region or catchment area that properly reflects the diversity of land use and environmental conditions, as well as a wide range of agricultural techniques, is vital. The selection of specific sample locations within the area is also vital, taking into factors like accessibility, land use variety, and proximity to agriculture. For this particular study, Kakinada, a rapidly growing city in Andhra Pradesh, was chosen as the ideal location due to its dynamic development and strategic position for assessing various agricultural practices and their impact on the local environment. Fig. 2 has shown the study area map.

Kakinada, located at latitude 16°57' North and longitude 82°15' East, serves as the administrative capital of the East Godavari District in Andhra Pradesh, India. The primary focus of our study centers on evaluating water quality in Kakinada's agricultural areas, where there is a growing need to monitor the presence of heavy metals. This monitoring is essential not only for environmental safety but also for safeguarding human health. Kakinada's abundance of small water bodies is vital for supporting agricultural activities in the region, underscoring the significance of assessing and ensuring the safety of these water sources.

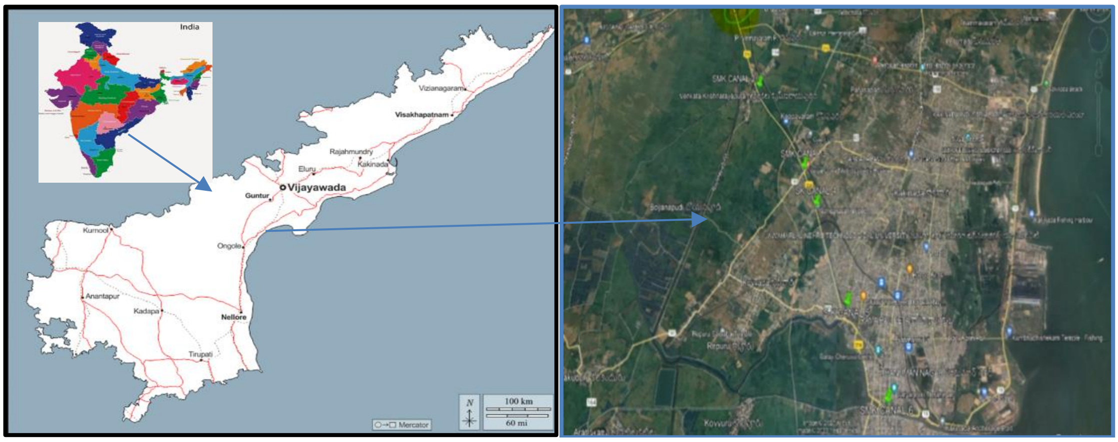

Fig. 2: Study area map

Data Collection:

Water Sampling: Conducting water sampling at regular intervals, typically on a monthly basis over an extended period, ensures that seasonal variations in water quality are comprehensively captured and studied. Maintaining the consistency of the sample level that is, collecting measures at a constant depth of 0.5 m below the water's surface is vital for maintaining the reliability and comparability of the data that was collected. Employing well-established water sampling techniques is essential for accuracy and the ability to make meaningful comparisons of the data collected over time.

Laboratory Analysis:

The laboratory analysis in this study plays a pivotal role, focusing on the comprehensive examination of water samples. These samples undergo a thorough parameter analysis that includes the measurement of heavy metals, utilizing established techniques such as Atomic Absorption Spectroscopy, chemical precipitation, ion exchange, and adsorption. Additionally, the analysis involves the detection and quantification of heavy metal residues, employing methods like chemical precipitation and ion exchange.

Impact Assessment:
An Ecological Impact Assessment for heavy metals is a crucial evaluation of the potential consequences of heavy metal contamination on ecosystems. It involves analyzing contamination levels, pollution sources, and pathways within ecosystems, considering the specific heavy metals involved and their toxicities. This assessment is essential for understanding and mitigating the impact of heavy metal pollution on the environment, wildlife, and human health, requiring collaborative efforts and remediation strategies to ensure ecosystem protection.
The assessment of potential human health implications includes the analysis of drinking water samples to gauge the levels of contaminants present. Additionally, it involves a thorough examination of potential exposure pathways that may stem from the pollution of surface waters, addressing the possible risks to human well-being.

Mitigation Evaluation:
Assessments of mitigation methods, such as buffer strips, nitrogen management, and cover crops, have to be done carefully and based on field data. The comparison of nutrient concentrations before and after the use of various methods is covered in this analysis. It also evaluates shifts in sediment loads in treated and untreated regions and does a cost-benefit analysis to determine the possibility of put different mitigation methods into practice affordably.

Data Analysis:
Within the realm of data analysis for this study, a meticulous approach is employed to not only unravel the intricate factors contributing to diffused pollution in surface waters but also to examine the presence and impact of heavy metals, which are vital components to consider in the context of water quality and agricultural runoff management.

6. Results and analysis:

Water Quality Parameters:
The information contained in Table 3, representing the heavy metal parameters collected throughout a year, serves as a significant resource for evaluating the environmental state of the studied region. These parameters are of utmost importance in the evaluation of the aquatic ecosystem's health and the extent of pollution present in the area. Fig. 3 has shown the Water quality criteria stated graphically.

Table 3: Heavy Metal Parameters in surface waters

Sampling Month	Chromium (Cr) (mg/l)	Manganese (Mn) (mg/l)	Iron (Fe) (mg/l)	Nickel (Ni) (mg/l)	Zinc (Zn) (mg/l)
January	12.43	10.3	226.75	6.94	143.53
February	10.32	9.67	202.85	5.57	139.28
March	9.09	8.83	95.32	5.32	133.81

April	8.46	6.78	65.23	4.92	127.36
May	7.75	6.15	63.46	4.35	100.28
June	6.82	5.47	50.73	4.24	87.23
July	6.19	3.21	39.86	4.04	67.21
August	5.64	1.54	32.38	3.96	58.93
September	4.43	1.32	26.28	3.43	49.31
October	3.32	1.2	22.13	2.85	45.86
November	3.1	1	20.21	2.16	30.68
December	2.3	1.1	16.18	1.80	20.01

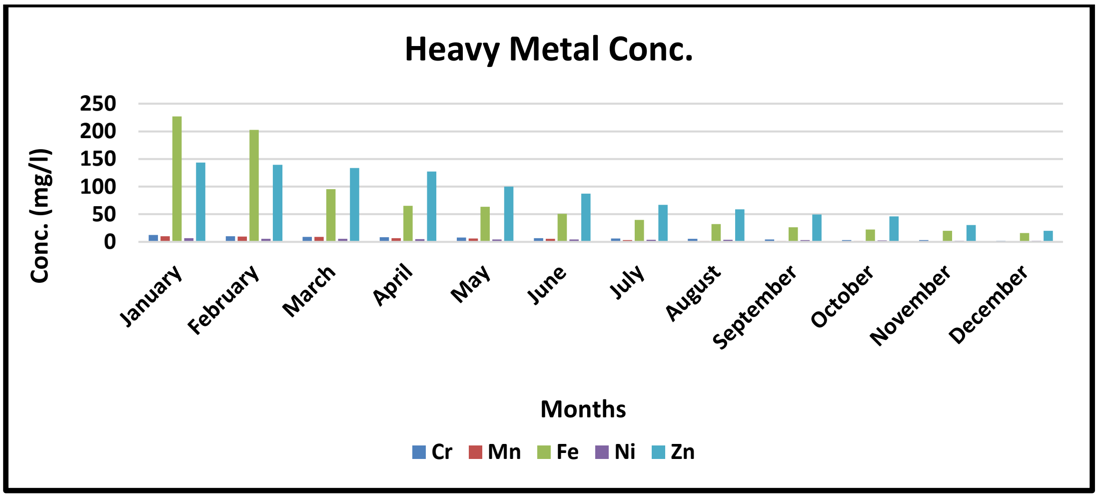

Fig. 3: Water quality criteria stated graphically

The evaluation of water quality measures in this study showed changes in important indicators throughout the year. Chromium levels fluctuate from 12.43 mg/l in January to 2.3 mg/l in December, with most of the variation coming from wastewater and agricultural runoff. Even while these levels are within acceptable bounds, the variations do prompt concerns about potential eutrophication. Manganese levels, on the other hand, have gone up only slightly from 10.3 mg/l in January to 11 mg/l in November. This suggests a seasonal influence, likely connected to agricultural practices and weather conditions. Iron concentrations, on the other hand, show a wide range, spanning from 226.75 mg/l in January to 16.8 mg/l in December, indicating the presence of agricultural contamination in the water. This needs potential mitigation measures as well as ongoing monitoring. There are seasonal variations in the amounts of nickel as well, which vary from 6.94 mg/l in January to 1.80 mg/l in December. This illustrates the dynamics of sediment movement from construction and agricultural areas. Finally, zinc levels, ranging from 143.53 mg/L in January to 20.1 mg/L in December, are still comparatively constant. To identify any variations that would imply pollution or changes in the chemistry of the water, heavy metal concentrations must be continuously monitored. The variations in water quality indicators show how vital it is to conduct careful monitoring in order protect aquatic ecosystems from potential ecological imbalances and pollution problems caused by agricultural practices.

Ecological Impact Assessment:

Table 4 presents an Ecological Impact Assessment, offering valuable perspectives on the environmental well-being and adaptability of the analyzed region with regard to various heavy metals. This assessment revolves around three crucial factors: the Water Quality Index (WQI), the Benthic Macroinvertebrate Index, and the composition of the Fish Community.

Table 4: Ecological Impact Assessment

Heavy metal	Water Quality Index (WQI)	Benthic Macroinvertebrate Index	Fish Community Composition
Chromium (Cr)	76	Excellent	Diverse
Manganese (Mn)	75	Good	Diverse
Iron (Fe)	65	Fair	Limited
Nickel(Ni)	96	Excellent	Diverse
Zinc(Zn)	75	Good	Diverse

The Water Quality Index (WQI) consistently reveals positive water quality conditions for the tested heavy metals. Notably, both chromium and nickel display high WQI values ranging from 76 to 96, indicating excellent water quality. These months often align with a shift from late winter to early summer, when natural processes like more vegetation and less runoff occur. These processes improve water quality and ecological balance. Studying the Benthic Macroinvertebrate Index shows variations in the health of aquatic ecosystems. In months with exceptional water quality, particularly for criteria such as Nickel, the index shows robust ecosystems supporting a variety of species, with populations of microorganisms that are varied and in good condition. Iron, on the other hand, causes the index to fall to a "Fair" level, indicating a weaker macroinvertebrate population. This could be caused by altering environmental factors or local stress that have an impact on the ecosystem. Fish Community Composition varies as well, with a range of communities and an Iron classification of "Limited". This may indicate seasonal shifts in fish behavior or a temporary decline in the overall health of the ecosystem. To understand these changes better, further investigations are essential to identify the specific contributing factors.

Human Health Implications:

The data presented underscores the presence of contaminants in surface water sources and its effects. While some concentrations may be relatively low, it's important to recognize that these levels are significant due to the widespread use of surface water as a drinking source in various regions. It's crucial to remain vigilant about potential exposure pathways, even when contaminant levels fall within acceptable limits.To ensure the safety of surface water supplies, continuous monitoring and assessment are paramount. This becomes particularly vital when considering the potential for seasonal and geographical variations in contaminant presence. Therefore, maintaining a rigorous regimen of water quality monitoring is imperative to protect this essential resource for many communities and safeguard human health.

Limitations of the Study:
This study offers important insights into heavy metal pollution in agricultural areas, but it does come with several limitations. The choice of the study area may restrict the applicability of the findings to regions with different agricultural practices. Furthermore, the study's one-year temporal scope might not account for long-term trends or extreme events in heavy metal pollution. The effectiveness of mitigation measures can be influenced by varying environmental conditions and management practices, warranting further investigation in different contexts.Lastly, the assessment of human health implications in the study is relatively basic, and conducting comprehensive health risk assessments may require additional data and a more in-depth analysis.

7. Discussions and Conclusion:

The infiltration of heavy metals such as chromium, manganese, iron, nickel, and zinc into aquatic ecosystems through agricultural runoff is a matter of significant concern. These metals can accumulate over time and contribute to eutrophication, leading to excessive nutrient levels in water bodies, which can disrupt the delicate balance of aquatic ecosystems.Furthermore, the presence of these heavy metals poses a direct threat to the health of aquatic habitats, potentially causing degradation and reducing their ability to support various species. Additionally, the ongoing introduction of these heavy metals puts surface water quality at risk, impacting not only the environment but also the availability of safe and clean water for various uses, including drinking and recreation. Effective measures to mitigate and monitor heavy metal contamination are essential to address this critical environmental and public health issue.
The detrimental consequences of heavy metal contamination extend beyond the immediate environment, posing a dual threat to both the ecosystem and the integrity of downstream drinking water sources. Our comprehensive analysis of various water quality parameters underscores the imperative need for ongoing monitoring, particularly in agricultural regions where runoff serves as a prominent pathway for heavy metal introduction into aquatic ecosystems. Sustained vigilance in these areas is crucial as it allows for early detection and proactive management, helping to mitigate the potential repercussions of heavy metal contamination and safeguard the well-being of both the environment and human populations relying on these water sources.
Although most variations in heavy metal levels remain within established acceptable limits, they serve as a reminder of the critical need for proactive management practices to avert potential water quality degradation. These seasonal trends also hint at intricate connections between agricultural activities, weather patterns, and fluctuations in water quality, reinforcing the importance of continuous, long-term data collection efforts to better understand and address the complex dynamics of heavy metal contamination in aquatic ecosystems.
The findings of the Ecological Impact Assessment vividly illustrate the dynamic and ever-changing nature of the aquatic ecosystem, particularly with respect to the presence of heavy metals. The observed seasonal fluctuations emphasize the need for in-depth investigation, allowing for the development of precise and effective conservation strategies aimed at safeguarding the ecosystem from the potential impacts of heavy metal contamination. This dynamic interplay between ecological factors and heavy metal dynamics underscores the intricate balance that must be maintained to ensure the long-term health and vitality of aquatic environments. When considering the human health implications, it becomes evident that persistent monitoring remains crucial to protect public well-being, even when contaminant

levels fall within acceptable limits. This comprehensive and interdisciplinary study sheds light on the intricate and diverse challenges associated with diffuse pollution, particularly in agricultural regions, underlining the critical role of proactive management and the continuous collection of data in addressing the complex issue of heavy metal contamination.
In brief, the study clarifies the complex dynamics of agricultural runoff-induced split pollution, giving particular attention to the presence of heavy metals. It shows the value of mitigation techniques like buffer strips and cover crops and stresses the need of continuous observing, proactive management, and well-informed decision-making in conserving water resources. These results offer a strong foundation for solving the complex problems linked to pollution from heavy metals, as well as opening the door for sustainable methods of farming within as well as outside of the study's area.

Conflict of Interest: Every author states that they have no competing interests.

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