Research Paper

Earthworm (lumbricus terrestris) as soil pesticide contamination mitigator

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ABSTRACT

This study examines the potential of earthworms (Lumbricus terrestris) in reducing pesticide contamination in soil. A controlled experiment was conducted using Puradan (0.5%), Ammonium Sulfate 21-0-0 (0.5% and 0.25%), and 14-14-14 Complete Fertilizer (0.5% and 0.25%), with each treatment containing 55 earthworms. One-way ANOVA and t-tests were applied to analyze pesticide contamination levels and earthworm survival rates. Results showed that higher chemical concentrations significantly reduced earthworm populations, with complete mortality observed at 0.5% contamination levels. Findings suggest that Lumbricus terrestris can absorb contaminants but are highly sensitive to chemical toxicity. The 0.5% Ammonium Sulfate group saw a reduction from 55 to 19 earthworms in one week, while the 0.25% group experienced fewer deaths. Excessive chemical use threatens soil health and agricultural productivity. Future research should explore long-term effects in diverse soil conditions and strategies to enhance earthworm resilience in contaminated environments.

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1. INTRODUCTION

Background of the Study

Earthworms are invertebrates belonging to the class Oligochaeta. These soil-dwelling organisms play a crucial role in breaking down organic matter, enriching the soil, and supporting plant growth. Their mucus-covered bodies and small bristles enable movement through various soil types. Through mechanical and biochemical interactions with soil components, earthworms improve soil aeration, drainage, and root penetration. They also help mitigate pesticide-contaminated soil by possessing detoxification systems that tolerate certain levels of potentially toxic elements (PTEs) [1].

Pesticide use in agriculture poses significant environmental risks, contaminating air, water, and soil. While efforts to reduce pesticide pollution often focus on runoff and airborne drift, soil contamination remains a pressing issue. Pesticides applied as drenches, granules, or seed coatings impact soil ecosystems, affecting microbial communities and soil health [2].

Earthworms contribute to pesticide removal through biodegradation, biotransformation, and physical activities. They help disperse toxins, reduce pesticide concentrations, and enhance natural degradation processes. Their interactions with microorganisms accelerate the breakdown of toxic agrochemicals, converting harmful substances into stable resources [3]. With urbanization and industrialization increasing soil contamination worldwide, earthworm-based remediation offers a promising solution [4]. Earthworms enhance phytoremediation and microremediation, promoting plant growth and microbial activity. Despite their potential, research on optimizing earthworm-driven remediation remains limited. Techniques to maximize their effectiveness in pesticide degradation need further exploration [5], [6].

Studies on the impact of agrochemicals on earthworm species in agricultural environments remain scarce. Research has primarily focused on Eisenia fetida and Eisenia andrei, common species in ecotoxicology studies. Earthworms can facilitate pesticide biodegradation, but challenges such as varying soil conditions and chemical toxicity require further investigation. Earthworms account for 60%–80% of soil invertebrate biomass and serve as bioindicators for soil contamination. Soil pollution poses a growing risk to human health, reducing agricultural productivity and food security. Understanding earthworm-mediated pesticide degradation can contribute to sustainable soil management and ecological restoration.

To evaluate their effectiveness, a controlled experiment will assess how earthworms influence pesticide degradation. Soil samples will be prepared, with some contaminated by a specific pesticide. Earthworms will be introduced to the contaminated samples, and pesticide levels, soil characteristics, and earthworm biomass will be monitored. Statistical analysis will determine whether earthworms significantly reduce pesticide concentrations and clarify the mechanisms involved. The study will also explore limitations, practical applications, and implications for sustainable soil management.

This research aims to investigate earthworms as natural agents for soil remediation, focusing on their role in breaking down pesticides through biodegradation, biotransformation, and soil interactions. The hypothesis suggests that earthworms directly reduce pesticide concentrations while enhancing microbial activity, transforming toxic chemicals into stable compounds. Addressing research gaps, this study seeks to optimize earthworm-driven remediation techniques and develop strategies for post-remediation harvesting. By targeting species found in agro-ecosystems, particularly in temperate regions, this research aims to provide a framework for integrating earthworm-based remediation into agricultural practices, promoting environmental sustainability and reducing pesticide-related soil contamination.

Statement of the Problem

The main problem addressed in this study is the use of earthworms (Lumbricus terrestris) in mitigating the contamination of pesticides in agricultural soil. This research will investigate and determine the biology of earthworms (Lumbricus terrestris) in reducing soil contamination from pesticides. To achieve this, the following questions will be answered:

What number of earthworms can mitigate contamination from pesticides?

What percentage of pesticide concentration can earthworms absorb to mitigate contamination?

What microbial assays can assess the influence of earthworms in pesticide degradation?

What specific role is observed in earthworms that improves soil health?

What specific role is observed in earthworms that mitigate pesticide contaminants in soil?

Objectives

The study aims to address the following specific goals:

To determine the number of earthworms that can mitigate contamination from pesticides.
To determine the percentage of pesticide concentration that earthworms can absorb to mitigate contamination.
To determine which microbial assays can assess the influence of earthworms in pesticide degradation.
To determine the specific role observed in earthworms that improves soil health.
To determine the specific role observed in earthworms that mitigate pesticide contaminants in soil.
Statement of Null Hypothesis
Ho1: There is no significant number of earthworms that can mitigate contamination from pesticides.
Ho2: There is no significant percentage concentration that earthworms can absorb to mitigate contamination.
Ho3: There is no significance in the microbial assays that assess the influence of earthworms in pesticide degradation.
Ho4: There is no significance in the role observed in earthworms that improves soil health.
Ho5: There is no significant role observed in earthworms that mitigate pesticide contaminants in soil.
Theoretical Framework.

This study builds on the work of Sims. On bioremediation of contaminated soils, focusing on soil biodegradation and waste characterization. Bioremediation uses microorganisms to break down hazardous chemicals, making soil safer and protecting public health. It is a reliable, cost-efficient approach that requires treatability studies to determine effectiveness. A detailed site assessment is crucial for success, and bioremediation can be integrated into a "treatment train" combining physical, chemical, and biological methods for site cleanup.

Supporting studies highlight bioremediation's effectiveness. O'Malley emphasized moisture control in microbial activity, while Marin explored landfarming of refinery sludge, showing soil properties impact remediation. Findings by Kincannon and Sims confirm landfarming can remediate petroleum-contaminated soils, even in harsh conditions. These studies reinforce bioremediation's adaptability and potential as a sustainable environmental solution.

2. RELATED WORK

Earthworms play a vital role in maintaining ecological balance, especially within forest ecosystems. They contribute significantly to soil health and support plant growth by enhancing physical, chemical, and biological processes that sustain soil fertility. Earthworms help with nutrient recycling, improve soil structure, and promote beneficial microorganisms, making them essential for healthy soil ecosystems [7].

One of the main ways earthworms support soil health is through their burrowing activities. As earthworms tunnel through the soil, they create channels that increase soil porosity, allowing air and water to penetrate deeper into the ground. This improved porosity promotes better root penetration, making it easier for plants to access essential nutrients and water. The increased porosity contributes to greater soil fertility, which supports plant growth. Earthworm activity also helps break down organic matter, releasing crucial nutrients like nitrogen, phosphorus, and potassium back into the soil. These nutrients are vital for plant productivity.

Earthworms also support the growth of beneficial soil microorganisms. Their castings, which contain a high concentration of beneficial bacteria and fungi, help decompose organic material and enrich the soil with nutrients. This relationship between earthworms and microorganisms is essential for long-term soil health. As organic material decomposes, microorganisms release essential nutrients that plants need, creating a sustainable environment for plant growth [8].

Arbuscular mycorrhizal fungi (AMF) also support soil health by forming symbiotic relationships with plant roots. These fungi improve nutrient and water uptake, especially in nutrient-poor soils, and reduce heavy metal toxicity in plants by sequestering contaminants. Combining AMF with organic matter or microbial inoculants can significantly improve soil fertility and enhance plant growth in challenging environments. The interaction between earthworms, microorganisms, and fungi demonstrates the importance of biological processes in maintaining soil health and mitigating contaminants [9].

Earthworms are especially beneficial in addressing contamination caused by heavy metals, pesticides, and excessive nutrients. Heavy metals like lead, arsenic, and cadmium accumulate in soils and pose risks to human health and the environment. Traditional methods of soil treatment, such as chemical interventions or mechanical processes, can be expensive and harmful to the ecosystem. Earthworms offer a more sustainable and eco-friendly solution by breaking down organic contaminants and improving soil structure, which allows for better water infiltration and root growth. Earthworms also contribute to carbon cycling, which is a critical component of the global carbon cycle [10].

In agricultural systems, excessive pesticide and fertilizer use has led to widespread soil degradation. Pesticides, while effective for pest control, harm soil microorganisms and disrupt the broader soil ecosystem. Studies show that pesticides reduce soil enzyme activities and bacterial diversity, making it harder for natural processes to restore soil health. The overuse of fertilizers can also lead to nutrient imbalances, further degrading soil quality and reducing agricultural productivity. Earthworm-assisted restoration offers a solution by promoting the breakdown of pesticides and restoring microbial balance in contaminated soils.

In polluted soils, earthworms are effective at breaking down organic pollutants, improving nutrient cycling, and increasing microbial activity. Their ability to process large amounts of organic material allows them to recycle nutrients and restore soil fertility. Earthworms also improve soil aeration and structure, which increases the bioavailability of nutrients and supports plant growth. However, the success of earthworm-assisted soil restoration depends on factors like environmental conditions and the type of contaminants present. Toxic pollutants can interfere with earthworm survival and activity, so further research is needed to determine optimal conditions for earthworm-based soil restoration [11].

The species Lumbricus terrestris has shown promise in pesticide-contaminated soils due to its superior enzymatic capabilities and resistance to toxic pollutants. This species contains high levels of carboxylesterase and phosphotriesterase, enzymes that break down pesticide residues in the soil. L. terrestris also has a higher tolerance to oxidative stress, which allows it to remain active in contaminated environments [12]. Research into earthworm gut microbiomes is also essential for understanding how earthworms break down pollutants. Pesticides and other chemicals can disrupt the microbial communities in earthworm guts, impairing their ability to process contaminants. Understanding these interactions is key for improving earthworm-assisted bioremediation [13].

In the Philippines, soil degradation is a significant issue, particularly in agricultural regions where heavy metals and excess nutrients from fertilizers have contaminated the soil. Soil degradation leads to reduced crop productivity and threatens food security. Earthworms offer a promising solution by improving soil conditions and reducing contamination. Studies show that earthworms can reduce the levels of heavy metals in contaminated soils, improving crop yields and reducing risks associated with toxic pollutants. The use of earthworms in soil restoration can support sustainable agricultural practices and contribute to food security in the region [14].

Earthworms can be combined with other bioremediation techniques for effective soil management. By integrating earthworms with additives such as biochar, microbial inoculants, or organic matter, soil health can be restored more efficiently. This holistic approach offers a solution to soil contamination, benefiting both agricultural productivity and environmental sustainability

The potential of earthworms in bioremediation extends to other contaminants, including organic pollutants like petroleum products and pesticides. Earthworms can help break down these pollutants and transform contaminated soils into healthier environments. They also support biodiversity by benefiting a variety of other soil organisms, enhancing the ecological functions of soil ecosystems.

While earthworms offer a promising approach to soil restoration, challenges remain, particularly in highly contaminated soils. Factors such as the level of contamination, soil type, and climate conditions affect the success of earthworm-based restoration. Further research is needed to explore optimal conditions for using earthworms in different soil types and to better understand the interactions between earthworms, contaminants, and other soil organisms. Ongoing monitoring is also essential to ensure the long-term sustainability of earthworm-assisted soil restoration. [15]

Earthworms are crucial for maintaining soil health and fertility, particularly in soil restoration efforts in contaminated environments. Their ability to improve soil structure, recycle nutrients, and support microbial life makes them indispensable in promoting ecological balance. Their potential in bioremediation, especially in the context of heavy metal and pesticide contamination, provides a sustainable alternative to traditional methods.

Scope and Delimitations

This research investigates the role of earthworms (Lumbricus terrestris) in bioremediating pesticide-contaminated soil. It focuses on their ability to degrade pesticides and enhance soil fertility through controlled laboratory experiments using chemical analysis, biological assays, and statistical modeling. The study is limited to one earthworm species, a specific pesticide, and controlled conditions. It excludes field experiments, other pollutants, and large-scale bioremediation projects, focusing solely on fundamental biological processes.

Conceptual Framework

This conceptual framework shows that Earthworms (Lumbricus terrestris) are introduced into pesticide-contaminated soil under controlled conditions. Over time, their impact on pesticide degradation, soil properties, and fertility is monitored. Data collected is analyzed to assess bioremediation efficiency, contributing to sustainable soil management insights.

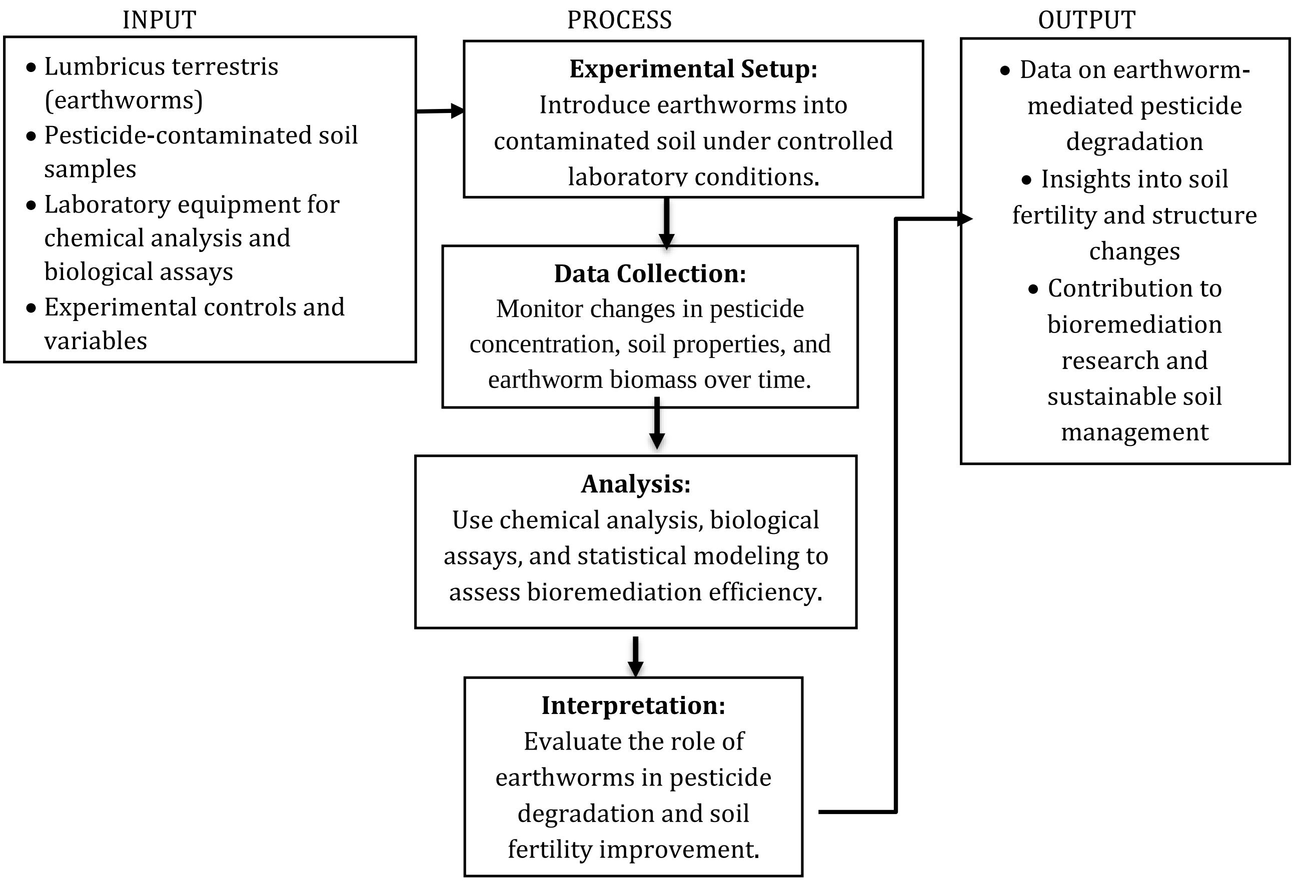


Figure 1. Conceptual Framework

Significance of the Study

The study aims to examine how effective earthworms are in mitigating soil pesticide contamination. The result of the study will benefit the following:

Farmers- This study will help farmers to reduce the soil contamination in the rice field, cost of their expenses, and their dependence on chemical pesticides.

Community- The result of this study will help the community by promoting more sustainable agricultural practices, which will result in healthier ecosystems and soils.

Future researchers- Future researchers will benefit from this study because it contributes to the existing body of information on bioremediation and sustainable soil management. The study opens additional research opportunities, such as investigating different kinds of earthworms and their effectiveness in different soil types and climates.

3. METHODOLOGY

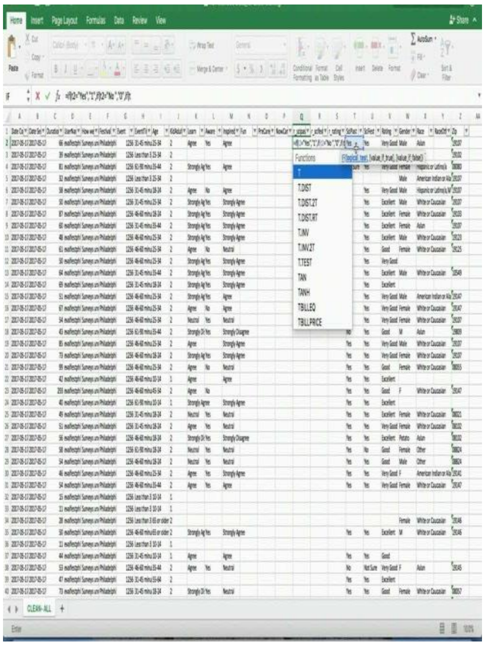
This study employed a laboratory-based experimental design to investigate the bioremediation character of earthworms (Lumbricus terrestris) in mitigating soil pesticide contamination. The research design consisted of three treatments: a control treatment with uncontaminated soil and no earthworms, a pesticide-contaminated soil treatment, and an earthworm treatment with pesticide-contaminated soil. This study provides a comprehensive framework for investigating the bioremediation character of earthworms in mitigating soil pesticide contamination. The results will help understand the underlying mechanisms involved in the bioremediation process and provide valuable insights for developing effective bioremediation strategies for pesticide-contaminated soils.

Materials and Equipment

Table 1. Materials and Equipment

Materials	Usage	Image
Biological Materials - Mature Lumbricus terrestris earthworms (from uncontaminated sources) - Contaminated soil samples (from pesticide-affected agricultural areas) - Uncontaminated control soil	Earthworms were utilized as the primary biological agents for bioremediation experiments. They were introduced into pesticide-contaminated soil to assess their ability to degrade and mitigate.	 Source: https://www.inaturalist.org/taxa/81545-Lumbricus-terrestris
		 Source: https://extension.unh.edu/resource/soil-testing-environmental-contaminants-interpreting-your-heavy-metals-test-results-fact

Containers & Housing -Containers	Containers served as controlled environments for housing earthworms and contaminated soil.	 Source: https://lifegardaquatics.com/products/20-gallon-rimless-clear-glass-aquarium-6mm-24-40x12-20x15-74?variant=41641510699181
Analytical Equipment Sieves Shovel Crowbar	Analytical equipment facilitated quantitative analysis of pesticide residues and soil parameters.	 Source: https://en.m.wikipedia.org/wiki/Sieve  Source: www.bricogroup.com/main/consejos/cesped-sembrado-y-mantenimiento

		 Source: [BuilderWare | Your hardware superstore!]
Data Recording	- Data recording software or logbooks for documenting observations and measurements.	 Source: https://study.com/academy/lesson/how-to-code-recode-data-in-excel.html

Procedure

The experimental procedure for the study, Bioremediation Character of Earthworm (Lumbricus terrestris) in Mitigating Soil Pesticide Contamination, followed these steps. First, soil samples were collected from three or more agricultural fields that used different types of pesticides. Each field represented distinct pesticide usage patterns. The soil was carefully divided into control and treatment groups. These samples were placed in clean, airtight containers to prevent further contamination or loss of volatile pesticide residues.

For each type of soil, two equal portions were prepared: one for the control group, which remained earthworm-free, and one for the treatment group, where Lumbricus terrestris earthworms were introduced. Both groups were placed in separate containers with similar environmental conditions. The control group acted as a baseline for comparison, and the experimental group was monitored weekly to ensure no mortality due to external factors.

Throughout the experiment, soil pH was measured regularly using a pH meter to track any changes caused by the earthworms or pesticide degradation. Soil samples from both groups were collected at predetermined intervals to assess pesticide contamination levels. Additionally, microbial activity was monitored to detect any shifts in microbial populations. At the conclusion of the experiment, the pesticide breakdown in both groups was compared to assess the effectiveness of earthworms in reducing pesticide contamination in soil.

Risk and Safety

Researchers conducting the study were exposed to sunlight while collecting earthworms, and the potential toxicity of pesticides could have harmed the earthworm population, affecting the reliability of results. Introducing earthworms into contaminated soils may have disturbed the natural soil balance. Additionally, earthworms were at risk of injury during handling, which impacted the experiment's success.

To mitigate risks, researchers wore proper personal protective equipment (PPE) such as gloves, lab coats, and goggles, and used sunscreen for skin protection. Strict adherence to safety protocols and guidelines was essential for the safety of both researchers and the environment.

Statistical Analysis Tools

This study examined the potential of Lumbricus terrestris to reduce pesticide contamination in soil. It included a control group with uncontaminated soil and a treatment group with pesticide-contaminated soil and earthworms. Soil samples were stored in airtight containers to preserve pesticide residues.

ANOVA and t-tests were used to analyze the data. One-way ANOVA compared pesticide contamination levels between the groups, with post-hoc tests identifying significant differences. Paired t-tests assessed temporal changes in pesticide levels within the treatment group. Descriptive statistics and effect size were also calculated to understand the results. The findings contribute to developing strategies for mitigating pesticide contamination in soil.

4. RESULTS AND DISCUSSION

Table 2. Results of the Effects of Different Concentration of Ammonium Sulfate on Earthworm after a Week.

Group	Chemical Used	Concentration	Number of Earthworms after 4 Days	Number of Earthworms after 1 Week	Total Number of Earthworm Deceased After 1 Week
C2	None	N/A	N/A	N/A	N/A
AT2	Ammonium Sulfate 21-0-0	0.5%	34	19	36
AT5	Ammonium Sulfate 21-0-0	0.25%	41	32	23

Table 2 shows the impact of Ammonium Sulfate 21-0-0 on earthworm survival over one week. In the 0.5% concentration group, earthworms decreased from 55 to 34 by day 4, and to 19 after one week, with 24 deaths overall. In the 0.25% group, numbers dropped from 55 to 41 by day 4, and to 32 after one week, with 23 deaths. This suggests that lower concentrations result in fewer earthworm deaths.

Figure 2 shows the effects of two chemicals, AT2 (0.5%) and AT5 (0.25%), on earthworm populations over time. After 4 days, the AT2 group had 35 earthworms, and the AT5 group had 40, indicating AT2's stronger initial impact. After 1 week, numbers dropped to 20 in the AT2 group and 25 in the AT5 group, demonstrating that both chemicals harm earthworms, with higher concentrations causing more damage. This decline suggests that stronger chemical concentrations can have long-term negative effects on soil health and the ecosystem.

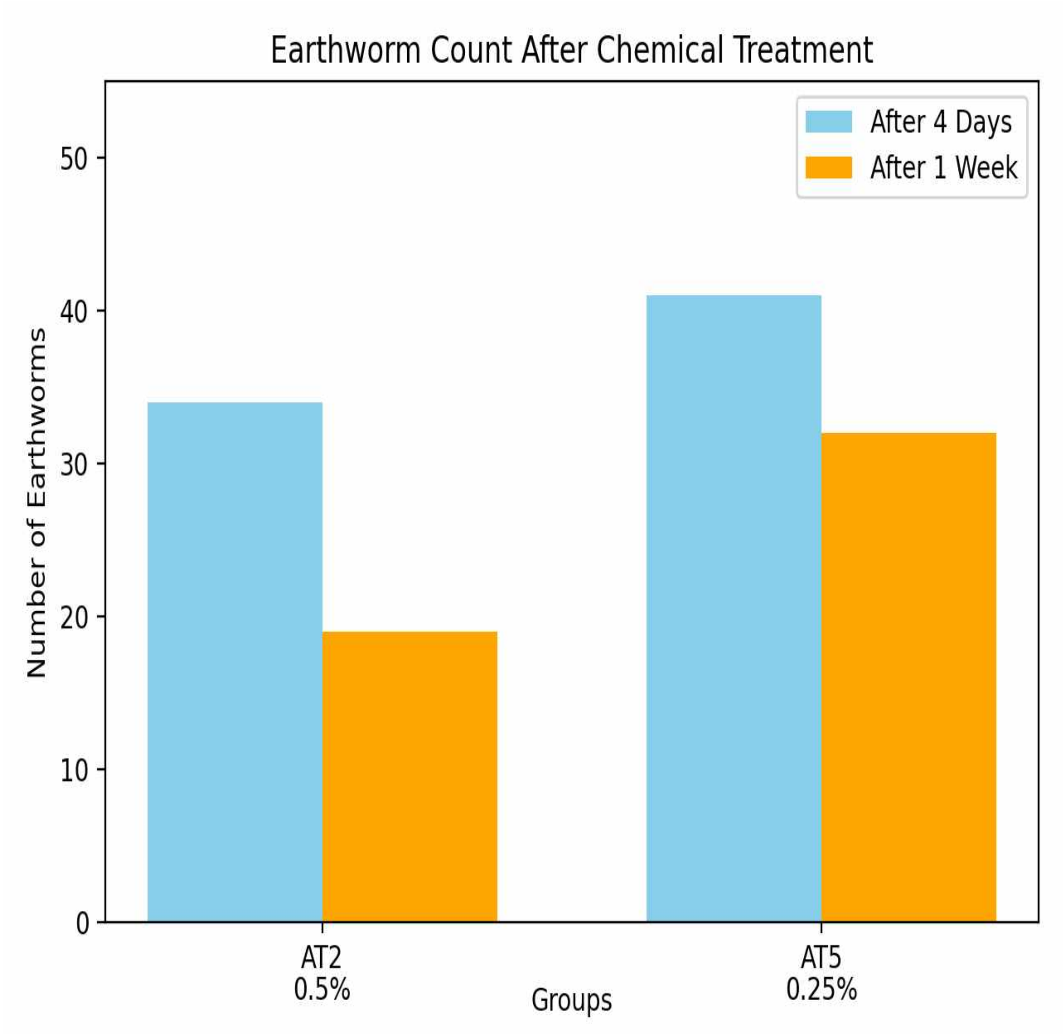


Figure 2. Earthworms after Chemical Treatment of Ammonium Sulfate

Table 3. Effects of Triple 14 Complete Concentration on Earthworm for 1 Week.

Group	Chemical Used	Concentration	Number of Earthworms after 4 Days	Number of Earthworms after 1 Week	Total Number of Earthworm Deceased after 1 Week
C3	None	N/A	N/A	N/A	N/A
1T3	Triple 14 Complete	0.5%	39	27	31
1T6	Triple 14 Complete	0.25%	42	30	25

Table 3 shows the effect of Triple 14 Complete concentration on earthworm for 1 week. After four days, there were 39 earthworms instead of 55 in a 0.5% concentration of Triple 14 Complete, and after a week, there were only around 27 left. Therefore, there are total of 31 earthworms who are found dead. With a 0.25% concentration of Triple 14 Complete, it dropped to 42 after 4 days, and only 30 earthworms remained after 1 week. The findings suggest that higher concentrations of Triple 14 Complete are more toxic to earthworms than lower quantities.

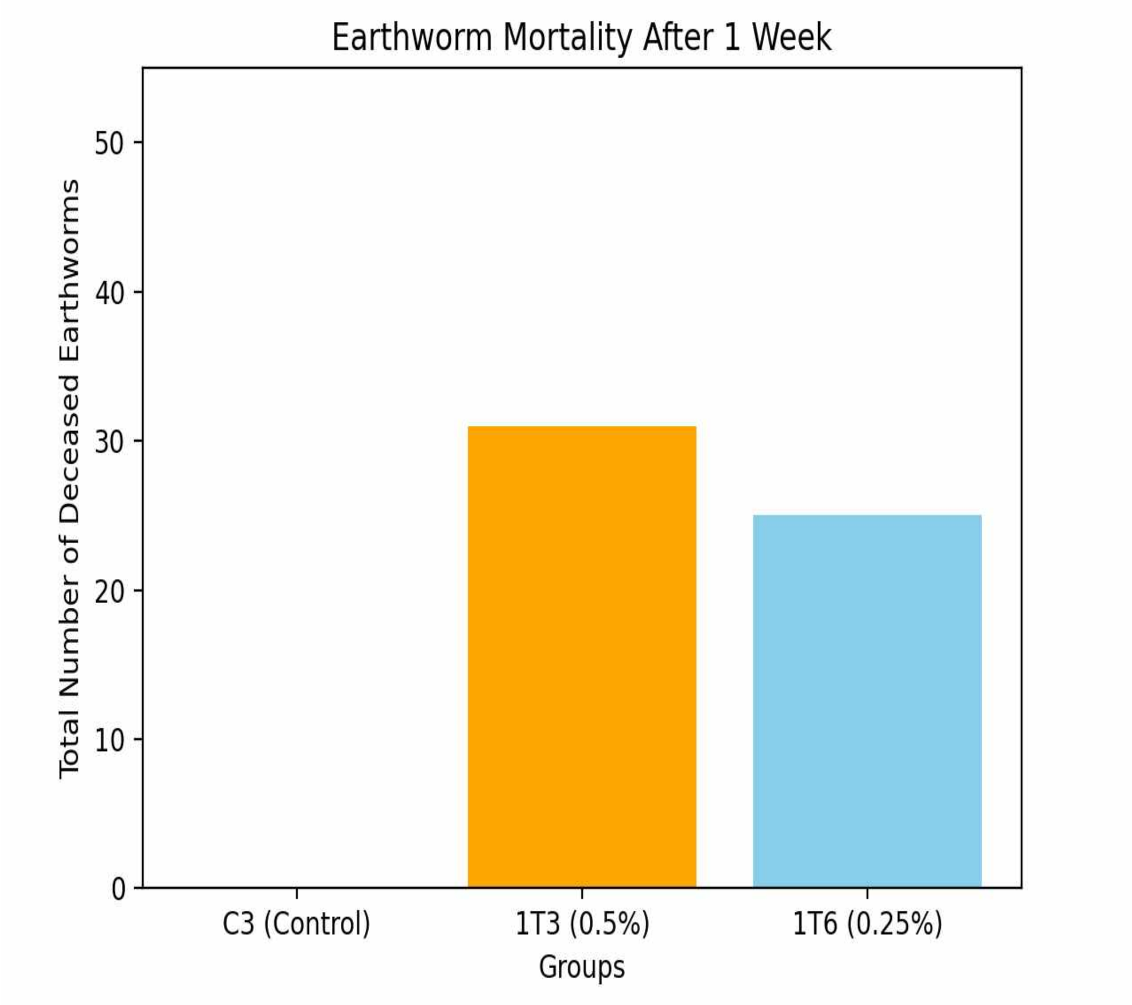


Figure 3. Earthworms after Chemical Treatment of Ammonium Sulfate

Figure 3 shows earthworm mortality after one week due to two chemicals, 1T3 (0.5%) and 1T6 (0.25%), compared to a control group (C3). No deaths occurred in the control group, indicating no harm from natural conditions. In the 1T3 group, 35 earthworms died, while in the 1T6 group, 30 died. This suggests that higher chemical concentrations, like 1T3, caused more harm than lower concentrations like 1T6, highlighting the harmful impact of both chemicals on earthworm populations.

Table 4. Effects of Puradan Concentrations on Earthworms after A Week.

Group	Chemical Used	Concentration	Number of Earthworms after 4 Days	Number of Earthworms after 1 Week	Total Number of Earthworm Deceased after 1 Week
C1	None	N/A	N/A	N/A	N/A
AT1	Puradan	0.5%	15	N/A	N/A
AT4	Puradan	0.25%	28	7	48

Table 4 shows the effects of Puradan concentrations on earthworms over a week. In the 0.5% Puradan group, only 15 earthworms remained after four days, and all were dead by the end of the week. In the 0.25% group, the number dropped from 28 to 7 after a week. A total of 48 earthworms died, with higher Puradan concentrations causing greater mortality, as seen in the 0.5% group.

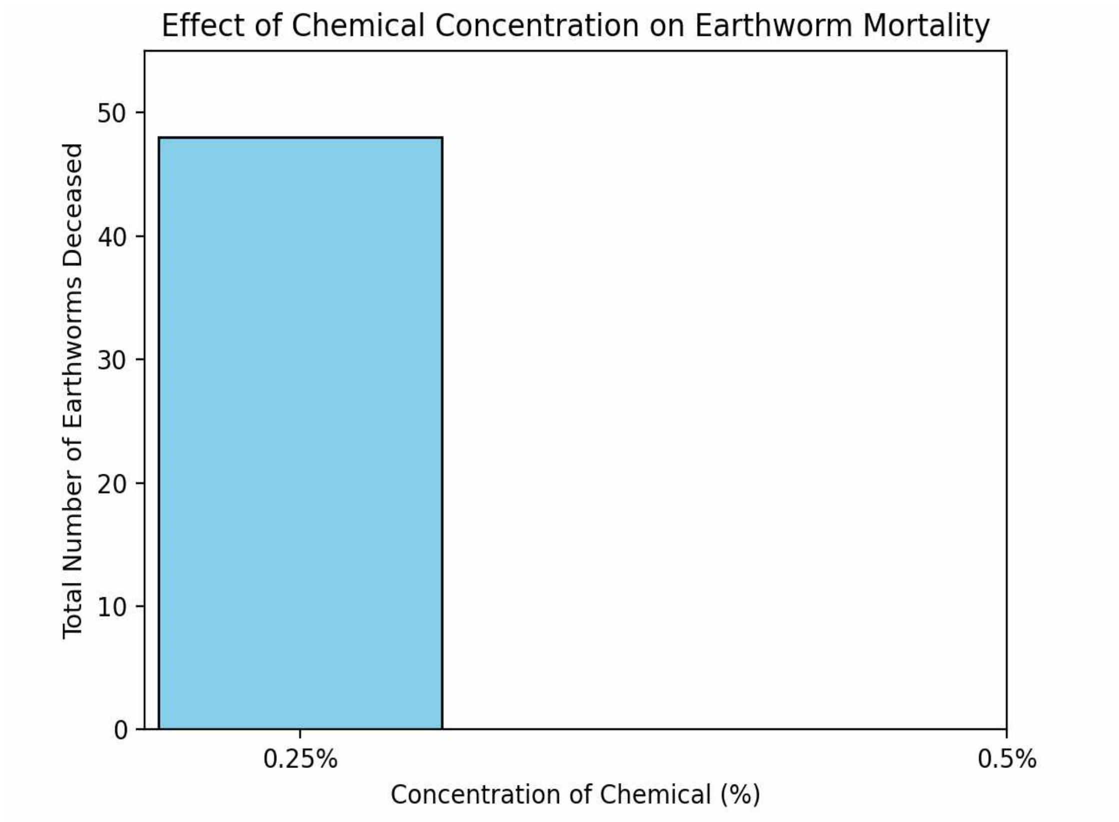


Figure 4. Earthworms after chemical treatment of Puradan

Figure *4* shows that a 0.25% chemical concentration caused nearly 50 earthworm deaths, indicating its high toxicity even at low doses. The absence of data for the 0.5% concentration suggests it was not tested or included. Earthworms, crucial for soil health, are highly sensitive to this chemical, and frequent use could harm their populations and disrupt soil ecosystems. The lack of comparison to a control group makes it difficult to fully assess the chemical's impact, but the data clearly shows that 0.25% is lethal. These results emphasize the need to evaluate the environmental consequences of chemical use.

5. CONCLUSION

The earthworm employed in this study is Lumbricus terrestris, a common earthworm. Based on our overall findings, this earthworm can absorb and survive in a contaminated soil with certain soil chemicals (Ammonium Sulfate, Triple 14 Complete, Puradan) only because earthworms did not survive for long in a strong contaminated soil with 0.5% as the highest concentration; thus, this earthworm has the potential to mitigate a soil with only 0.4% as the highest concentration of chemical. However, these kinds of earthworm may not be able to survive for a few days in a high-concentration chemical since they can only take a few amounts of chemicals for at least a week, according to the researchers' observations. The amount of earthworms may also influence their behavior in contaminated soil. The researchers gave the treatment group with a suitable number of earthworms; but, given the high concentration of chemicals in one treatment group, the researchers determined that the amount provided may not be sufficient in a highly concentrated chemical soil. Area and temperature can also influence the behavior of these earthworms; high temperatures can delay the movement of earthworms, and the space provided by the researchers limits the movements of earthworms, which has a significant impact on their potential. Overall, the researchers concluded that while the area, temperature, and number of earthworms can reduce earthworms' ability to mitigate soil contaminants, earthworms do have the potential to mitigate contaminated soil.

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Author Contributions Statement

Bianca Nicole Maxino and Hazel Joy Rebucas played a pivotal role in the conceptualization, methodology design, and overall supervision of the study. In addition to their leadership, they were also responsible for gathering and analyzing data to ensure accuracy and reliability. Ashlei Carpio and Sean Cagampang contributed significantly to the development of the original manuscript, meticulously crafting the initial draft and creating insightful data visualizations to enhance clarity and comprehension. Alongside Eunice Malinao, they worked collaboratively in refining the manuscript through extensive revisions, thorough reviews, and detailed editing. Meanwhile, Bianca Nicole Maxino, Hazel Joy Rebucas, and Eunice Malinao took charge of the investigation process and effectively managed the project, ensuring its smooth execution and successful completion.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Hazel Joy Rebucas		✓			✓			✓	✓	✓	✓	✓		
Ashlei Carpio	✓	✓		✓		✓	✓	✓	✓	✓			✓	
Sean Cagampang		✓			✓			✓	✓	✓	✓	✓		
Eunice Malinao	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

The authors declare that there are no conflicts of interest related to this research. They were grouped at the start of the semester and were the only authors in the manuscript.

Informed Consent

All participants provided written informed consent before participating in the study. All of the authors were given and collected parental/guardian consent specifying risk of their study as they were minor at the time of the conduct of the study.

Ethical Approval

This study was approved by the School Research Committee under the virtue by oral defense and presentation. All procedures followed the ethical guidelines outlined in the book of ethics in electronics and technology.

Data Availability

The datasets used and analyzed during this study are available from the corresponding author upon reasonable request.

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