International Journal of Innovative Multidisciplinary Research(IJIMR)

Environmental Impact of Detergent Use: A Chemical Risk Assessment

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Abstract

The issue of environmental pollution has brought up the big question because there is increased use of synthetic detergents which have harmful chemicals like optical brighteners, surfactants and phosphates. These pollutants are dangerous to the environment and health when released into the water and land. The study aimed to assess the concentration of toxic substances in the most popular detergents, calculate the environmental load of these substances, and evaluate the risks based on the Hazard Quotient (HQ) and Risk Quotient (RQ) models. Analytical testing was done on five branches of detergents, and five contaminated sites were also tested in the lab and field. Such parameters as pH, BOD, COD, TDS, and surfactant levels were determined, and risk assessment models were implemented. Brand D had the largest concentration of pollutants (e.g., LAS: 6.2 mg/L, phosphates: 8.3 mg/L), above WHO/EPA limits with an RQ of 2.5 and heavy metals (at S3 and S4, there was severe contamination including heavy metals up to 2.8 ppm Pb). Brand E had insignificant risk (RQ = 0.7). The research shows an immediate need for stricter regulations, eco-safe formulations, and awareness to address the issue of pollution from detergents.

Keywords: Detergents, Environmental Pollution, Hazard Quotient, Phosphates, Soil Contamination, Surfactants, Water Quality.

I. Introduction

1.1 Background of the Study

Urbanization and increasing consumerism over the last 30 years have led to a massive increase in global use of synthetic detergents (Kogawa et al., 2017; Hajbabaie et al., 2023). Synthetic detergents are generally effective for cleaning purposes; however, many synthetic detergents contain hazardous chemical agents, surfactants, phosphates, and bleaching agents (Kulkarni et al., 2024; Allahverdiyeva, 2024). Most chemical agents found in detergents are not always biodegradable and often end up in the environment due to domestic or industrial wastewater treatment (Ngeno et al., 2022). Upon release into the environment, these chemical agents posed significant threats to aquatic ecosystems and the quality of groundwater reserves, as well as soil quality. For example, phosphate-based detergents, added phosphates to water, contributed to lake and river eutrophication, harmful blooms of algae, depletion of oxygen, and adverse effects on aquatic life (Barua et al., 2022; Badamasi et al., 2019).

Surfactants such as linear alkylbenzene sulfonates (LAS) and nonylphenol ethoxylates (NPEs) were also found to bioaccumulate along with potential endocrine disruption in aquatic and terrestrial organisms (Badmus et al., 2021; Chamai et al., 2024). Furthermore, the environmental cumulative loads of detergents would have been extremely significant due to the frequent and ubiquitous use of detergents in households, laundries, and industrial operations. Thus, understanding and quantification of the chemical hazards associated with detergent use were critical for policy development and awareness of safer alternatives (Vasilachi et al., 2021; Gupta & Sekhri, 2014).

1.2 Problem Statement

While commonly used elements of daily life, most people were unaware of the environmental impact associated with the chemicals in detergent (Naidu et al., 2021; Buchmüller et al., 2022). The bulk of consumers engaged with these products with little consideration of what might happen to the waste they create. Furthermore, docker-level or regional data quantifying contamination from detergent residues specifically was limited (Karpińska & Kotowska, 2021; Shetty et al., 2023). While there were general statistics on water contamination, it was clear that risk assessments - and thus concentrations, toxicity levels, or environmental impacts - for chemicals in detergents were missing.

The lack of data made it challenging to comprehend the injury these types of substances had on the environment for policymakers and the agencies responsible (Li et al., 2024). Without robust, systematic risk assessments, it remained challenging to formulate priorities or even evaluate existing operations and efforts to minimize wastewater impact. There was an urgent need for structured, chemical-based environmental risk assessments to begin to understand how much damage detergents were causing under real environmental conditions (Di Giacomo & Romano, 2022).

1.3 Objectives of the Study

- To test the concentration of harmful chemicals in popular detergents.
- To test their interaction with water and soil using a scientific methodology.
- To determine their risk based on a chemical risk assessment model (i.e., Hazard Quotient, Risk Quotient).
- To compare the measured pollution concentrations with those are considered safe at the international level.

1.4 Research Questions

- What are the concentrations of major pollutants in different detergent brands?
- What is the risk level posed by these pollutants to aquatic and soil environments?
- How do these risks vary by detergent type (powder/liquid/eco-friendly)?
- Are pollutant levels exceeding permissible environmental limits?

1.5 Significance of the Study

This research project was meant to fill the gap between the day to day activities of the consumers and the scientific knowledge of the consequence of human behaviour to the environment. When performing a risk analysis related to the use of detergents by consumers, the research could access rich information concerning the possible environmental risks related to the consumption of detergents as extensively used products (Kholod et al., 2023; Pinto & Mizrachi, 2025). This was valuable information to the reading population and beyond the reading population, this information could also be used to ascertain that regulatory agencies could limit safe amounts of the use of the prescribed chemical or it could be discontinued in the use of the detergent (Angerville et al., 2013).

There was data from this study that could be useful in developing environmentally friendly detergent formulas and improvements in public labeling that could inform consumers. Furthermore, this study could influence waste management processes and procedures by letting authorities know which chemicals would need rigorous treatment. Ultimately, this study helped promote the goals of sustainable consumption, pollution reduction, and eco-safe product design (Arokiasamy et al., 2022).

II. Literature Review

2.1 Chemical Composition of Detergents

Detergents were normally a combination of a number of chemical substances that enhanced their efficacy in cleaning, but most of these substances were dangerous to the environment (Cortez et al., 2024; Petry et al., 2024). A very common ingredient was the surfactants that reduced the surface tension of water, and took the dirt out of surfaces and the oil out of surfaces. Linear Alkylbenzene Sulfonates (LAS) and Sodium Dodecyl Sulfate (SDS) were the most widespread forms of such surfactants, which had been utilised previously (Cheng et al., 2020). These were artificial products and, despite their biodegradability, their existence in the aquatic environment remained in some situations (Badmus et al., 2021). Surfactants had been recognized among the aquatic flora toxicants even at low levels.

Besides using just surfactants, the detergents used also had builders- Sodium Tripolyphosphate (STPP) (Mestri et al., 2021). Construction workers made sure that cleaning power was enhanced through softening water and binding it with calcium and magnesium ions. Nevertheless, STPP has been observed to be a major contributor to eutrophy in the freshwater ecosystems. Phosphates caused the occurrence of environmental degradation in water systems through stimulating algal blooms that resulted in the buildup of nutrients and the death of aquatic organisms (Barua et al., 2022).

The detergents also had optical brighteners, enzymes, and bleaches. Optical brighteners helped improve the appearance of fabrics under UV light, but their environmental fate was poorly understood and potentially toxic to some microorganisms (Ngeno et al., 2022). Enzymes such as proteases and lipases were added to enhance stain removal, and though generally biodegradable, they could still cause allergic reactions in humans and interact with ecosystems. Bleaching agents, like perborates and hydrogen peroxide, were effective at removing stains but added oxidative stress to the environment when discharged without proper treatment (Vasilachi et al., 2021).

2.2 Environmental Effects of Detergent Chemicals

The release of detergent-related chemicals into the environment caused a wide range of negative impacts. Water pollution was the most direct and visible effect. Surfactants, phosphates, and other substances entered rivers, lakes, and oceans through domestic sewage and industrial effluents. These were chemicals that reduced the quantity of dissolved oxygen in the water, disrupted the reproductive cycles of living things in the water, and were also lethal at low amounts (Di Giacomo & Romano, 2022). In toxicity work, constant exposure to detergent residues may cause a change in the activity of enzymes and damage to the cells in fish and amphibians (Angerville et al., 2013).

The PH of soils, the activities of soil microbes, and the fertility of soils were affected because of the detergent residues present in soil systems. There was the accumulation of some surfactants and builders in the upper layers of the soil, which altered the physical and chemical characteristics of the soil. This decreased the capacity of the plant to uptake nutrients and water, which in the long run led to low agricultural productivity in these polluted areas (Karpińska & Kotowska, 2021).

In addition, certain detergent chemicals proved to be non-biodegradable or very poorly biodegradable and thus followed the bioaccumulation process. Chemicals such as nonylphenol ethoxylates (NPEs) were also discovered to take a long time in the environment and accumulate in the food web of small water creatures. They were also endocrine disruptors and thus they mimicked the effect of the hormone and interfered with the reproduction of wild animals such as fish and amphibians (Badmus et al., 2021). This degradation was not very rapid and the consequence of such a chemical was excessively high in the long run and consequently brought about long term ecological imbalances.

2.3 Quantitative Risk Assessment Models

The researchers have used the quantitative risk assessment (QRA) models to determine the quantification of the environmental risks of chemical detergents. At least four phases could be used with such models, and they included the determination of hazards, the dose-response assessment, the exposure evaluation, and risk characterization (Arokiasamy et al., 2022). Identification of hazards was conducted whereby it was determined whether a particular chemical might lead to any harm or not and dose-response analysis whereby it was determined at which level of exposure different levels of chemicals led to a particular level of harm.

The other frequent risk assessment tool was Hazard Quotient (HQ) which was assumed to be the component of an exposure level to that of a reference (HQ= Exposure / Reference Dose). The reasoning was that the risk took place when the HQ was above one. This practice was especially useful with regard to identification of the effects of commonly used additives to detergents like LAS and phosphates on the ecological environment (Di Giacomo & Romano, 2022).

The Risk Quotient (RQ) model, which used measured concentrations of an environmental chemical as compared to PDNEC (Predicted No Effect Concentration), was another widely used model. The resultant RQ was hence provided as the following RQ = PNEC/measured concentration. An RQ larger than 1 signified that there was an expected threat to the surroundings (Barua et al., 2022). This has been used on top of surface waters, on sediments, and wastewater treatment plant effluents.

These tools could give helpful estimates, but they could only work on situation-specific local data, which was in many cases non-existent in developing countries. Besides, the QRA models were occasionally unable to take into account combined or synergistic effects of more than one chemical and thus resulted in understating actual environmental damage in the real world.

2.4 Previous Studies

To evaluate the environmental effects of detergents, a number of researchers carried out case studies in various regions around the world. In the city of China, Zhu et al. (2024) investigated whether it is possible to detect surfactants in municipal wastewater, and the answer is yes, and there was a high concentration of LAS beyond safe limits to the environment. In Europe, Parida et al. (2022) analyzed hospital wastewater and discovered toxic effects from various surfactants and disinfectants used in detergents. Another study by Badmus et al. (2021) summarized global findings on the environmental fate of surfactants and highlighted their persistence and bioaccumulation potential in aquatic environments.

In India, Vasilachi et al. (2021) investigated river water quality near urban areas and linked detergent pollution to reduced biodiversity and increased algal blooms. Similarly, Ngeno et al. (2022) examined detergent pollution in Africa and noted the absence of regulatory frameworks for wastewater disposal, which worsened environmental conditions.

Despite these studies, there were significant gaps in the literature, especially regarding the local environmental impact of modern detergent formulations that used newer, synthetic ingredients (Osta-Ustarroz et al., 2024; Cortez et al., 2024). Most existing studies focused on older surfactants like LAS, but newer formulations with potentially unknown toxicities remained understudied. Additionally, very few studies collected longitudinal or seasonal data, which were important for understanding how detergent pollution varied over time.

In developing countries like Pakistan, the lack of monitoring systems and scientific research made it difficult to assess real-world exposure levels. Consequently, local risk assessments were rarely performed, and environmental regulations often lacked scientific backing. This highlighted the need for updated, region-specific studies that evaluated the impact of detergent use using modern analytical tools and QRA models.

III. Methodology

3.1 Research Design

This study followed a quantitative, empirical approach that included both laboratory-based experiments and field investigations. A cross-sectional research design was used to collect data at a single point in time. This methodology assisted in the evaluation of the envisaged effects of using detergents regarding up-to-date and locally based information. It was sampled both in the field and in regulated conditions to come up with high-reliability data.

3.2 Study Area and Sample Selection

The survey was conducted in urban residential areas in locations that include neighbourhoods and small-scale laundromats that consume a lot of detergents. The study used 10 samples of both the soil and water solutions; these were five samples of the commonly used brands of detergent and five sampling points where soil and water solutions were sampled. The sites were performed by observing whether there is wastewater being released into the environment near households or laundry services. However, one water and one soil sample were collected, and as a result, five water and five soil samples were collected.

3.3 Data Collection Procedures

The data collection was as follows: motion pictures were made of purchasing the five products of detergents in local markets, as they are the most common products used. Such detergents were then experimented on in controlled laboratory simulations to take note of their effect on the quality of water and soil. Also, five wastewater field samples were taken, and five samples of contaminated soil were taken after choosing the drains. Samples of water were kept in clean glass containers after sterilizing them, and the top 15 cm of the soil was taken using a clean coring instrument.

3.4 Laboratory Testing Techniques

The samples were analyzed at the laboratory to test all five waters and five soil samples. The water was tested to determine the extent of contamination, and this was done by pH, BOD, COD, as well as TDS. The condition of presence of anionic surfactants, and in particular of LAS and SDS, shows up as assessed by the Methylene Blue Active Substances (MBAS) method.

To perform soil testing, nutrient content and the presence of heavy metals in the soil, as well as pH of the soil and conductivity of soil, have been observed in each of the five samples to ascertain the degree of degradation and contamination. These tests helped determine the impacts of detergents on the quality of soil in areas where there is frequent release of detergents.

3.5 Risk Assessment Protocol

The Material Safety Data Sheets (MSDS) on the five chosen detergents were consulted so as to single out the hazardous chemicals, including the surfactants, phosphates, and brighteners. The figures of the subsistence level of aforementioned substances in the samples collected in the water (mg/l) and soil (mg/kg) were estimated. Using these measurements, the Hazard Quotient (HQ) and Risk Quotient (RQ) model was used to identify the level of risks. The obtained values have been compared to the safety provisions of the World Health Organization (WHO), U.S. Environmental Protection Agency (EPA), and environmental control agencies in the local areas..

3.6 Data Analysis Techniques

Descriptive statistics that study the mean, range, and standard deviation of the levels of contamination were used as the solutions for the total sample of ten samples (five of water and five of soil). The analysis of correlation was used to determine the relationship existing between concentrations of chemicals and their effect on the environment. The one-way ANOVA was applied to determine the difference between pollution levels of the five brands of detergents. The findings were displayed using charts, tables, and graphs to clearly present the data.

RESULTS

4.1 Descriptive Statistics

Table 4.1: Summary of Chemical Concentrations in Detergent Brands (mg/L in water tests)

Detergent Brand	LAS (mg/L)	Phosphates (mg/L)	SDS (mg/L)	Optical Brighteners (mg/L)
Brand A	3.5	5.1	2.2	1.0
Brand B	4.8	6.7	3.1	1.4
Brand C	2.9	4.5	2.0	0.8
Brand D	6.2	8.3	4.2	2.1
Brand E	1.6	2.8	1.1	0.4

Interpretation: Brand D had the highest concentrations of all pollutants, especially LAS and phosphates, indicating a greater potential for environmental harm. Brand E had the lowest values, aligning better with eco-safety.

Table 4.2: Soil and Water Quality from Field Sites

Site	Sample Type	pH	BOD (mg/L)	COD (mg/L)	TDS (mg/L)	Surfactant Level (MBAS, mg/L)

S1	Water	6.4	17	140	380	3.9
S2	Water	7.1	12	95	330	2.4
S3	Water	6.8	20	180	410	4.5
S4	Water	6.2	23	195	440	5.1
S5	Water	7.3	11	90	310	1.8

Site	Sample Type	pH	EC (µS/cm)	Heavy Metals (ppm)	Nutrient Deficiency
S1	Soil	6.5	820	2.1 (Pb)	Nitrogen, Phosphorus
S2	Soil	7.0	750	1.6 (Pb)	Potassium
S3	Soil	6.3	890	2.5 (Pb)	Nitrogen
S4	Soil	6.1	940	2.8 (Pb, Cd)	NPK deficiency
S5	Soil	7.4	700	1.3 (Pb)	None

Interpretation: Sites S3 and S4 showed the worst environmental quality, particularly high BOD, COD, and MBAS in water and heavy metal concentration in soil—highlighting severe contamination from detergent discharge.

4.2 Chemical Risk Scores

Table 4.3: Hazard Quotient (HQ) and Risk Quotient (RQ) Scores

Brand	LAS HQ	Phosphate HQ	SDS HQ	RQ (vs. PNEC)
A	1.4	1.2	0.9	1.3
B	2.1	1.7	1.3	1.8
C	1.2	1.0	0.8	1.0
D	2.8	2.3	1.9	2.5
E	0.8	0.6	0.5	0.7

Interpretation: Brand D scored above the threshold (HQ > 1) for all components, identifying it as the highest risk product. Brand E was below concern levels in all categories.

4.3 Comparison with Environmental Standards

Table 4.4: Detergent Component Levels vs. WHO and EPA Safe Limits

Chemical	WHO Limit (mg/L)	Max Observed Value (mg/L)	Exceedance Detected
LAS	1.0	6.2 (Brand D)	Yes
Phosphates	2.0	8.3 (Brand D)	Yes
SDS	1.0	4.2 (Brand D)	Yes
MBAS in Water	0.2	5.1 (Site 4)	Yes
Heavy Metals (Pb)	0.01 (soil ppm)	2.8 (Site 4)	Yes

Interpretation: Several detergent components far exceeded acceptable limits. Phosphate and LAS concentrations in both water and detergent samples were significantly above WHO/EPA standards. MBAS and Pb in environmental samples also posed clear ecological risks.

Discussion

5.1 Interpretation of Key Findings

The study focused on carrying out a chemical risk assessment on five major brands of detergents commonly used by consumers so as to determine their effects on the environment especially with regard to water and soil quality. It was found that there exist colossal disparities in the chemist measurement of the products which were brought into a test as well as the ecological hazard of these products. Brand D was however the worst, in which the concentration of Linear Alkylbenzene Sulfonates (LAS), phosphates and Sodium Dodecyl Sulfate (SDS) were recorded as the highest in such brand. This chemical level far exceeded the advisable levels as recommended by the World Health Organization (WHO) and Environmental Protection Agency (EPA) because it was measured to be at 6.2mg/L (WHO limit: 1.0mg/L) of LAS, 8.3 mg/L (WHO limit: 2.0 mg/L) of phosphates as well as 4.2mg/L (EPA limit: 1.0 mg/L) of SDS. In line with this, its Hazard Quotient (HQ) and Risk Quotient (RQ) were greater than the critical line (HQs > 2.0; RQ = 2.5) and hence the threat to the environmental safety was at a high level.

Brand E, in its turn, was linked with fewer risks possible and risk indicators of all the chemicals were significantly less than the acceptable limits (HQ < 1.0; RQ = 0.7). These findings show that detergent formulation is critical in the environmental safety of cleaning products and that there would be a possibility of deriving environmentally friendlier cleaning products.

The above five field sites were monitored by the Environmental group to determine the most affected sites in terms of water and soil quality. The field sites S3 and S4 have been found to be most severely affected. Samples of water at such locations showed a high BOD, COD, TDS, and MBAS, which also implies extreme levels of pollution. As an example, at Site S4, MBAS levels were as high as 5.1 mg/L, which is even more than a quarter of the recommended safe level of 0.2 mg/L. The respective soil observations were also categorized as inferior quality since they had high electrical conductivity, heavy metal contamination (up to 2.8 ppm lead and cadmium), and nutrient deficiency, mostly in nitrogen, phosphorus, and potassium. These results confirm that both aquatic and terrestrial environments are negatively impacted by continuous exposure to detergent residues.

5.2 Link to Literature

The results of this study are consistent with international findings on the ecological risks of detergent chemicals. For instance, Zhu et al. (2024) reported that LAS concentrations in Chinese municipal wastewater frequently exceeded permissible levels, paralleling the high LAS levels found in Brand D. Similarly, Vasilachi et al. (2021) identified eutrophication and biodiversity loss as direct outcomes of phosphate-rich detergents, aligning with the nutrient-induced degradation observed at Sites S3 and S4 in this study.

In Europe, Parida et al. (2022) examined hospital effluents and identified surfactants and disinfectants as major environmental toxins, again supporting the observed ecological damage caused by detergents in the current research. Moreover, Badmus et al. (2021) emphasized the persistent and bio accumulative nature of LAS and SDS in aquatic systems, which corresponds to the detected long-term contamination at the sampling sites.

Despite these alignments, some differences emerged. Chemical concentrations in Pakistani detergent brands were found to be higher than those typically reported in developed countries, suggesting either more lenient regulatory frameworks or insufficient enforcement of product safety standards in the local context. Furthermore, while most global studies focused primarily on LAS and phosphates, the present research also assessed optical brighteners, an underexplored but potentially toxic class of chemicals, as emphasized by Ngeno et al. (2022).

This study contributes to the literature by filling a regional research gap, particularly in the South Asian context where local chemical risk assessments are rare. By applying quantitative risk assessment models such as HQ and RQ using field-based and laboratory data, the research provides localized insights with global relevance.

5.3 Implications

Implications for Public Awareness and Health

The findings have serious implications for public health and awareness. Many consumers remain unaware of the ecological and health consequences associated with the daily use of chemical-based detergents. The contamination of water and soil systems with surfactants, phosphates, and optical brighteners may lead to bioaccumulation in the food chain, hormonal disruption, and increased risk of waterborne diseases. These risks are compounded by the widespread use of untreated greywater in urban and peri-urban settings.

Public awareness campaigns are urgently needed to educate consumers on the environmental risks associated with commonly used detergents. Clear product labeling that includes chemical concentrations, eco-toxicity ratings, and usage guidelines could help consumers make informed decisions. Encouraging behavioral change toward reduced usage and preference for eco-friendly products will be essential for mitigating long-term risks.

Implications for Environmental Regulation and Detergent Formulation

From a policy perspective, the findings advocate for stricter regulation of detergent formulations and wastewater discharge. Current standards in Pakistan appear inadequate in limiting environmental exposure to hazardous chemicals. Regulatory bodies should consider aligning local guidelines with international safety thresholds and enforcing mandatory pre-market chemical evaluations.

In addition, detergent manufacturers should be incentivized to reformulate their products using biodegradable surfactants, phosphate alternatives, and non-toxic additives. Encouraging innovation through eco-label certification programs and green procurement policies can further drive the market toward safer alternatives. This aligns with the global move toward sustainable consumption and production outlined in the United Nations' Sustainable Development Goals (SDG 12).

5.4 Unexpected Findings and Limitations

An unexpected finding of this study was the detection of heavy metals (lead and cadmium) in soil samples, particularly at Site S4. These metals were not listed in the detergent Material Safety Data Sheets (MSDS), suggesting the possibility of combined or synergistic pollution from other household or industrial sources. This emphasizes the complexity of environmental contamination in urban settings, where multiple pollutants may interact and amplify ecological harm.

The other interesting finding was that even relatively low chemical concentration detergents like the Brand C had Risk Quotient values that were just approaching 1.0, and therefore, they could cause harm under normal or high use. This observation implies that there is an important factor determining environmental risk, which consists of cumulative exposure and the frequency of use, even of relatively milder products.

Limitations of the Study

Although the study has been a great thought-conducting process, there are a number of limitations that should be considered:

1. Sample Size and Scope: The research was limited to five detergent brands and five environmental sites, which may not fully represent the diversity of products and environmental conditions across the region.
2. Temporal limitations: The study was done using a cross-sectional design where the data were collected at a specific time point. Seasonal variations in temperature, rainfall, and detergent usage could affect pollutant concentrations and were not accounted for.
3. Chemical Synergy: The risk assessment focused on individual chemical components using HQ and RQ models, which do not account for combined or synergistic toxic effects—an important consideration in real-world scenarios.
4. Detection Limitations: Some pollutants, such as enzymes, synthetic fragrances, and micro plastics, were not assessed due to methodological constraints, despite their potential environmental relevance.

Recommendations to Overcome Limitations

To address these limitations, future research should:

- Expand the sample size and geographic coverage to include a wider variety of detergent brands, product types (e.g., dishwashing liquids, floor cleaners), and urban/rural sampling sites.
- Incorporate seasonal and longitudinal monitoring to observe temporal trends and long-term effects.
- Employ mixture toxicity models to evaluate the combined effects of multiple pollutants on ecosystems.
- Include a broader spectrum of pollutants, including emerging contaminants like enzymes, nanomaterials, and synthetic dyes, to better assess the evolving composition of modern detergents.

Conclusion

6.1 Summary of Findings

This study assessed the environmental impact of detergent use through a chemical risk assessment approach, focusing on five widely used detergent brands and their influence on water and soil quality. Laboratory analysis and field data revealed that detergent formulations varied significantly in their ecological risk profiles. Among the tested brands, Brand D was identified as the most hazardous, with the highest concentrations of Linear Alkylbenzene Sulfonates (6.2 mg/L), phosphates (8.3 mg/L), and Sodium Dodecyl Sulfate (4.2 mg/L)—substantially exceeding World Health Organization (WHO) and Environmental Protection Agency (EPA) limits. The Hazard Quotient (HQ) of the three chemicals was far beyond 1.0, and the total Risk Quotient (RQ) was 2.5, which means this poses a serious threat to the ecological terms.

Brand E, on the other hand, showed the lowest concentrations when compared to each of the tested contaminants with an RQ value of 0.7, which indicates that the risk to the environment is minimal. Among measures that characterize the environment, S3 was the most polluted, and S4 followed with high indicators of BOD, COD, TDS, and MBAS concentration of surfactants and high concentration of heavy metals (up to 2.8 ppm of lead and cadmium). These findings confirm the presence of substantial detergent-related pollution that threatens both aquatic ecosystems and terrestrial soil systems, especially in urban areas with poor wastewater management.

6.2 Answers to Research Questions

1. What are the concentrations of major pollutants in different detergent brands?

The concentrations varied by brand, with Brand D showing the highest levels: LAS (6.2 mg/L), phosphates (8.3 mg/L), SDS (4.2 mg/L), and optical brighteners (2.1 mg/L). Brand E showed the lowest values across all parameters.

2. What is the risk level posed by these pollutants to aquatic and soil environments?

Using Hazard Quotient (HQ) and Risk Quotient (RQ) models, Brand D exceeded safe limits for all chemicals (HQ > 2.0, RQ = 2.5), indicating high ecological risk. Brand E posed low risk (HQs < 1.0, RQ = 0.7). Water and soil samples from S3 and S4 also exceeded permissible limits, confirming environmental damage.

3. How do these risks vary by detergent type (powder/liquid/eco-friendly)?

Though the study did not segregate products by form, brands labeled as eco-friendly (such as Brand E) tended to have significantly lower pollutant concentrations, suggesting that environmentally conscious formulations may offer reduced ecological risks.

4. Are pollutant levels exceeding permissible environmental limits?

Yes. Several pollutant levels, especially LAS, phosphates, and surfactants (MBAS), significantly exceeded the WHO and EPA safe limits. For example, MBAS concentrations in Site 4 water samples reached 5.1 mg/L, far above the 0.2 mg/L safety threshold. Soil lead levels were also markedly above acceptable concentrations (e.g., 2.8 ppm at Site 4 vs. the WHO limit of 0.01 ppm).

6.3 Final Statement

The findings of this study highlight the urgent need to address detergent-related pollution as a growing threat to environmental sustainability. The widespread use of chemically intensive detergent products, especially those with high concentrations of non-biodegradable surfactants and phosphates, contributes to alarming levels of contamination in water and soil systems. The clear evidence of elevated risk scores and exceedances of international safety limits underscores the necessity for immediate regulatory interventions, public awareness initiatives, and the development of eco-safe detergent alternatives. Without swift and sustained action, the cumulative impact of these pollutants will continue to degrade ecosystems, compromise public health, and hinder sustainable development efforts.

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