Malaysian Journal of Chemistry, 2026, Vol. 28(1), 283-295
(Special Issue: *12th International Conference of the College of Science & 3rd Conference of Chemistry Department 2025*)

Analysis of Several Quality Parameters & Environmental Indexes for Performance & Eco-friendliness of Commercial Detergents

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This study evaluates quality parameters and environmental indices to assess the performance and eco-friendliness of commercial detergents available in the Iraqi market. The detergents were analyzed for key performance metrics, including detergency, solubility, foaming ability, pH, wetting performance, emulsion stability, and cleaning efficiency. The environmental impact was assessed by measuring phosphate levels and examining ingredient toxicity via beetroot and hemolysis assays. Furthermore, the heavy metal content (As, Cr, Hg, Pb, Cd, and Co) was quantified using atomic absorption spectroscopy. The results indicated that many detergent brands exceeded permissible limits for toxic metals and phosphates, which raises significant environmental and health concerns. Trade liquid hand soap exhibited the lowest toxicity and highest eco-compatibility. However, their cleaning performance was relatively inferior. Whereas Lifebuoy and Carmel demonstrated strong cleaning performance despite containing elevated levels of harmful compounds, and are easier to rinse off, highly soluble, and less biotoxic. Consequently, this research reveals the urgent need for stricter regulations, improved labeling, and increased public awareness regarding the composition and safety of detergent products.

Keywords: Detergent, biotoxic, hemolysis, phosphate, environmental

Received: September 2025; Accepted: October 2025

The rapid advancement of industrial and domestic technologies has led to a significant increase in the production and widespread use of chemical products, especially synthetic detergents. These products are indispensable in modern life for cleaning clothes, dishes, household surfaces, and industrial equipment [1]. However, their potential impacts on the environment and health have become a growing concern. Protecting the environment and human health is one of the most critical global challenges. Although pollution cannot be eliminated due to human reliance on various manufactured goods, it is essential to understand and mitigate the consequences of chemical contamination through scientific evaluation and the development of safer products [2].

Surfactants, the primary active components of detergents, are responsible for cleansing. These substances reduce surface tension between water and dirt. This enables the removal of grease and impurities. Detergents fall into four categories: anionic, cationic, nonionic, and amphoteric (zwitterionic) surfactants. The most common are anionic surfactants, which have a negative charge and are used in laundry and dishwashing products [3]. Cationic surfactants carry a positive charge and are often used as fabric softeners and disinfectants. Nonionic surfactants are uncharged and used to solubilize oils and greases. Amphoteric surfactants change their charge with pH and are used in personal care products for their mildness [4].

Modern detergent formulations contain a variety of chemical additives to enhance performance. In addition to surfactants, these include bleaching agents (e.g., hydrogen peroxide, sodium hypochlorite), optical brighteners, enzymes, corrosion inhibitors, water softeners, and preservatives [5]. Optical brighteners improve fabric appearance but can cause skin and eye irritation. They also pose significant risks to aquatic organisms. Many detergents still contain harmful compounds such as sodium lauryl sulfate (SLS), sodium laureth sulfate (SLES), and sodium tripolyphosphate (STPP) [6]. STPP is effective as a water softener and cleaning enhancer, but it is a major contributor to eutrophication. This process leads to excessive algae growth, oxygen depletion, and disruption of aquatic ecosystems. Because of these risks, STPP use has been restricted or banned in various regions [7].

The presence of heavy metals in detergents poses an environmental and health risk. Heavy metals such as Arsenic, Chromium, Mercury, Lead, Cadmium,

†Paper presented at the 12th International Conference of the College of Science & 3rd Conference of Chemistry Dept. 2025

and Cobalt are toxic to humans and wildlife [8]. These elements interfere with enzymatic functions and cellular processes [9]. These metals enter the environment mainly through domestic and industrial wastewater from detergents. Their long-term accumulation can cause bio-magnification in food chains [10, 11].

Although soaps are biodegradable and break down into harmless byproducts, synthetic detergents resist degradation and add to chemical loads in aquatic systems. Runoff from detergent-laden wastewater puts surfactants and metal ions into rivers and lakes, causing environmental stress. Mohomed et al. (2018) found that these chemicals often bypass municipal wastewater treatment and directly impact water quality, aquatic biodiversity, and the people who depend on these water sources [12].

In Iraq, the detergent market is growing rapidly, driven by rising population, urbanization, improved education, and higher consumer income. Reports indicate 15% annual growth in detergent sales, with synthetic detergents projected to grow at 25% annually over the next decade. The market is segmented into a mass-market category, comprising widely used commercial detergents, and a premium category, including brand products such as Lifebuoy and Caramel. Despite this expansion, public awareness of the environmental and health impacts of detergent use remains limited. Consumers tend to prioritize price, cleaning efficacy, and brand reputation, with little consideration for eco-toxicity or ingredient safety. Furthermore, detergent packaging often lacks detailed chemical content labels, and there is limited regulatory enforcement or promotion of eco-friendly or biodegradable alternatives [13].

In light of these concerns, a comprehensive evaluation of detergents commonly available in the Iraqi market is crucial. This evaluation should assess both their performance-related characteristics and their environmental impact. Parameters such as detergency percentage, active ingredient concentration, active alkalinity, phosphate levels, sodium tripolyphosphate (STPP) content, moisture, lather production, and packaging quality must be examined against Iraqi national standards. For example, detergency for Grade 1 detergents should be at least 65%, and the active ingredient concentration should be at least 19%. Similarly, the maximum acceptable levels of STPP and phosphates are also specified for each grade. Despite these standards, many local products fail to meet, raising concerns about their efficacy and safety [3].

Furthermore, this study focuses on the analysis of toxic heavy metals within selected detergent samples. The goal is to determine the type and concentration of metals such as Arsenic, Chromium, Mercury, Lead, Cadmium, and Cobalt, which are commonly used in formulations either as stabilizers or due to contamination during manufacturing. This analysis is vital not only from an environmental standpoint but also for consumer health, particularly among women, who are the primary users of household cleaners. By identifying these risks and comparing them to national and international benchmarks, this study aims to raise awareness about the hidden dangers in commonly used detergents and to support the development of safer, more sustainable alternatives [14].

Materials and Methods

All detergents (Lifebuoy liquid hand soap D-1, trade liquid hand soap D-2, Carmel dishwashing liquid D-3 and trade dishwashing liquid D-4) and sodium dodecyl sulphate (SDS) used in this quality design study were purchased by local markets and examined for several quality characteristics (Solubility, pH, foaming stability, Wetting performance, Stability, hard water, Beetroot assay), environmental indices (Cytotoxic Test: Hemolytic Activity which included Phosphate content, Cleaning procedure) and the heavy metal content (Arsenic (As), Chromium (Cr), Mercury (Hg), Lead (Pb), Cadmium (Cd) and Cobalt (Co)) of the sample solutions was determined and the absorbance was calculated from standard curve using an atomic absorption spectrophotometer (Model Analytik Jena GmbH - novAA 400 P) supplied with flame and graphite furnace, was used at the following wavelength 193, 357, 253, 283, 228) and 240 nm, respectively.

Figure 1. Studied detergent brands.

Quality Characteristics

Solubility

A 2% solution of each detergent was taken and placed in a conical flask for the test [15] to be conducted. For 3 min, each solution flask was heated to 40 °C in a water bath. After that, it was left alone for 2 min. Using a vacuum pump and pre-weighed Whatman filter paper 1, the solution was filtered via a Buchner funnel. After the residue-filled filter paper was carefully lifted and dried at 100 ºC ±5 ºC in an oven, a consistent mass was achieved, and the final weight was recorded.

pH

A 0.1% solution containing several detergents was obtained. A pH meter was calibrated with pH 4, 7, and 10 buffers, and the pH of each detergent was measured and recorded.

Test for Foaming Stability

Foam stability was measured using the Ross and Miles criteria [16]. A test tube containing 10 mL of 0.1% detergent solution was shaken ten times. We timed and compared the point at which the 2 mm foam vanished.

Wetting Performance Test

Wetting criteria were measured using Draves' method [17]. 200 milliliters of a 0.1% detergent solution was placed in a beaker, and one gram of cotton thread was weighed and laid on the surface. It was noted how long it took the thread to reach the bottom of the beaker.

Emulsion Stability Test

The test was conducted according to the method described in [18]. 5 mL of a 1% detergent solution was mixed with 0.5 mL of mustard oil and vortexed for min. When it became apparent what to do, time was recorded. Water was used as the control medium.

The Hard Water Test [18]

Three test tubes were each filled with 15 milliliters of a detergent solution prepared from 2 g of detergent. Then, ten drops of 5% $MgCl_2$, 5% FeCl3, and 5% $CaCl_2$ were added to each of the three test tubes mentioned above to conduct the tests, and observations were noted.

Beetroot Assay [19]

The Beet Root bioassay was performed using the method described by Kirby et al. [19]. To remove excess color, uniformly sliced 0.1-inch beetroot slices were submerged in water, and the water was added again until the water lost all color. After that, beetroot slices were placed in a test tube containing 5 mL of 0.1% detergent solution and left at room temperature for 1 h., undisturbed. Following this time period, the absorbance was measured at 535 nm using a spectrophotometer. The 100% cell disruption was compared with 1% HCl in methanol.

Cytotoxic Test: Hemolytic Activity

The red blood cells (RBCs) hemolysis assay was performed based on the protocol of Dehgham-Noudeh et al. [20]. RBCs preparation involved centrifuging heparinized blood at 4000 rpm for 10 min. The pellet was resuspended in an equal volume of PBS and centrifuged again at 4000 rpm for 10 min. This process was repeated twice to obtain the pellet, and the pellet was then resuspended in the same volume of PBS to obtain suspended RBCs. Test: Three Eppendorf tubes were prepared. I) control tube: 20 µL of RBC and 980 µL of PBS. II) 100% lysis reference:20 µL of RBCs and 980 µL of Triton X-100 (1%). 20 µL of RBC, 880 µL of PBS. III) test: 100 µL of detergent. After 15 min. of incubation at 37 °C, the tubes were centrifuged, and the absorbance at 540 nm was measured.

Phosphate Content

The phosphate content was determined using a modified version of the Fiske and Subbarow assay [21], as described by Satyanarayana and Vohra. Briefly, 1 mL of the test sample solution was mixed with 0.6 mL of 2.3% ammonium molybdate in 10 N sulfuric acid. Then 0.2 mL of ANSA solution (0.25 g of 8-aniline-1-naphthalene sulfonic acid in 15% sodium bisulfite solution and 5 mL of 20% sodium sulfite solution) was added. After incubating for 10 min at room temperature, the absorbance was measured at 660 nm.

Cleaning Procedure

Cotton cloth was stained with various substances and allowed to dry overnight. The clothing was first pre-soaked in 200 mL of 0.1% detergent solution for 15 min. After that, the cloth was swirled in the same solution for an additional 15 min. using magnetic stirrers. Following that, the cloth was washed with distilled water and dried.

Atomic Absorption Analysis of Liquid Detergents

Sample Preparation

Four different samples of locally available liquid detergents were selected. In a 50 mL beaker, 0.25 g of each sample was weighed, 10 mL of deionized water was added, and the mixture was heated to 90 °C and stirred for 7 min. Then, a dissolving solution of aqua regia was added to each sample, and the samples were heated for 10 min. The samples were covered with a watch bottle to reduce solvent evaporation and to ensure the completion of the digestion process. The samples were then removed from the heater and allowed to cool to laboratory temperature. The samples were then transferred to a 25 mL volumetric flask, and the volume was filled to the mark with deionized water. Thus, the samples were ready for measurement.

Elemental Analysis

By using atomic absorption spectrophotometer (Model Analytik Jena GmbH - novAA 400 P) supplied with flame and graphite furnace, was determined the concentration of Arsenic (As), Chromium (Cr), Mercury (Hg), Lead (Pb), Cadmium (Cd) and Cobalt (Co) at (193), (357), (253), (283), (228) and (240) nm, respectively. The heavy metal content of the sample solutions was determined, and the absorbance was calculated from a standard curve.

RESULTS AND DISCUSSION

Following a comparative analysis of the detergents on the market, the following conclusions were reached:

Trade dishwashing liquid (D-5) demonstrated the least solubility among the provided detergents, while trade liquid hand soap (D-2) showed the highest solubility in water, as shown in Figures 2,3. Because they all leave fewer residues, washing with less water is necessary when using liquid detergents. Detergents, therefore, reduce the amount of water needed for washing.

pH: The liquid hand soap detergents displayed a virtually neutral pH, whereas the dishwashing gel detergents had an alkaline pH. Neutral-pH detergents are safe for hands and beneficial for aquatic environments.

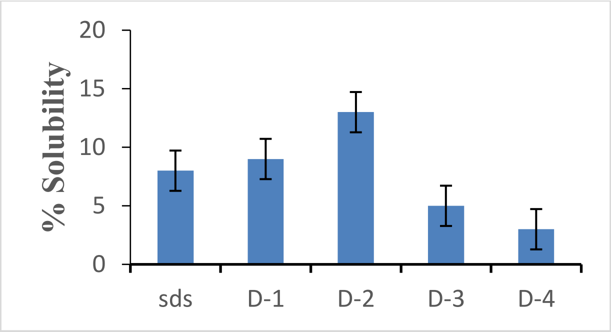


Figure 2. Solubility of 2% wt. Detergent solution.

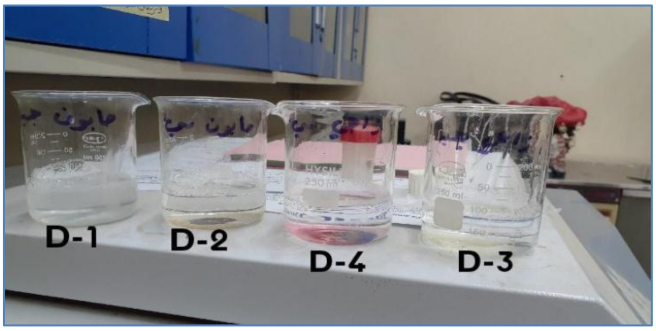


Figure 3. Solubility of studied detergents.

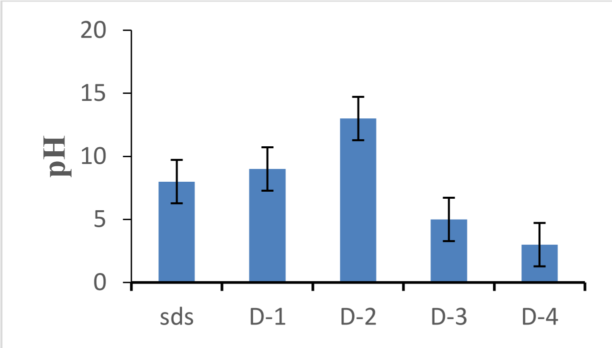


Figure 4. pH 0.1% wt. of detergents solution.

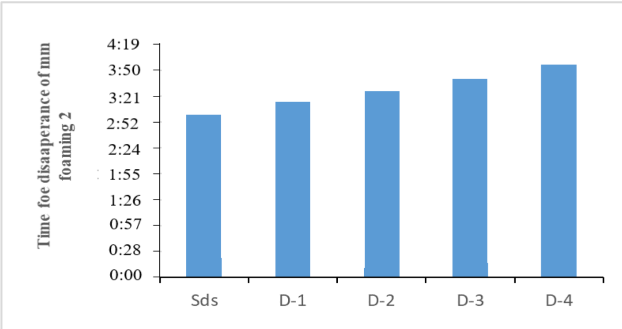


Figure 5. Foaming of a 0.1% wt. of detergents solution.

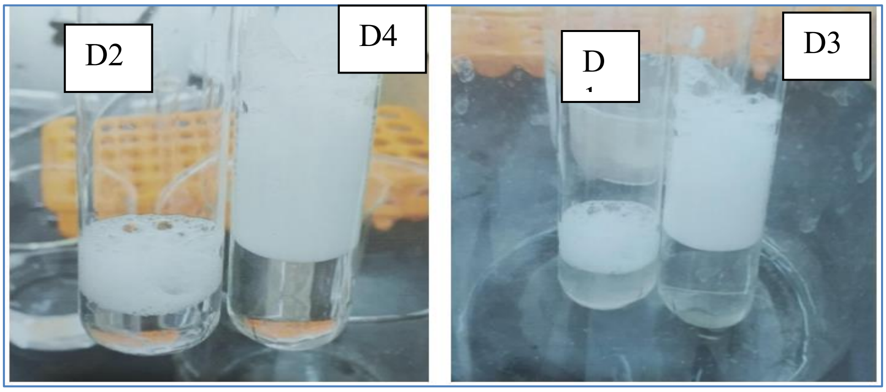


Figure 6. foaming stability of studied detergents.

A good detergent should generate foam readily and collapse quickly, requiring less water during washing. This is known as the foaming test. (Figure 5,6) shows that Lifebuoy liquid hand soap (D-1) takes comparatively less time and is therefore more water-efficient than Trade dishwashing liquid (D-4), which takes the longest and requires the most time for foam collapse.

Wetting performance test: The thread functions better as a detergent the faster it soaks up and sinks into the soapy solution. A good wetting performance is achieved by the thread sinking faster in SDS and taking the longest to sink in trade dishwashing liquid (D-4), life buoy liquid hand soap (D-1), and caramel dishwashing liquid (D-3).

Hard water test: A good detergent works well in hard water and doesn't build scum. Carmel dishwashing liquid (D-3) and Lifebuoy liquid hand soap (D-1) revealed little to no precipitate or scum formation (Figures 9,10).

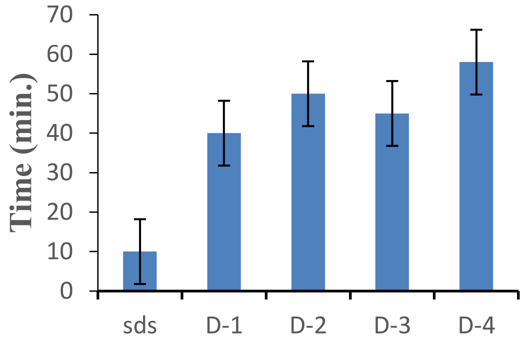


Figure 7. Wetting performance of a 0.1% wt. of detergents solution.

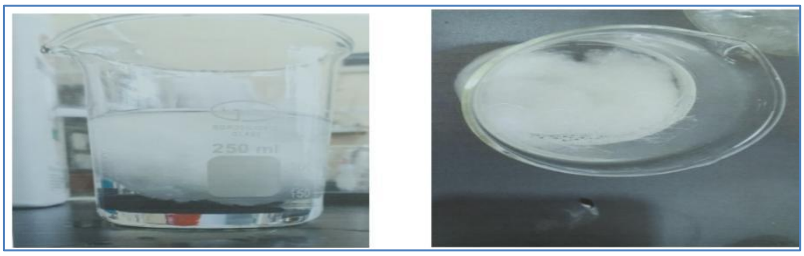


Figure 8. wetting criteria of studied detergents.

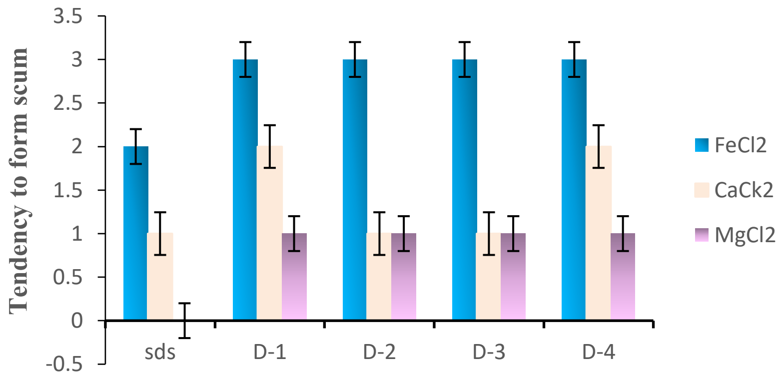


Figure 9. Hard water test of detergent solution.

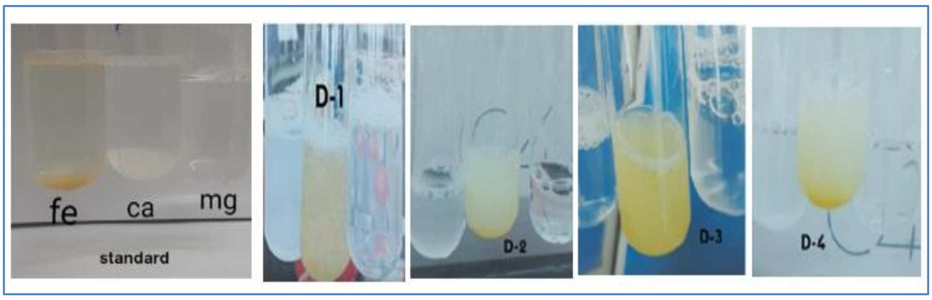


Figure 10. Hard water test of studied detergents.

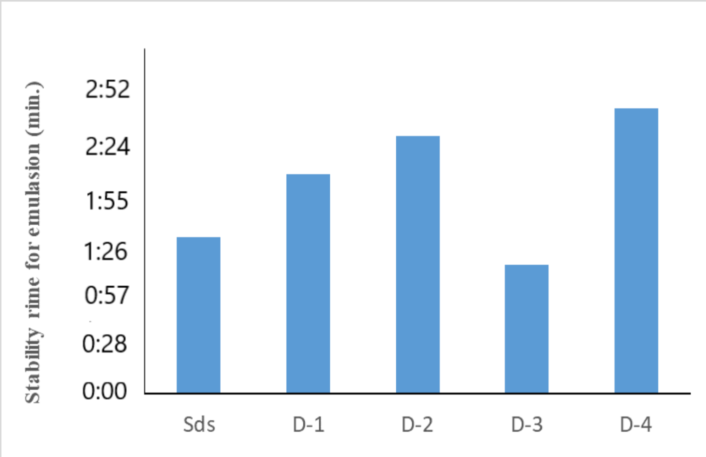


Figure 11. Emulsification of 0.1% wt. Detergent solution.

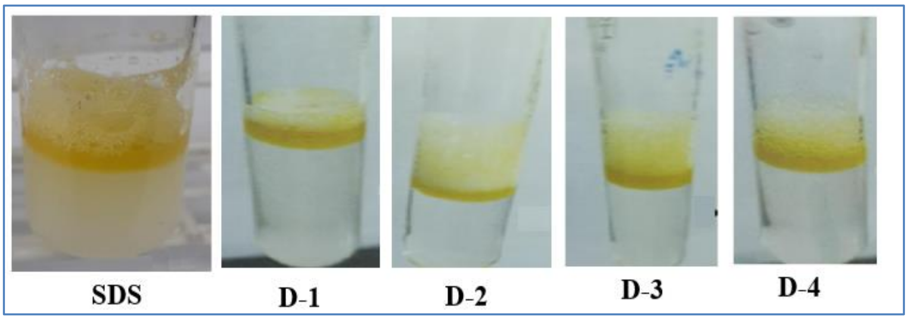


Figure 12. emulsion stability of studied detergents.

Emulsion Stability. Since emulsion formation is the foundation of cleaning action, a good detergent must have good emulsion qualities. Trade dishwashing liquid (D-4) produced the most stable emulsions, while Carmel dishwashing gel produced the least stable emulsions (Figure 11,12).

Beetroot assay: The beetroot assay essentially measures a detergent's toxicity. Because detergents are amphipathic, they can damage the bilayer of the cell membrane and release a red pigment that is held in beetroot vesicles. Trade dishwashing liquid (D-4) and Carmel dishwashing gel (D-3) are the most hazardous because they produce the greatest membrane disruption. The least bio-toxic type of hand soap is trade liquid (D-2) (Figure 13,14).

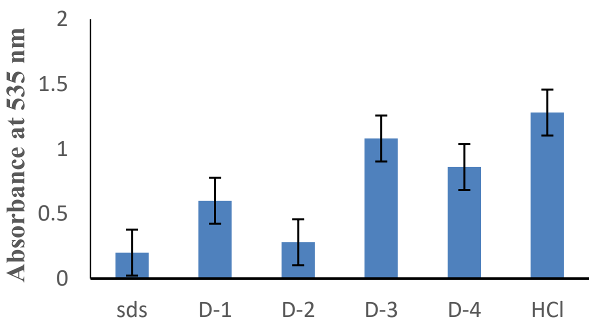


Figure 13. Beetroot assay of 0.2% wt. Detergent solution.

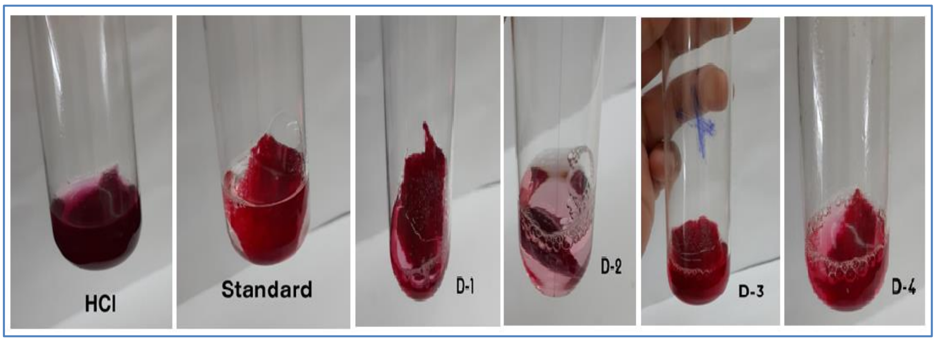


Figure 14. A detergent's toxicity by the Beetroot assay of studied detergents.

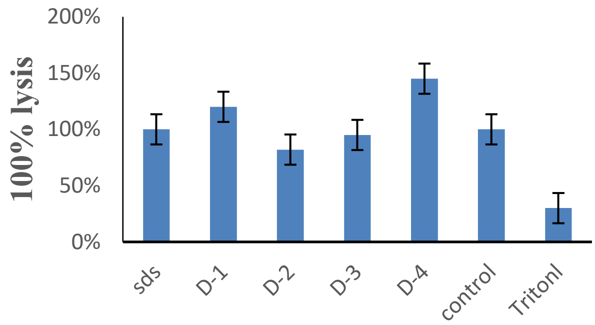


Figure 15. Hemolytic effect of 100 µL of the detergent solution.

Hemolysis activity: A detergent's toxicity can be gauged by its hemolytic activity. Because detergents are amphipathic, they can cause hemoglobin to leak out of the RBC plasma membrane. Trade liquid hand soap) D-2) are less hazardous since they exhibited the least amount of RBC lysis. The most hazardous detergents among those provided are commercial dishwashing liquid (D-4) and life buoy liquid hand soap (D-1), both of which exhibit lysis levels exceeding 100% (Figure 15).

Phosphate content: Using phosphate is extremely harmful to the environment. It is a sign that the detergent is not eco-friendly. The least environmentally friendly products include Lifebuoy anti-liquid hand soap (D-1) and Carmel dishwashing liquid (D-3), which have the highest phosphate concentration. Trade liquid hand soap (D-2) is environmentally benign since its phosphate content is so low (almost nonexistent) (Figures 17,18).

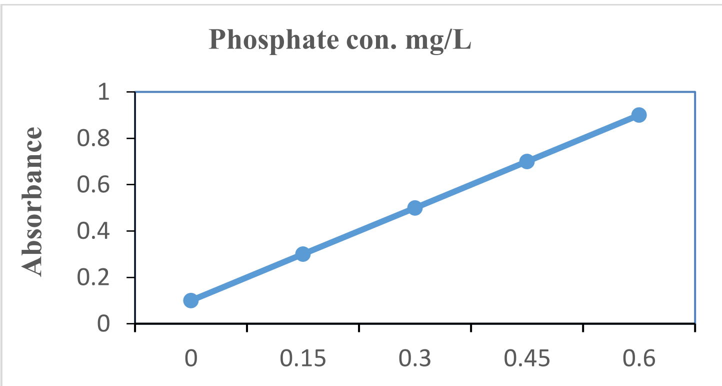


Figure 16. Standard curve of phosphate.

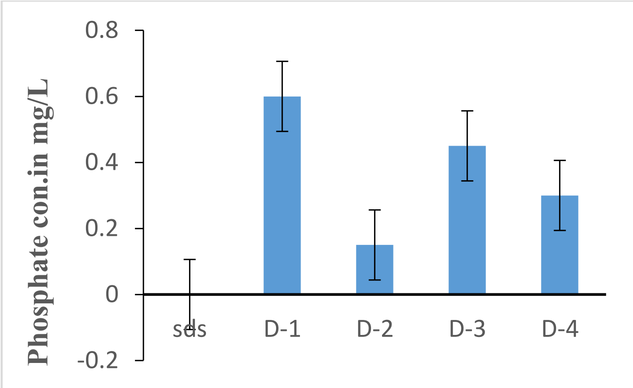


Figure 17. phosphate content of 1% wt. of the detergent solution.

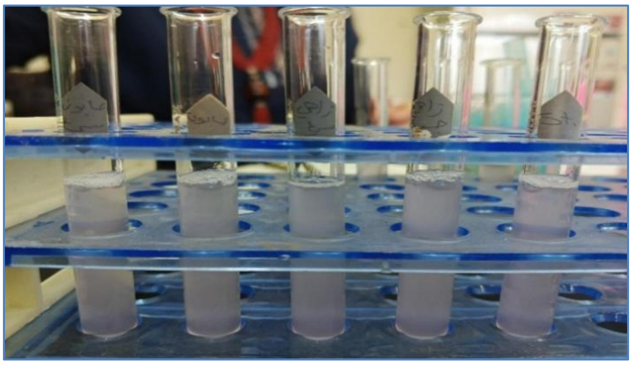
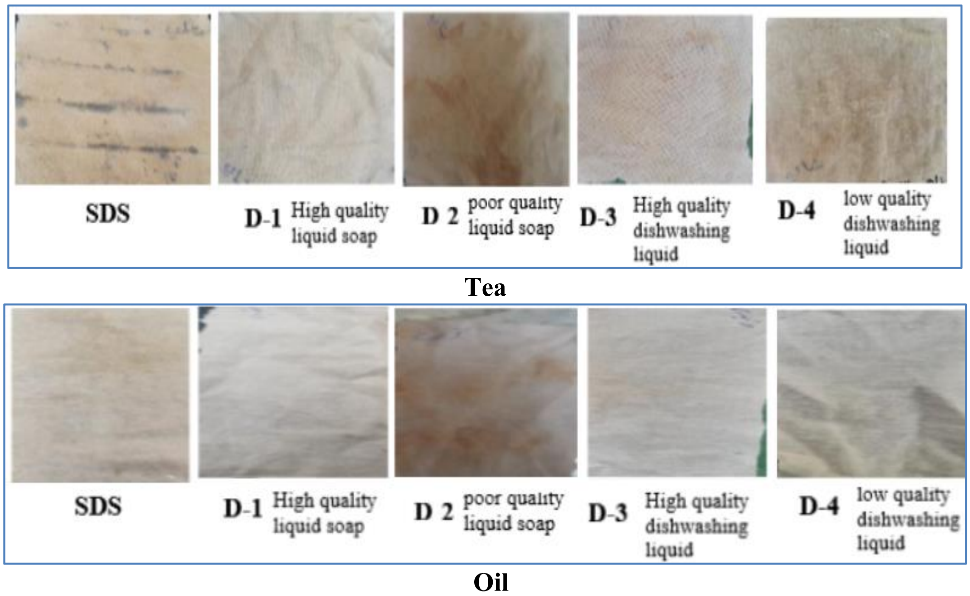


Figure 18. Phosphate content of studied detergents.

Cleaning action:
Carmel dishwashing gel (D-3) and Lifebuoy liquid hand soap (D-1) offer the best cleaning action in terms of stain removal and brightness, whereas Trade liquid hand soap (D-2) shows the least color fading.



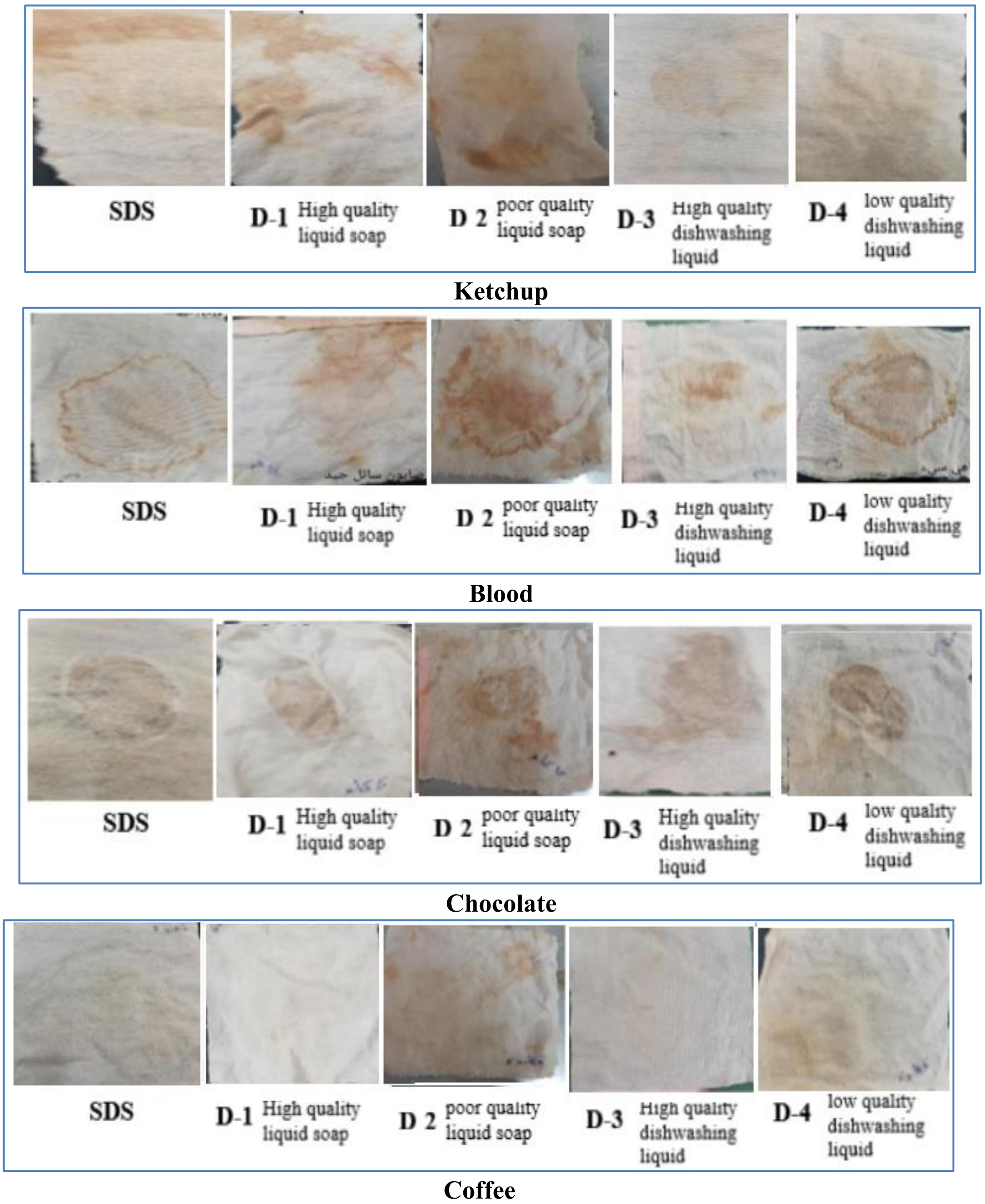


Figure 19. Cleaning performance of studied detergents.

This study conducted a comparative examination of the cleaning performance, environmental impact, and bio-toxicity of four detergent brands for the first time in Iraq. Solubility, pH, wetting performance, foaming ability test, emulsion stability, cleaning action, phosphate estimation, hemolysis assay, and beet root assay were among the characteristics that were put to the test. Our pertinent research on widely used detergents led us to conclude that, compared with more expensive detergents like Lifebuoy and Carmel, many less expensive detergents, such as Trade Liquid Hand Soap (D-2), were less bio-toxic, with less hemolysis, and more environmentally friendly, with fewer phosphates. However, they performed less well at cleaning. For most people, these detergents offer a good, less expensive alternative. In contrast to dish liquid, most liquid hand soap detergents are easy to wash, readily soluble, and low in bio-toxicity. In addition, it was discovered that dishwashing liquid contains a large amount of phosphates. Our research did not identify a clear champion in the current detergent industry. Nonetheless, the study might work as a catalyst for consumer awareness-raising and increased demand for green detergents that are both environmentally friendly and effective cleaners. This would put pressure on the government to enact stricter laws and on detergent producers to market cleaners that are more environmentally friendly, water- and energy-efficient, and more effective at cleaning. Better items would hit the market, and more stringent laws and regulations similar to those in Western nations would result from informed public opinion. The atomic absorption result of liquid detergents is listed below:

Table 1. Concentration of heavy metals in liquid detergents (ppm).

Entry	As	Cr	Hg	Pb	Cd	Co
D-1	0.131	0.722	0.145	0.778	0.288	0.429
D-2	0.147	0.889	0.185	0.481	0.264	0.202
D-3	0.150	0.944	0.163	0.544	0.231	0.322
D-4	0.144	0.750	0.191	0.479	0.242	0.310
Permissible limits in drinking water in (ppm) (22,23)						
	0.01	0.1	0.002	0.0015	0.005	0.1
	Health Effects (24)					
	Cancer, renal system Failure, skin damage,	kidney failure, diarrhea, Teeth abnormalities,	Neurological disorders, Renal failure, cancer	Nervous system impairment, Cancer, brain damage	Osteoporosis, cardiovascular issues, and cancer	Pulmonary and system issues Cardiovascular

Detergents and soap are used for cleaning. Some of it may be transferred to food and thus to the human body if utensils are not rinsed well, leading to mild intestinal disorders. Or it may occur by touching the mouth after using detergents containing heavy metals; the USAP limit is 0.01 ppm. Arsenic is a toxic element that causes skin, lung, and bladder cancer. Chromium (Cr) had a high concentration of 0.7-0.95, while the permissible limit for human exposure is 0.1 according to USAP. Some symptoms affecting human health were explained in Table 1. Mercury (Hg) concentrations in these samples increased significantly, ranging from 0.14 to 0.19 ppm, well above the permitted limit of 0.002 ppm. According to the World Health Organization, mercury is one of the chemical elements that raises significant public health concerns. Once mercury is released into the environment, bacteria can convert it into methyl mercury, which can have toxic effects on the nervous, digestive, and immune systems (even in small quantities). While Lead (Pb) was clearly concentrated in these samples at a high level of 0.4-0.78 ppm, which is much higher than the permissible levels of 0.0015 ppm. Lead can be absorbed through the skin. As for adults, exposure to lead causes memory loss, insomnia, nausea, loss of appetite, reproductive failure, and joint weakness. Encephalopathy is one of the most severe clinical disorders resulting from lead poisoning [22-24].

The level of Cadmium (Cd) in USAP is 0.005 ppm, which differs from the levels observed in the detergent samples under study, which ranged from 0.22 to 0.24 ppm. High ingestion of soluble cadmium salts causes acute gastroenteritis. Long-term occupational exposure to cadmium has caused severe chronic effects, predominantly in the lungs and kidneys [25]. Even in the absence of environmental contamination, cadmium, as a trace constituent, is present in most food commodities. High inhalation exposure to cadmium oxide fume may result in acute pneumonitis with pulmonary oedema, which may be a cause of death in extreme cases [26].

The Cobalt (Co) range is 0.2 -0.43 ppm in the detergent samples under study; this value is much higher than what is recommended by USEPA (0.1). Cobalt has both beneficial and harmful effects on human health. Cobalt is beneficial to humans because it is part of vitamin B12, which is essential for maintaining human health. Cobalt has also been used as a treatment for anemia. Cobalt is capable of being absorbed via the skin, and it is harmful to the cardiac muscle; excessive exposure can result in heart muscle damage (toxic cardiomyopathy) [27]. When too much cobalt is taken into your body, however, harmful health effects can occur [28]. Serious effects on the lungs, including asthma, pneumonia, and wheezing, have been found in people exposed to cobalt while working with hard metal, a cobalt-tungsten carbide alloy [29].

The findings suggest a clear trade-off between safety and cleaning effectiveness in commercial detergents. While some products, like Trade liquid hand soap, prioritize low toxicity and environmental compatibility, their cleaning power is comparatively weak. In contrast, popular brands such as Lifebuoy and Carmel offer strong cleaning performance but contain higher levels of harmful chemicals. This raises concerns about chronic exposure to toxic metals and phosphates, which can affect human health and aquatic ecosystems. The results emphasize the need for stricter regulatory standards, more transparent labeling, and public education to guide consumers toward safer and more environmentally friendly products. Overall, the study highlights the challenge of balancing efficacy with safety in household cleaning products.

CONCLUSIONS

Our research on commonly used detergents revealed that, compared to premium brands such as Lifebuoy and Carmel, many lower-cost alternatives—such as Trade Liquid Hand Soap (D-2)—exhibited lower biotoxicity, caused less hemolysis, and were more environmentally friendly due to their reduced phosphate content. However, their cleaning performance was relatively inferior. Despite this, these detergents represent a cost-effective option for most consumers. In contrast to dishwashing liquids, most liquid hand soaps are easier to rinse off, highly soluble, and less biotoxic. Additionally, the study found that dishwashing liquids contain significantly higher phosphate levels.

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