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Sodium Dodecyl Sulphate-Aided Washing of Heavy Metals from Contaminated Soils at Auto-Mechanic Sites in Urban Makurdi

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ABSTRACT

Three automobile mechanic sites in urban Makurdi with many years of operation contaminated with petroleum products were assessed for remediation using Sodium Dodecyl Sulphate (SDS) as the surfactant. The main aim of the study was to remove heavy metals (Cd, Cr, Cu, Ni, Pb, Zn). Since soil pH, soil type, cation exchange capacity (CEC), particle size, organic matter content all affect removal efficiency, these parameters were also checked. All soil types were sandy, low in organic content which makes it good for soil washing. The surfactant Critical Micelle Concentration (CMC) was determined using electrical conductivity measurement as 5.0 mM, thereafter the effect of surfactant pH, surfactant concentration, soil/SDS ratio, washing and agitation time on the removal efficiency were studied. The results showed that pH 3 gave 70-90 % removal, pH 5 gave 50-60 % removal, pH 11 gave 10-30 % removal for heavy metals while, the surfactant concentration studies showed that increase in concentration of the surfactant increases the concentration of the contaminants in solution with 80-90 % removals, soil/surfactant ratio was also studied a ratio of 1:50 was recorded as the minimum and the best when considering surfactant aided soil washing, contact time of soil and surfactant was also studied 120 mins gave the highest removal.

KEYWORDS: Soil contamination, Heavy metals, Sodium Dodecyl Sulfate (SDS), Surfactant, CMC.

1. INTRODUCTION

Soil contamination from industrial and mechanical activities is a critical environmental issue that significantly impacts human health, ecosystems, and soil productivity. The presence of man-made substances or wastes not originally found in nature alters the natural soil environment [1]. Automobile mechanic workshops, in particular, contribute to substantial contamination due to the improper disposal of spent engine oil, lubricants, and other hazardous materials [2]. In Nigeria and other developing countries, the lack of proper waste disposal regulations exacerbates the problem, as many automobile workshops indiscriminately dump waste into nearby soil and water bodies [3].

The contaminants of concern, primarily heavy metals (HMs) such as lead (Pb), cadmium (Cd), zinc (Zn) can persist in the environment, bioaccumulate in living organisms, and pose long-term risks to human health. Soil pollution from mechanic workshops is particularly challenging to address due to the complex mixture of hydrophobic organic contaminants and metal pollutants that typically co-exist in these environments [4].

This study focuses on the application of surfactant-enhanced soil washing (SESW) using Sodium Dodecyl Sulphate (SDS) as an effective method for remediating contaminated soils. The goal is to determine the optimal conditions for removing HMs from mechanic workshop soils in Makurdi, Nigeria, a region heavily impacted by mechanic activities.

A few studies has shown that surfactants are used in remediation of HMs contaminated soils at automobile mechanic workshops such as the study conducted in Mexico by Salinas *et al*.[5]. Surfactant enhanced soil washing for the remediation of sites contaminated with pesticides [6]. Using SDS and Brij 30 at six different concentrations, when surfactants were added, the pesticide extraction increased considerably even for the lowest surfactant concentration, using SDS, 2,4-D extraction increased from 7% using water alone to 48.7% using 5 g/L SDS from 5 to 10 g/L a slight improvement in pesticide extraction from 48.7 to 50.7%. Using Brij 30, the surfactant resulted in an improvement in pesticide extraction efficiency compared to water alone but with a lower amount compared to SDS which was explained by the differences in the nature of the polar head group of the surfactants and SDS was more affected by surfactant concentration than in using Brij 30. Agarry *et al*[7] also carried out soil washing remediation of soil artificially contaminated with Naphthalene using palm kernel oil, coconut oil and waste cooking oil as solubilisation agents as alternatives to conventional solvents and surfactants.

2. MATERIALS AND METHODS

2.1. Chemicals/Reagents and Apparatus

Sodium dodecyl sulfate (SDS) (Kermel, 99.5%w/v) deionised water, distilled water, nitric acid, acetic acid , ammonium hydroxide, ammonium acetate, sodium acetate, magnesium chloride, calcium chloride, hydrogen peroxide, hydrochloric acid, hexametaphosphate Volumetric flasks, ae Adam digital chemical balance (max 180 g), thermometer, OAKTON pH meter pH/CON 510 series, EC 215 Conductivity meter (HANNA Instruments), Hy-2 Speed Adjusting Multi-purpose Vibrator, Genlab oven, beakers, conical flasks, < 2mm mesh sieve, whatman filter paper, funnel, serviette, Atomic Absorption Spectrophotometer.

2.2. Study Area and Sample Collection

Soil samples were collected from three major automobile workshops in Makurdi: Kanshio, North Bank, and New Garage. Samples were taken in black polythene bags, labeled, air-dried, homogenized, and sieved using a 2 mm mesh sieve [8, 9].

2.3. Soil Characterization

Key physicochemical properties of the soil samples were analyzed, including pH, bulk density, organic matter content, cation exchange capacity, and textural analysis [10, 11,] Heavy metal concentrations (Cd, Cr, Cu, Ni, Pb, Zn) using atomic absorption spectrophotometry (AAS) [12].

2.4. Surfactant Preparation and Soil Washing Experiments

Sodium dodecyl sulfate (SDS) was used as the surfactant for soil washing. The critical micelle concentration (CMC) was determined through electrical conductivity measurements, identifying 5.0 mM as the CMC, the concentration at which SDS starts to form micelles and efficiently remove contaminants [13].

Soil washing experiments evaluated four key variables:

1. **Initial pH of the surfactant solution**: SDS solutions were prepared at various pH levels (3, 5, 7, 9, and 11), and the soil samples were agitated at 200 rpm for 2 hours. Heavy metals and TPHs were measured after washing [15].

2. **Initial SDS concentration**: SDS concentrations ranging from 5 to 10 mM were tested to assess their effectiveness in removing contaminants [15].

3. **Soil-to-surfactant ratio**: The amount of soil (2 g, 3 g, 4 g, 5 g, and 6 g) was varied while keeping the surfactant concentration constant to examine the impact on contaminant removal efficiency.

4. **Washing time**: Contact times of 10, 30, 60, 90, and 120 minutes were tested to determine the effect of washing time on the removal of HMs [16].

2.5. Quality Assurance and Data Analysis

All measurements were conducted in triplicate, and statistical analyses were performed to assess the significance of the experimental parameters. The results were analyzed using two-way analysis of variance (ANOVA) to determine the effect of the different variables on contaminant removal [17].

3. RESULTS AND DISCUSSION

The results from the physicochemical analysis on the soil samples are presented in Table 1. The study revealed that the soils collected from the automobile workshops were predominantly sandy with low organic matter content. The bulk densities (1.3 to 1.56 g/cm³) and high sand composition (74-82%) indicate that the soils possess a high permeability, promoting the leaching of contaminants, into the groundwater. The low clay and silt content and reduced cation exchange capacity (CEC) suggest that the soils are suitable for remediation through soil washing.

Table 1: Physicochemical Properties of the Study Soils

Property	Kanshio (KS)	North-Bank (NB)	New Garage (NG)
pH	7.30	7.34	7.22
Bulk density (g/cm^3)	1.56	1.30	1.49
Sand (%)	80.24	74.24	82.24
Clay (%)	15.76	15.76	13.76
Silt (%)	4.00	10.00	4.00
Organic carbon (%)	1.54	1.72	1.64
Organic matter (%)	2.66	2.97	2.84
Na (cmol kg^{-1})	0.26	0.36	0.30
K (cmol kg^{-1})	0.27	0.30	0.29
Mg (cmol kg^{-1})	3.20	3.60	3.30
Ca (cmol kg^{-1})	3.60	3.80	3.40
Ea (cmol kg^{-1})	0.88	0.80	0.92
CEC (cmol kg^{-1})	8.21	8.82	8.21
Cd (mg kg^{-1})	3001.5	4444.5	4815.5
Cr (mg kg^{-1})	1595	2601	3656
Cu (mg kg^{-1})	1756	1960.5	2305.5
Ni (mg kg^{-1})	945	1030	1757.5
Pb (mg kg^{-1})	3522.5	4945.5	5316.5
Zn (mg kg^{-1})	1027.5	1862.5	2937.5

3.2. Critical Micelle Concentration (CMC) of Sodium Dodecyl Sulphate

The conductivity method was employed to determine the CMC of SDS by reading off the point of intersection of conductivity vs sodium dodecyl sulphate concentration plots (Figure 1).

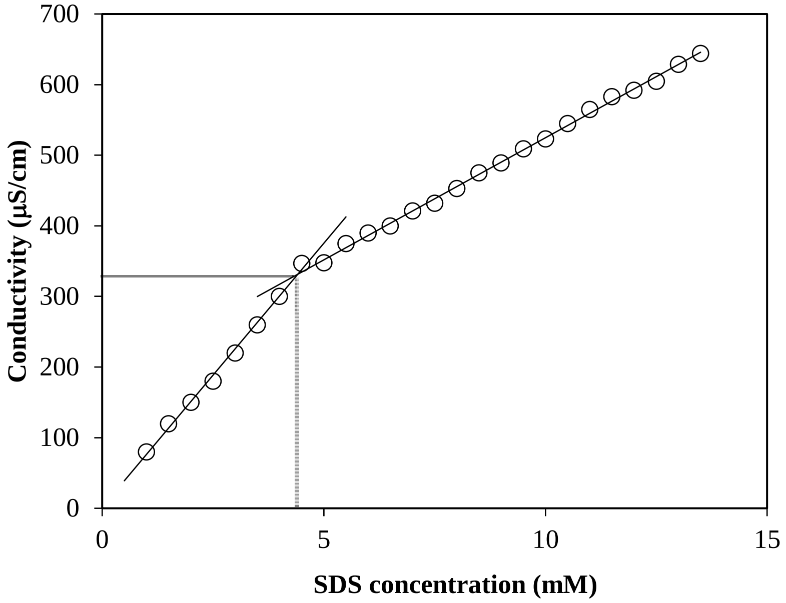


Figure 1: Plot of Conductivity vs Sodium Dodecyl Sulphate Concentration for Determination Critical Micelle Concentration (CMC)

The CMC of sodium dodecyl sulfate (SDS) was determined to be 5.0 mM. Below this concentration, surfactant molecules do not effectively reduce surface tension or mobilize contaminants, reinforcing the need for concentrations at or above this level for effective soil washing.

3.3. Effect of Initial SDS pH on heavy metals washing efficiency

The effect of initial surfactant pH on heavy metals removal efficiency from the contaminated soils was carried out, the actual metal concentration (mg/kg) leached from the soil by SDS are recorded in Table 2a-2c, the concentrations were transformed into percentage removal efficiencies with the aid of an equation similar to that reported by Wuana *et al* (2010) as:

$$\text{Percentage removal efficiency (\%)} = \frac{CmVm}{CsMs} \times 100$$

Where C_m is the concentration of metal in supernatant (mg/L), C_s is concentration of soil in mg/kg, V_m is the volume of supernatant in L, M_s is the mass of dry soil in kg.

The pH of the SDS solution was found to significantly impact the removal of heavy metals, with a pH of 3 showing the highest leaching efficiency for most metals, including cadmium (Cd), chromium (Cr), and lead (Pb). Soil from the New Garage site demonstrated the highest levels of heavy metal removal under acidic conditions, with Cd leaching reaching an average concentration of 3306 mg/kg. This finding aligns with previous studies indicating that acidic conditions enhance the desorption of heavy metals from soils.

Table 2a: Metal Concentration in mg/kg Leached by SDS from contaminated Soils at KS

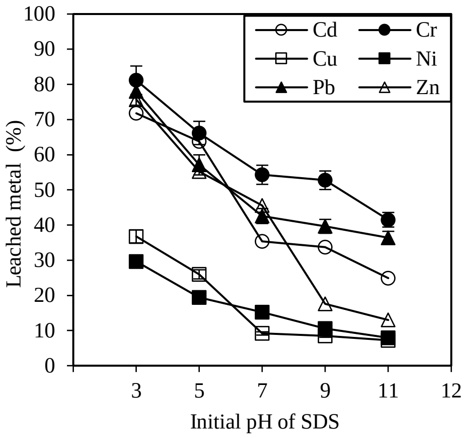
pH	Cd	Cr	Cu	Ni	Pb	Zn
3	2154.5	1294.5	645.5	280	2746.5	777.5
5	1915	1055.5	456	183.5	2011.5	567.5
7	1061.5	866	161	144	1499	468
9	1010.5	841	149.5	100	1396	180.5
11	748	662	127	75	1282	133.5

Table 2b: Metal Concentration in mg/kg Leached by SDS from contaminated Soils at NB

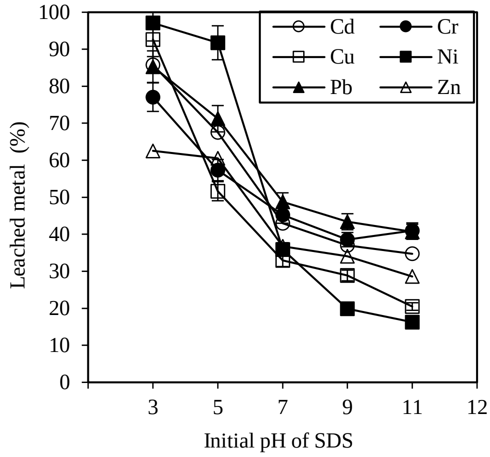
pH	Cd	Cr	Cu	Ni	Pb	Zn
3	3811.5	2004	1816.5	1000	4218	1165
5	3003	1491.5	1012.5	945	3522.5	1127.5
7	1911.5	1177	645.5	370	2411.5	685
9	1643	1003	566	205	2146	635
11	1543	1067	401.5	167.5	2011.5	532.5

Table 2c: Metal Concentration in mg/kg Leached by SDS from contaminated Soils at NG

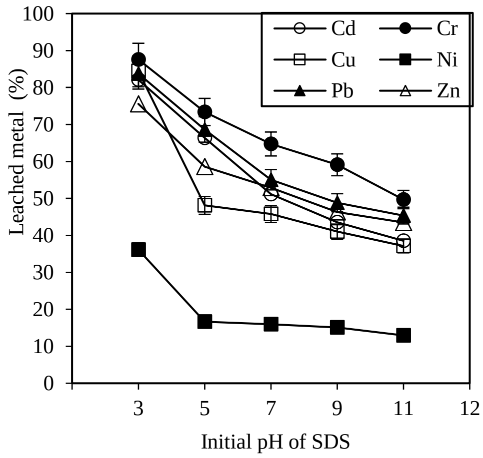
pH	Cd	Cr	Cu	Ni	Pb	Zn
3	3952	3202	1946	635	4453	2220
5	3198	2683	1109	292.5	3650	1720
7	2461.5	2366	1055.5	280.5	2927	1552.5
9	2095.5	2160.5	945.5	265.5	2596	1360
11	1855.5	1816.5	856	227.5	2411.5	1277.5



Kanshio soil



North-Bank soil



New Garage soil

Figure 2: Effect of Initial Sodium Dodecyl Sulphate pH on Heavy Metals Washing Efficiency in Contaminated Soils at Automobile Mechanic Sites

3.4 Effect of initial SDS concentration on heavy metals washing efficiency

The soil washing operations conducted using different surfactant concentrations in mg/kg are recorded in Table 3a-3c using the equation above and represented in figure 3a

Table 3a: Metal Concentration in mg/kg Leached by SDS from contaminated Soils at KS

Conc.	Cd	Cr	Cu	Ni	Pb	Zn
5mM	1336.5	745.5	566	150	1946.5	427.5
6mM	1565	811	666	150	2011.5	82.5
7mM	1895.5	955.5	826	165	2411.5	945
8mM	2400.5	1000.5	1405.5	330	3192	1017
10mM	2605.5	1294.5	1645	367.5	3411.5	1280

Table 3b: Metal Concentration in mg/kg Leached by SDS from contaminated Soils at NB

Conc.	Cd	Cr	Cu	Ni	Pb	Zn
5mM	1395.5	799.5	456	250	1946.5	802.5
6mM	1895	1005	645.5	266.5	2411.5	895
7mM	2295.5	1156	1345	3125	2746.5	1052.5
8mM	3395	1605.5	1645	355.5	4011.5	1222.5
10mM	4006	2004	1846	697.5	4507.5	1506

Table 3c: Metal Concentration in mg/kg Leached by SDS from contaminated Soils at NG

Conc.	Cd	Cr	Cu	Ni	Pb	Zn
5mM	1860.5	1156	456	277.5	2427	427.5
6mM	1961.5	1505.5	1006.5	384	2491	945
7mM	2485.5	1606.5	1345	945	2927	1061
8mM	2896	1745	1556	1883.5	3522.5	1480
10Mm	3661	2261.5	1960.5	1652.5	4107	1722.5

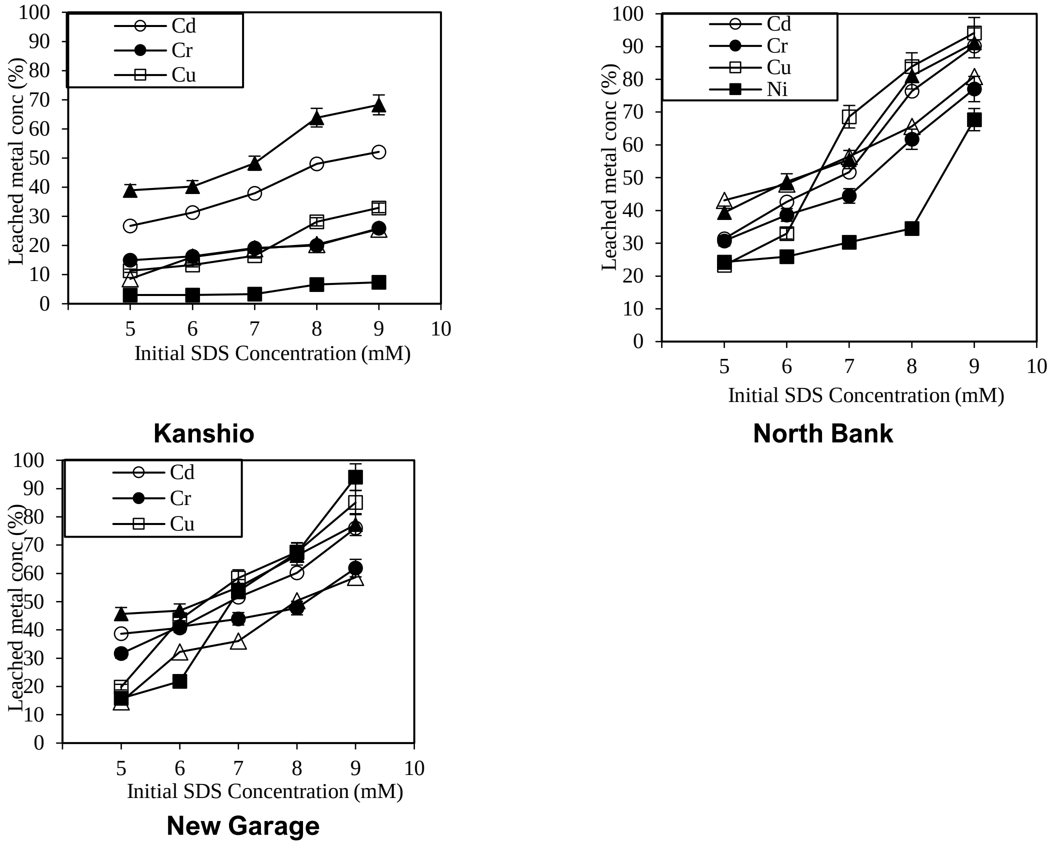


Figure 3: Effect of Initial Sodium Dodecyl Sulphate Concentration on Heavy Metals Washing Efficiency in Contaminated Soils at Automobile Mechanic Sites

The research also highlighted the impact of SDS concentration on the efficiency of heavy metal removal. At a concentration of 10 mM, the highest removal efficiencies were observed for lead and cadmium for all sampling points as can be observed in figure 3a. These results suggest that higher concentrations of SDS are crucial for maximizing the removal of metals from contaminated soils.

3.5. Effect of soil/surfactant ratio on heavy metals washing from soil

Ratio of Soil/SDS conducted by varying the mass of soil at constant volume of SDS has metal concentration leached (mg/kg) and the percentage removal efficiency calculated also using the above equation is illustrated in figure 4.

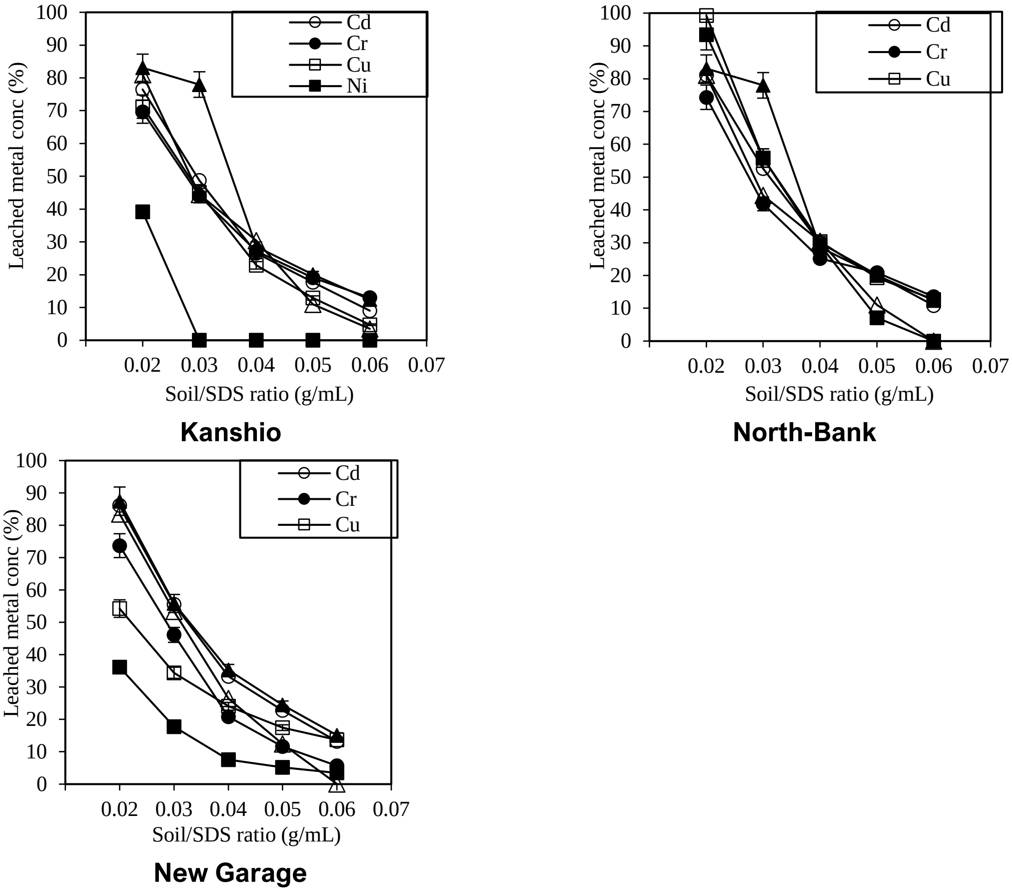


Figure 4: Effect of Soil/Sodium Dodecyl Sulphate Ratio on Heavy Metals Removal from Contaminated Soils at Automobile Mechanic Sites

The soil-to-surfactant ratio was another key variable, with lower soil-to-surfactant ratios (0.02-0.03 g/mL) providing higher removal efficiencies for all metals, including cadmium and lead. A ratio of 0.02 g/mL yielded the highest removal efficiency, further supporting the efficacy of surfactant-enhanced soil washing at lower soil loads.

3.6 Effect of Washing Time on Heavy Metals Removal from Contaminated

Time an important factor influencing the removal of contaminants from soils in washing process by SDS at different contact times was also studied for HMs. The transformed concentrations to removal efficiencies in percentages are illustrated in figures5a for HMs.

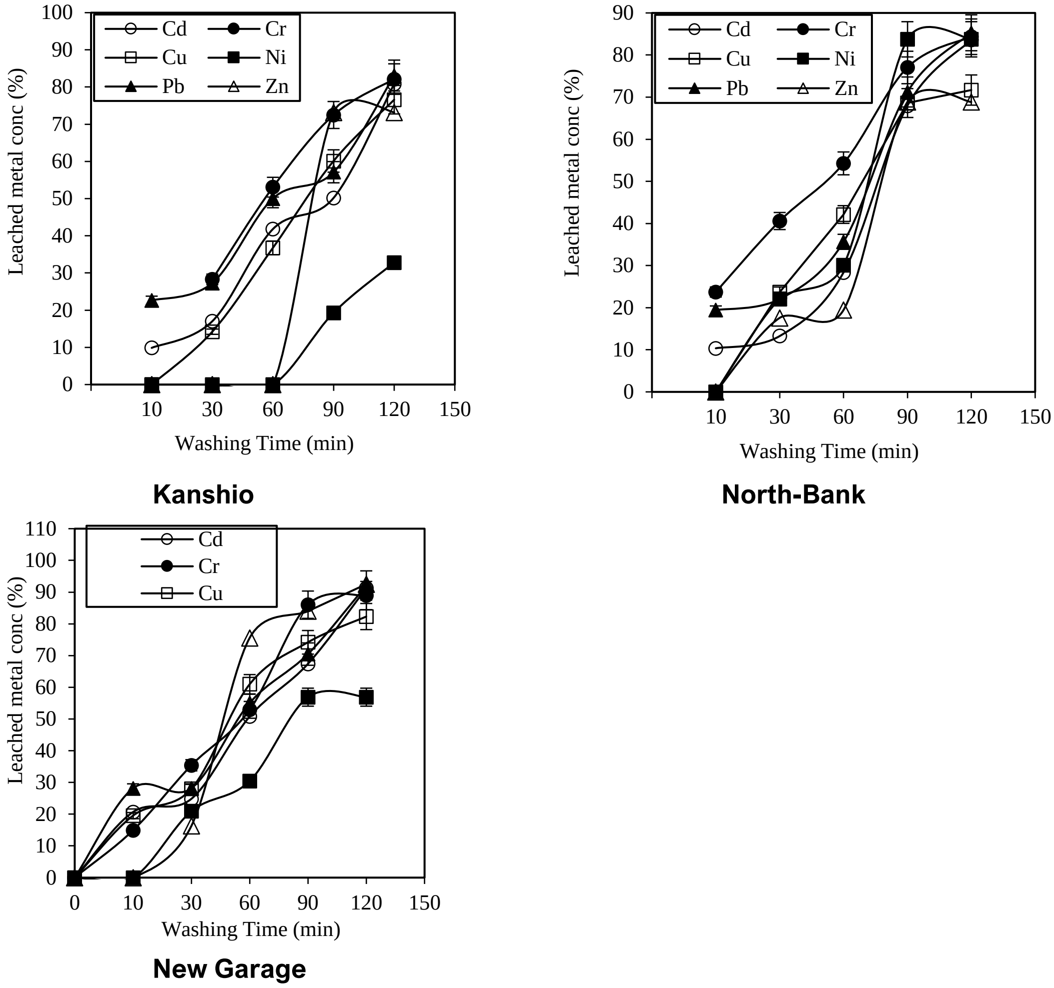


Figure 5: Effect of Washing Time on Heavy Metals Removal by Sodium Dodecyl Sulphate from Contaminated Soils at Automobile Mechanic Sites

Washing time significantly affected the removal of heavy metals, with longer durations (120 minutes) yielding greater removal efficiencies for cadmium (87.91%) and lead (97.93%). The data suggest that extended washing time allows for more interaction between the surfactant and soil particles, improving contaminant desorption.

4. CONCLUSION

The remediation of soil contaminated by heavy metals is necessary so as to reduce associated human and plant risks and preserve the land for living and agricultural practices, the assessment of washing parameters for the SDS aided soil washing considered pH of surfactant, Concentration of surfactant, Soil/SDS ratio and Contact time of the surfactant and the contaminated soil, this was to assess the parameter that had the highest removal of the contaminant and the concentration of the surfactant at the greater removal, the greater removals were recorded for the high acid solution of the surfactant (pH 3) for heavy metals, higher concentration (for this research 10mM) above the CMC value had the highest removals, this implies that before a surfactant is used the CMC must be known, when the ratio of Soil/SDS was also checked it was discovered that a ratio of 1: 50 should be considered, the effect of washing time played a very significant role in washing contaminated soils, to achieve high percentage removal more time should be employed at least 3hours for heavy metals.

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