Surfactant-Mediated Techniques for Heavy Metal Removal in Water Treatment

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Abstract

Heavy metals pose a significant threat to environmental and public health due to primarily from agricultural runoff and sugar industry effluents. The physicochemical parameters such as pH, total hardness, total deposit solids, turbidity and chemical oxygen demand (COD) of water is determined. The water samples are analyzed that various metal ions presented durring analysis. In this study, we found that various metal ion such as iron (Fe), lead (Pb), cadmium (Cd) and chromium (Cr), exceeding permissible limits from collected samples. It is task for scientific community to removal of heavy metals from water samples. We observed that the iron metal ions levels are very high than other metal ions in this region. Therefore, we have used nonionic surfactants and polymer, particularly Triton X-100 (TX-100), Triton X-114 (TX-100), Polyethylene glycol 200 (PEG-200), polyethylene glycol 400 (PEG-400) for the removal of heavy metals from contaminated water samples from different regions by cloud point extraction techniques. The efficiency of surfactants viz. TX-100, TX-114, PEG-200, PEG 400 are influenced by factors such as pH, surfactant concentration. These method operate through micellar solubilization, enhanced adsorption and chelation, offering a sustainable and cost-effective solution for heavy metal removal in water.

Keywords: Non-ionic Surfactant, polymers, heavy metal, cloud point extraction, Iron

1.0 Introduction

The rapid pace of industrialization, urban expansion and intensified agriculture has led to a substantial rise in heavy metal contamination of aquatic ecosystems [1-2]. These pollutants often originating from industrial effluents, mining, agricultural runoff and improper waste management, pose significant ecological and public health risks due to their toxicity, persistence, bioaccumulation, and non-biodegradable nature [3]. Heavy metals such as iron (Fe), lead (Pb), cadmium (Cd), nickel (Ni) and chromium (Cr) are frequently found in contaminated water sources and have been linked to adverse health effects including kidney damage, neurological disorders, and carcinogenic outcomes [4].

The increasing pollution in this vital water body, primarily from agricultural runoff and industrial discharge, underscores the urgent need for effective and sustainable remediation strategies [5]. Traditional remediation techniques such as chemical precipitation, ion exchange, reverse osmosis and chelation are often limited by high costs, low selectivity, and operational inefficiencies [6]. Moreover, while trace amounts of certain metals are essential for biological functions, elevated concentrations demand immediate intervention [7].

Surfactant-based approaches are emerging as promising alternatives for heavy metal remediation [8]. Surfactants, particularly non-ionic types like Triton X-100 and Triton X-114, exhibit favorable properties such as high solubility, low ionization, and the ability to form micelles above their critical micelle concentration (CMC) [9-10]. These micelles can encapsulate heavy metal ions through electrostatic interactions or chelation, forming stable complexes that can be separated by filtration or phase transitions [11]. Furthermore, surfactants can enhance the adsorption capacity of materials like activated carbon and clays and improve membrane-based filtration by altering surface characteristics [12].Advanced techniques such as micellar-enhanced ultrafiltration (MEUF), cloud point extraction (CPE), and the use of surfactant-modified adsorbents leverage these unique properties for efficient pollutant removal [13-14]. Non-ionic surfactants are particularly advantageous due to their stability, lower environmental impact, and compatibility with a wide range of conditions [15].

When selecting surfactants for environmental applications, critical factors such as toxicity, biodegradability, breakdown products, cost, and regulatory acceptance must be considered [15]. Ideal surfactants for remediation should possess low toxicity, high biodegradability, low soil adsorption, good solubility at environmental temperatures, low CMC, and effectiveness at low concentrations [16-17]. Biosurfactants offer additional advantages, including enhanced biodegradability and resilience to environmental fluctuations, and are increasingly being explored for their cost-effective applications in soil and water remediation [18].

Sahu et al. [19] investigated the removal of color and chemical oxygen demand (COD) from sugar industry wastewater using thermolysis processes. Their study highlighted that sugar industries generate approximately 1 m^3 of wastewater per ton of cane processed, which carries a substantial pollution load, particularly in terms of organic matter. Similarly, Bhatta and his research team [20] conducted a physico-chemical analysis of sugar mill effluents from Kabirdham (C.G.), revealing that these effluents contain both acidic and alkaline compounds, a significant amount of suspended solids, and high levels of biochemical oxygen demand (BOD), COD, and sugar concentration.

Ghafar and his group [21] explored the removal of hazardous contaminants from water using natural and zwitterionic surfactant-modified clay. They evaluated the physical, chemical, and adsorption properties of natural clay (NC) before and after its modification with the zwitterionic surfactant cocamidopropyl betaine (CAPB). They found that modification was critical for the effective adsorption of reactive yellow 160 (RY160), although it was ineffective for Pb^{2+} adsorption. The sample heated at 60°C for 3 hours and treated with a CAPB concentration equal to twice the cation exchange capacity (CEC) of NC showed the highest RY160 removal. The adsorption interaction between RY160 and CAPB-modified NC was strong, favored at pH 2, and led to the formation of multilayers. Asweisi et al. [22] studied the use of propylene oxide–ethylene oxide block polymers for the removal of metal ions via cloud point extraction techniques. Their research demonstrated that these polymers possess excellent physicochemical properties, making them effective for metal ion removal using cloud point extraction. In the persent investigation, we have investigated that the physicochemical parametes of water samples taken from various sites. Heavy metal containing water samples are analysed and deterime the higher concentration range of metal ions from selected regions. Herein surfactant mediated techniques have been used for removal of heavy metal from water samples. We have discussed the removal of iron with ADPC in presence of TX-100, TX-114, PEG -200, PEG-400 under reaction condtions by cloud extraction techniques.

2. Materials and Methods

2.1 Study Area

Bhoramdev Sugar Factory, Kawardha (SIWW-1) [19, 23], Louvapurush Sugar Factory, Rohra (SIWW-2) and near situated hamp river are selected for study area. These factories discharge industrial effluents into surrounding water bodies, while intensive agricultural practices involving pesticides and insecticides further elevate the risk of heavy metal contamination. To assess the extent of pollution, water samples were collected from three representative locations—SIWW-2, the vicinity of SIWW-2 in Rohra and the Laduva stretch of the Hamp River during monsoon, winter, and summer seasons. These sites were selected to reflect industrial, agricultural, and semi-urban influences.

2.2 Sample Collection

Samples were collected following standardized procedures using pre-cleaned, airtight 200 mL plastic bottles. At each location, bottles were rinsed with distilled water and then with site water to reduce contamination. All samples were stored in iceboxes, transported to the laboratory, and refrigerated at 4°C to maintain their physico-chemical integrity and inhibit biological activity.

2.3 Materials

All the chemicals and reagents are used for experiments and procured by laboratory grade, sourced from Merck India Ltd. (Mumbai). Triple distlled water have been used for experiments. Analytical procedures utilized high-purity water and analytical-grade reagents. Surfactants such as Triton X-100, Triton X-114, and polyethylene glycols (PEG 200 and PEG 400) were chosen for their micelle-forming capabilities and procured from Hi-Media. Ammonium pyrrolidinedithiocarbamate (APDC, extrapure, 98.5%) was purchased from SRL Chemicals. A 1.0%(w/v) surfactant solution was prepared and used for heavy metal encapsulation.

2.4 Used Instrumentation for analysis

Physico-chemical parameters including pH, total hardness, total deposit solid (TDS), turbidity and chemical oxygen demand (COD) were analyzed within 24–48 hours. Water quality parameters were determined using standard methods: pH was measured with a calibrated Systronics Model 362 digital pH meter; total hardness via EDTA titration, COD using the dichromate open reflux method. Sample color was measured at 420 nm using a atomic absorption spectrophotometer model No PG 8000. Heavy metal concentrations of water sample were determined by the National Institute of Technology, Raipur. The systronics 232 digital flame atomic absorption spectroscopy (FAAS), was used for metal detection per the manufacturer's specifications.

2.5 Experimental setup and procedure

Cloud Point Extraction (CPE) experiments were conducted. A 12 mL sample was prepared containing 10 mL of iron (Fe) cotaining solution, 1 mL of surfactant and 1 mL of ammonium pyrrolidinedithiocarbamate (APDC). The mixture was placed in a temperature controlled water bath and heated at temperatures ranging from 20°C to 100°C for 15 minutes. Phase separation was achieved by centrifugation at 3000 rpm for 2 minutes. After cooling the mixture in an ice bath for 5 minutes, the surfactant-rich phase and the diluted aqueous phase became immiscible, allowing for easy separation of the supernatant aqueous phase. The surfactant-rich phase was then introduced into the FAAS system via conventional aspiration for metal analysis. The efficiency of iron extraction using the CPE method was evaluated by calculating the extraction yield (%) using the following equation:

$\%E = (C_0 - C_t C_0) \times 100$

where %E is the extraction yield, C_0 is the initial metal ions concentration in the feed phase, and C_t is the final metal ions concentration in the aqueous phase after extraction.

3.0 Result and Discussions

The physico-chemical assessment of water indicates moderate pollution levels with elevated heavy metal concentrations in some areas. Accurate detection and quantification of heavy metals in water samples are critical for assessing pollution levels and environmental risk [19-20]. The different physicochemical parameters of water samples are analyzed by various techniques, shown in Table 1.

3.1 pH

pH is a fundamental parameter that indicates the acidity or alkalinity of water, with the safe drinking range [1, 5]. Samples from the SFWW-2 at Rohra, Near SFWW-2 at Laduva and Laduva Hamp river exhibited pH values of 5.6, 6.1 and 6.2 reflecting acidic conditions. Acidic conditions increases the solubility of heavy metals like iron, lead, copper and cadmium, making them more bioavailable and potentially toxic. Variations in pH may also influence metal corrosion, nutrient availibility, microbial metabolism, water treatment efficiency. These fluctuations influence water quality, aquatic life and chemical reactivity.

3.2 Total Hardness

Hardness is an important indicator of water quality, reflecting its concentration of calcium and magnesium ions, which hinder soap lather formation [24]. In this study, total hardness in groundwater samples such as SFWW-2, Near SFWW-2 Laduva, and Laduva Hamp river are analyzed and found ranged from 957, 810, 830 mg/L. Higher total hardness in water, due to excess calcium and magnesium, causes scaling in pipes and appliances, reducing efficiency [25]. It hinders soap lathering and leaves residues. While not harmful to health, it may cause skin dryness. In agriculture and aquatic systems, it affects soil quality and disturbs aquatic life.

3.3 Total Dissolve Solid

Total Dissolved Solids (TDS) represent the total concentration of dissolved substances in water, including minerals, salts and organic matter. TDS influences the taste, hardness and electrical conductivity of water. While lower TDS generally indicates higher purity, extremely low levels can affect taste and essential mineral content [20]. According to the Bureau of Indian Standards (BIS), the acceptable limit for TDS in drinking water is 500 mg/L. Elevated TDS levels can originate from natural geological sources, industrial discharges or agricultural runoff and may pose health risks. Samples from SFWW-2 at Rohra (1450 mg/L), near SFWW-2 at Laduva (1130 mg/L) and Laduva Hamp river (1110 mg/L) showed significantly higher TDS levels.

3.4 Turbidity

Turbidity measures the cloudiness of water caused by suspended particles like silt, clay, organic matter and microorganisms [19]. According to the National Drinking Water Quality Standards, the acceptable limit is 1 NTU, with a permissible maximum of 10 NTU. In this study, turbidity analyzed from sites such as SFWW-2 at Rohra, Near SFWW-2 at Laduva and Laduva Hamp river and observed 85, 63, 52

NTU. Higher turbidity in water reduces light penetration, affecting aquatic plant growth and disrupting ecosystems. It can reducing water quality and increasing treatment costs. Turbid water may also carry suspended solids, organic matter, and pollutants, posing health risks and making the water aesthetically unpleasant and unsuitable for consumption.

3.5 Chemical Oxygen Demand (C.O.D.)

The Chemical Oxygen Demand (COD) test measures the amount of oxygen required for the chemical oxidation of organic matter using a strong chemical oxidant. It is widely used to evaluate the degree of pollution in domestic and industrial wastewater, as it reflects the quantity of oxygen needed to convert organic matter into carbon dioxide and water [20]. In the study, COD values ranged from 3604 to 3252 mg/L, indicating a relatively high level of organic load. However, all values remained within the permissible limits specified for wastewater discharge, suggesting moderate pollution levels manageable by conventional treatment processes.

Table 1- The physicochemical parameters are analyzed by various techniques.

S.No.	Parameters	Standard Value for Drinking (BIS)	SIWW -1 (Reference Data)	SFWW-2 Rohra	Near SFWW-2 Laduva	Laduva Hamp River
1	pH	6.5-8.5	5.5	5.6	6.1	6.2
2	Total Hardness (mg/l)	500	902	957	830	710
3	Total dissolved solid (TDS) (mg/l)	500	1447	1450	1130	1110
4	Turbidity (NTU)	1	76.1	85	63	52
5	COD (mg/l)	200	3682	3604	3512	3252

3.6 Analysis of metals from water samples

The concentration of heavy metals in water samples was determined to assess the extent of contamination in various environments [26]. The analysis revealed spatial and seasonal variations in metal concentrations, with higher levels generally detected near industrial discharge points, particularly around the Louvapurush Sugar Factory (SIWW-2). Among the metals tested, iron exhibited the highest concentration, followed by zinc and copper, while cadmium and lead were present in lower amounts but still detectable. In this study, iron concentrations in all groundwater samples exceeded the permissible limits set by water quality standards. Detailed results of iron levels across the sampling locations are presented in Table 2 and Fig 2-5.

Table 2 - The sample analyzed from various source by atomic absorption spectroscopy

	Summer Season			Winter Season			Mansoon Season		
Metals in Water	SFWW-2 Sample 1 mg/L	Near SFWW-2Sample 2 mg/L	Laduva Hamp River 3 mg/L	SFWW-2 Sample 1 mg/L	Near SFWW-2Sample 2 mg/L	Laduva Hamp River 3 mg/L	SFWW-2 Sample 1 mg/L	Near SFWW-2Sample 2 mg/L	Laduva Hamp River 3 mg/L
Fe	1.071	0.512	0.263	2.404	1.204	0.812	0.958	0.853	0.893

Mn	0.214	0.321	0.157	1.682	0.833	0.61	0.432	0.631	0.632
Pb	0.02	0.01	0.02	0.06	0.05	0.04	0.04	0.03	0.03
K	0.118	0.032	0.038	0.938	0.818	0.532	0.018	0.043	0.031
Ni	0.01	0.009	0.007	0.12	0.11	0.12	0.002	0.004	0.002
Cr	0.02	0.03	0.05	0.03	0.02	0.02	0.007	0.004	0.003
Zn	0.112	0.028	0.025	1.485	0.312	0.028	0.012	0.013	0.023
Cd	0.02	0.01	0.01	0.02	0.01	0.01	0.001	0.002	0.003
Cu	0.01	0.01	0.01	0.081	0.062	0.073	0.21	0.032	0.015

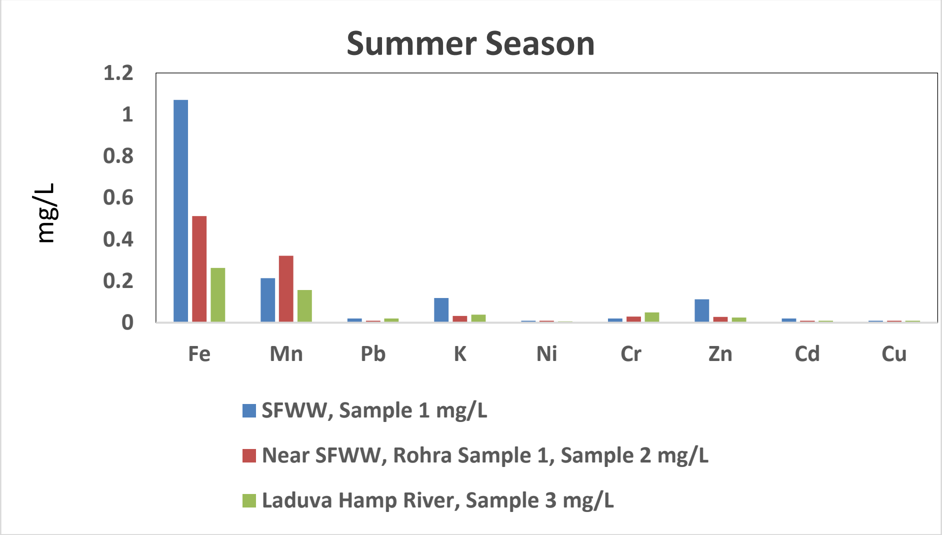

Fig. 2 - The heavy metals in water samples analyzed by atomic absoption spectroscopy durning summer season.

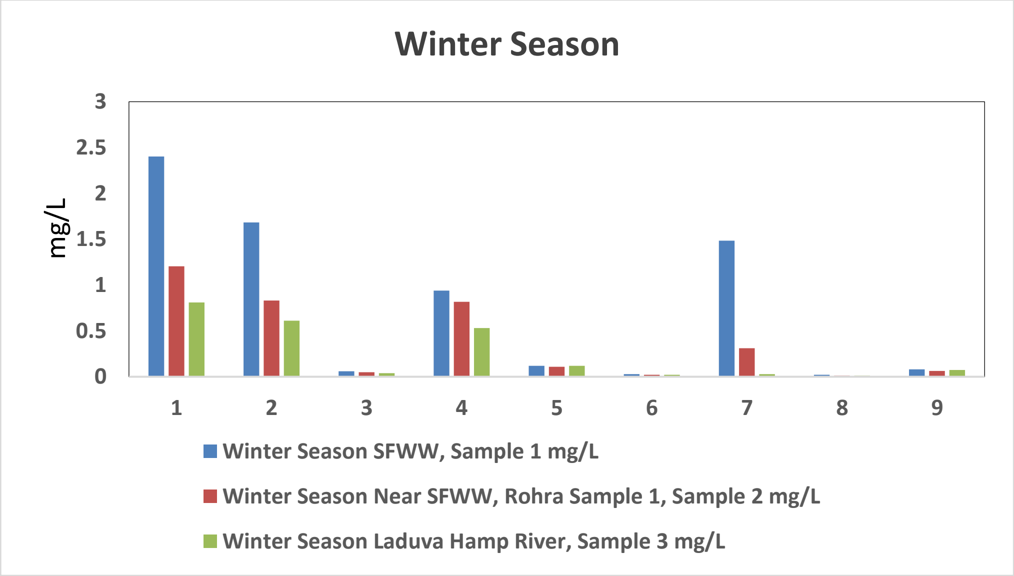

Fig 3- The heavy metals in water samples analyzed by atomic absoption spectroscopy durning winter season.

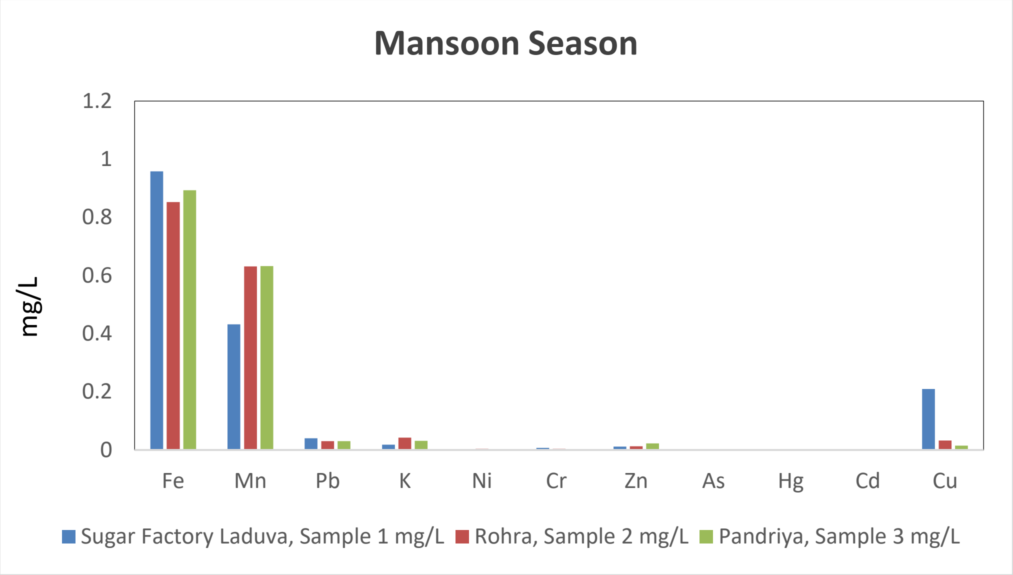

Fig 4.- The heavy metals in water samples analyzed by atomic absoption spectroscopy durning Mansoon season.

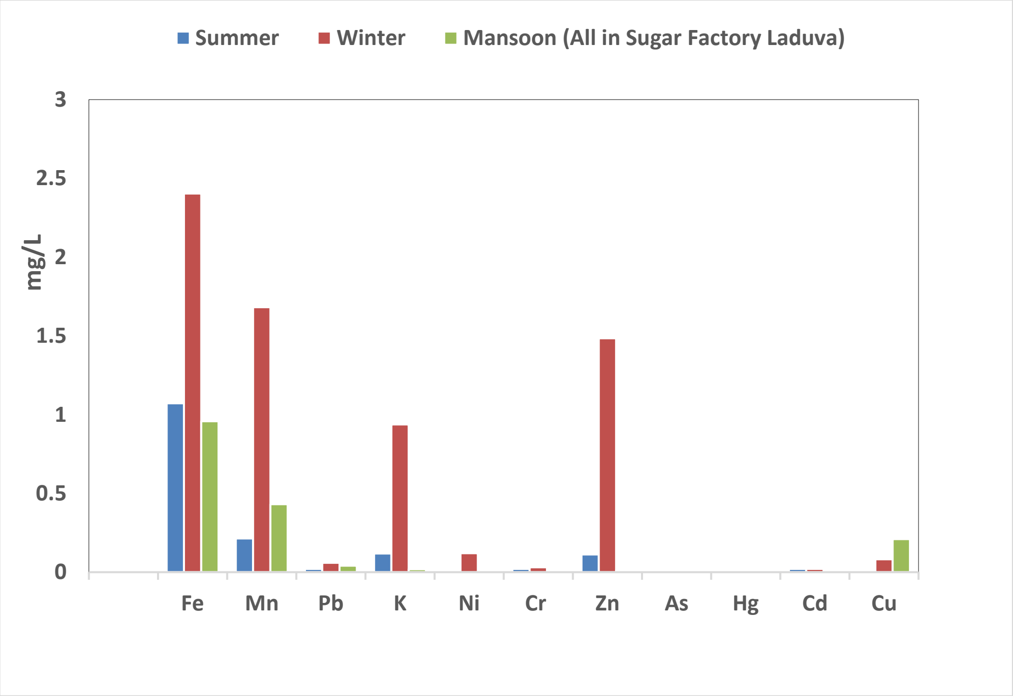

Fig 5- Comparative the heavy metals in water samples analyzed by atomic absoption spectroscopy durning summer, winter and mansoon seasons.

3.7 Role of Non-Ionic Surfactants in Heavy Metal Extraction from Water

Non-ionic surfactants, zwitterionic surfactants and polymers are widely utilized in heavy metal removal from water due to their biodegradability, environmental compatibility, and cost-effectiveness [27-28]. Surfactants enhances adsorption onto solid and liquid interfaces forming more compact layers shifts surface interactions from repulsive to attractive, decreases colloidal stability and alters microemulsion structures from oil-in-water to water-in-oil [29]. For effective water remediation, surfactants must exhibit strong solubilising capabilities for pollutants and minimal direct adsorption onto metal particles.

However, selective adsorption of surfactant-pollutant complexes onto activated carbon is crucial for surfactant recovery and overall process efficiency [30]. In this study, Triton X-100, Triton X - 114, PEG-200, PEG 400 was employed as a surfactant for extracting iron (Fe) metal from water source. The various types of metal ions have been analyzed in water samples (Table 2). Herein, the removals Fe have been discussed by cloud point extraction techniques due to its major amount of avaibility with water samples in SFWW-2, Near SFWW Laduva and Laduva Hamp River. Table 2 shows that Fe is analyzed and found in highest level among them metal in water samples. Cloud Point Extraction (CPE) is a low-cost, eco-friendly method widely employed for the preconcentration and separation of analytes, offering distinct advantages over conventional liquid-liquid extraction [31] Non-ionic surfactants and polymers such as Triton X-100, TX-114, PEG-200, PEG-400 are used due to their high water solubility and minimal ionization [21,32].

CPE involves phase separation induced by temperature, with optimal extraction occurring within a specific surfactant concentration range. Too high a concentration reduces the preconcentration factor, while too low may result in poor analyte recovery [33]. Metal ion extraction via CPE relies on complexation with suitable ligands, which is highly pH-dependent. Common chelating agents include azo dyes, dithizones and dithiocarbamates, though ligand-free methods have also been developed. For instance, Tween-80 has been used to preconcentrate Cd^{2+}, Ni^{2+}, Pb^{2+}, Bi^{3+}, Cu^{2+} and Cr^{3+} from various samples at pH 8.5 [34]. Reseacher has explained that the extraction of cobalt and lead using 8-hydroxyquinoline with Triton X-114 [31]. The clouding phenomenon also observed in systems with zwitterionic or ionic surfactants and saltsoccurs at the cloud point (CP), where the solution separates into surfactant-rich and surfactant-lean phases. As CP is reached, dehydration of micelle hydrophilic segments causes micelles to aggregate into larger clusters [31].

3.8 Effect of pH on Iron Extraction Efficiency via Cloud Point Extraction

pH plays a pivotal role in the efficiency of extraction processes, particularly for ionic species such as metal ions. The effectiveness of Cloud Point Extraction (CPE) largely depends on the formation and stability of metal–ligand complexes, which are strongly influenced by pH. Surfactants and polymers can modulate this stability, thereby affecting the overall extraction efficiency [35]. Each CPE system has an optimal pH range, typically where the analyte exists in a neutral or weakly charged form, promoting its incorporation into the surfactant micelles [36]. In CPE, metal ions must first form hydrophobic complexes that can be solubilized within the micelle-rich phase [37]. The extent of complex formation and thus extraction yield is highly pH-dependent. In the present study, Fe extraction was evaluated over a pH range of 2–10 using various non-ionic surfactants. The results, shown in Figure 6 and Table 3 indicate that extraction efficiency peaked at pH 5 for all tested surfactants. Among them, Triton X-114 and PEG-200 demonstrated the highest extraction efficiencies at this pH.

Quantitative extraction was achieved in the pH range of 5.5–6.0. Beyond this range, a decline in recovery was observed. At pH values above 6.0, the decrease in extraction efficiency is likely due to the precipitation of Fe as ferric hydroxide, which inhibits micellar solubilization. Conversely, at pH values below 5.5, reduced efficiency may result from competition between hydronium ions and Fe for complexation with ammonium pyrrolidinedithiocarbamate (APDC), or from the decomposition of the metal–ligand complex under more acidic conditions. A pH of 6.0 was selected for subsequent experiments, as it provided an optimal balance between ligand deprotonation and minimized hydrogen ion interference. While improved extraction at moderately higher pH is attributed to enhanced ligand availability, further increases in pH led to a gradual decline in extraction efficiency due to metal precipitation or reduced complex solubility.

Table 3. The effect of pH shown in presence of surfactants and polymers

S.No.	pH	TX-114	TX-100	PEG-200	PEG-400
1.	2	42	32	38	34
2.	3	65	41	49	38
3.	4	84	55	68	51
4.	5	97	76	85	64
5.	6	93	73	82	60
6.	7	81	69	75	52
7.	8	68	56	64	44
8.	9	55	45	52	42
9.	10	44	37	41	31

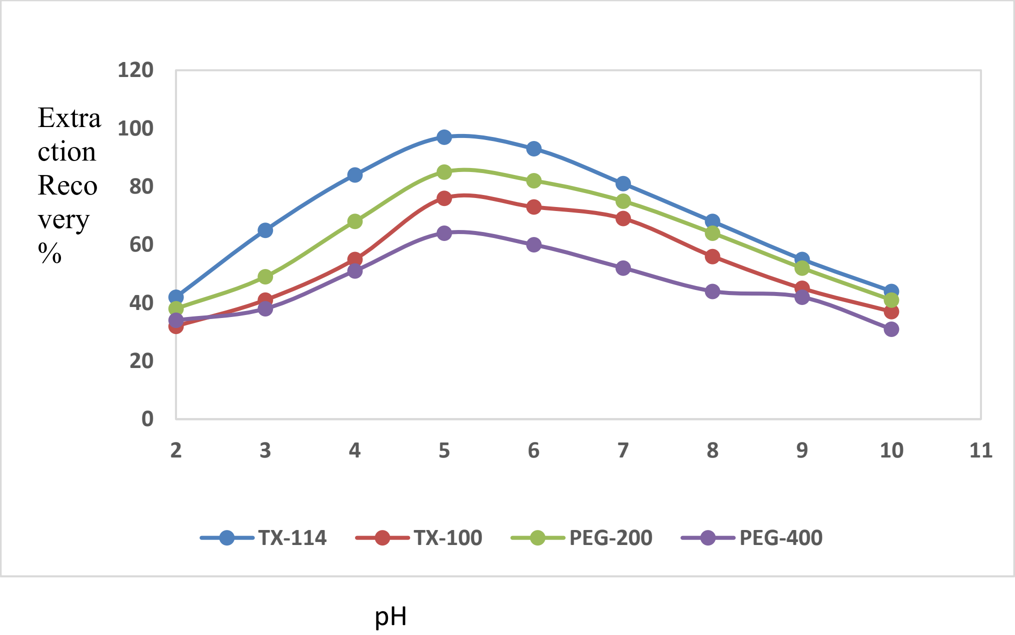

Fig 6- Effect of pH on the extraction recovery of iron, Conditions:[surfactant] 0.08%(w/v) mM, APDC: 0.1mM

3.9 Effect of ammonium pyrrolidinedithiocarbamate (APDC) concentration

In this study, ammonium pyrrolidinedithiocarbamate (APDC) was employed as a chelating agent for Fe ions in the cloud point extraction (CPE) process, owing to its high solubility and complex stability in aqueous systems. A solution containing10 mL of Fe was prepared in 0.08 % solutions of various non-ionic surfactants sucn as Triton X-114, Triton X-100, PEG-200, and PEG-400at pH 5.0and containing varying concentrations of APDC. These solutions were subjected to CPE to evaluate the impact of ligand concentration on extraction efficiency. At an APDC concentration of 0.1 mM, approximately 100% extraction efficiency was achieved, establishing this concentration as optimal for subsequent experiments. As depicted in Table 4 and Figure 7, the influence of APDC concentration on Fe extraction yield was systematically studied. Results showed that, with PEG-400 and Triton X-100, APDC addition had minimal impact on extraction efficiency, suggesting that effective Fe recovery could occur even in the absence of the ligand. However, in the presence of Triton X-100, a decline in extraction yield was observed at higher APDC concentrations. This reduction is likely due to ligand overload, which can interfere with micelle formation by increasing the organic content or promoting the formation of charged complexes, thereby reducing micelle incorporation efficiency. Furthermore, saturation of the surfactant's active binding sites may have limited further metal–ligand complex formation, ultimately decreasing extraction performance [38].

Table 4 - Data shows the concentration effect of APDC with different Types of surfactants Conditions:[surfactant] 0.08%(w/v) mM, APDC: 0.1mM.

S.No.	APDC, mM	TX-100	TX-114	PEG-200	PEG-400
1.	0.02	14	18	16	15
2.	0.05	23	34	19	18
3.	0.07	33	45	26	24
4.	0.1	43	55	40	38
5.	0.15	42	54	41	37
6.	0.2	41	52	39	36
7.	0.25	42	51	39	37
8.	0.3	41	53	38	36
9.	0.35	42	52	38	36
10.	0.4	42	51	37	36

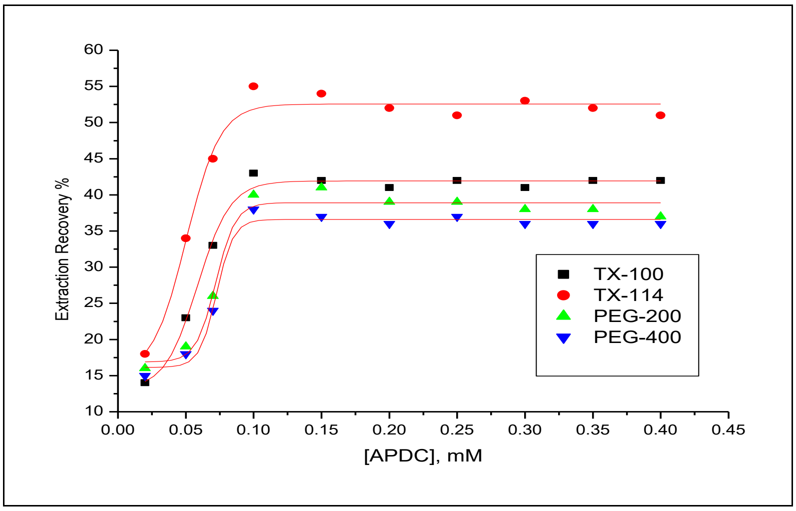

Fig 7- Effect of APDC on the extraction recovery of iron, Conditions:[surfactant] 0.08%(w/v) mM, APDC: 0.1mM.

4.0 Effect of surfactant Concentration on Metal extraction

Polyethylene glycol-200 (PEG-200), polyethylene glycol-400 (PEG-400), Triton X-100 (TX-100), and Triton X-114 (TX-114) were employed as non-ionic surfactants due to their favorable physicochemical properties. Their high-density surfactant-rich phases enable efficient phase separation via centrifugation, while their low cloud point temperatures (20–80 °C) facilitate effective extraction and preconcentration of analytes and metal-chelate complexes at moderate thermal conditions [19]. The impact of surfactant concentration on extraction efficiency was investigated over a range of 0.01% to 0.15% (w/v) for TX-100, TX-114, PEG-200, and PEG-400. As illustrated in Figure 3, the extraction efficiency reached its maximum at a Triton X-114 concentration of 0.07% (v/v). Beyond this concentration, a decrease in analytical sensitivity was observed, likely due to the dilution effect caused by excess surfactant, which reduces the effective concentration of the analyte in the surfactant-rich phase. Based on these findings, 0.07% (v/v) Triton X-114 was selected as the optimal concentration for subsequent experiments. Additionally, as shown in Figure 8 and Table 5, only a marginal increase in metal ion uptake was noted with increasing surfactant volume, indicating that higher surfactant concentrations do not significantly enhance extraction efficiency beyond the optimal point.

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Table 5: The various surfactants concentration on the cloud point extraction of iron. Reaction Conditions: pH: 5.0, ADTC: 0.1mM

S.No.	[Surf.], mM	Fe+TX-114	Fe+TX-100	Fe+PEG-200	Fe+PEG-400
1.	0.02	53	45	48	44
2.	0.05	86	73	58	47
3.	0.08	108	84	97	72
4.	0.2	106	85	94	74
5.	0.4	102	82	92	70
6.	0.6	98	78	84	63
7.	0.8	96	69	76	54
8.	1	89	65	72	51
9.	1.1	88	64	69	48

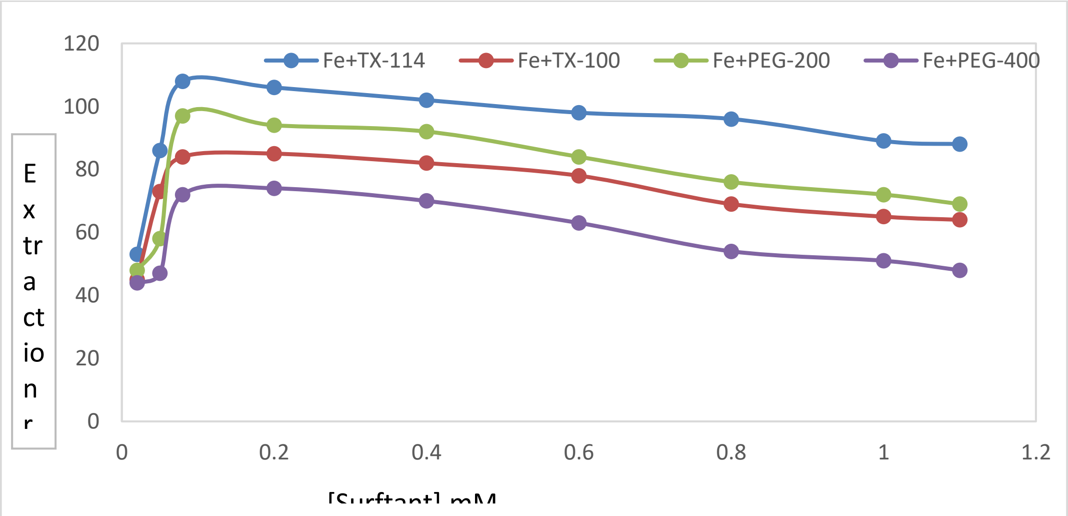

Fig8 Effect of various surfactants concentration on the cloud point extraction of iron. Reaction Conditions: pH: 5.0, ADTC: 0.1mM

4.1 Effects of equilibration temperature and time

To optimize the Cloud Point Extraction (CPE) of Fe, the effects of equilibration time and temperature were evaluated to achieve efficient phase separation and complete extraction [39]. An equilibration temperature of 40°C was found to be ideal for effective micelle formation and analyte partitioning using non-ionic surfactants. Extraction efficiency was tested over 5–30 minutes, with 15 minutes identified as the optimal equilibration time for quantitative recovery. The low cloud point temperatures (CPTs) of the surfactants used enabled rapid micelle formation, enhancing process efficiency. Fe extraction was further examined across a temperature range of 2–100 °C, with phase separation initiating consistently at 40 °C. Beyond this, no significant increase in efficiency was observed. As no improvement was noted with longer centrifugation, this condition was used in all further experiments to ensure fast and reproducible separation [40].

5.0 Effect of parameters

5.1 Effect of pH

pH is a crucial parameter in Cloud Point Extraction (CPE), as it directly influences the formation of metal-chelate complexes and governs overall extraction efficiency. Therefore, pH optimization is typically conducted before evaluating other experimental variables. As outlined in Table 5, optimal extraction conditions were reported at pH 4 with 0.3% (v/v) Triton X-114 at 40–80 °C and pH 5.5 with 1.25% (v/v) Triton X-114 at 40 °C (31, 41-42). Extraction efficiency declines at low pH (<5) because analytes remain protonated and do not readily partition into the surfactant-rich phase. Conversely, at high pH (>8), deprotonated species remain in the aqueous phase, reducing recovery (Noorashikin et al., 2013). Additionally, pH affects metal speciation: for example, copper becomes more soluble at low pH, while higher pH favors hydroxide complex formation or precipitation.

5.2 Effect of surfactant concentration

Surfactant concentration plays a vital role in phase separation during cloud point extraction (CPE). At low concentrations, incomplete phase separation occurs, while excessive surfactant concentrations increase the viscosity of the surfactant rich phase and reduce its volume, thereby hindering efficiency [43]. In a study on Fe ion extraction, 0.08 mM surfactants was identified as the optimal concentration, yielding the highest recovery. Beyond 0.4%, recovery declined due to increased viscosity and micellar phase volume [44].

5.3 Effect of time and temperature

Effective cloud point extraction (CPE) also depends on selecting an appropriate incubation time and equilibrium temperature to facilitate phase separation and analyte preconcentration. The formation of the surfactant-rich phase is largely governed by the temperature-dependent behavior of the surfactant [45]. Extraction times shorter than 5 minutes are typically insufficient, as phase separation remains incomplete. Optimal extraction is usually achieved within 5 to 10 minutes. However, temperatures exceeding 40 °C can lead to solvent evaporation and loss of target analytes. Conversely, at temperatures below room temperature, analyte mobility is reduced, and the surfactant fails to form the micellar phase effectively, resulting in poor separation efficiency.

5.4 Effect of Organic matter

Organic Matter refers to a complex mixture of water-insoluble organic compounds commonly present in various environmental matrices such as water, soil, and sediments. A predominant form of organic matter in these systems is humic substances, which are responsible for the characteristic brownishyellow coloration of natural waters. Studies have shown that organic matter can significantly influence heavy metal mobility and removal, often complicating the development of effective remediation strategies.

6.0 Conclusion

This study explored the effectiveness of non-ionic surfactants for extracting of metal ion from aqueous samples under various reaction conditions. The physicochemical parameters of heavy metal containing water samples are analyzed and observed acidic pH, higher total hardness, TDS, COD for SFWW-2 than other sites. The heavy metals from water samples are analyzed and observed that iron metal present in higher amount in all three seasons. For the removing heavy metals contamination from water samples used Triton X 114, Triton -100, PEG-200, PEG-400 by cloud point extraction techniques. Triton X 114, Triton -100, PEG-200, PEG-400 achieved complete Fe extraction at pH 5with APDC. Elevated iron levels and acidic pH were observed in some location SFWW-2 Near SFWW-2 Laduva, Laduva Hamp river, highlighting the need for continuous monitoring and treatment. Overall, surfactant-based methods are better practical, scalable solutions for heavy metal remediation in both rural and industrial settings.

7.0 Reference

1. Qasem N. A. A., Mohammed R H. Lawal D U. Removal Of Heavy Metal Ions From Wastewater: A Comprehensive And Critical Review, Npj Clean Water (2021)4:36; 1-15 Https://Doi.Org/10.1038/S41545-021-00127-0
2. Aslam H., Umar A., Honey S., Manel M., Khan M. U., Nusrat N., Ayesha G., Abbas M.Sohail J., Ali M., Ayuabs., Adsorbents For The Removal Of Heavy Metals From Wastewater: A Review. Biomed J Sci & Tech Res 2024, 58 (3) 50333-50354.
3. Heavy Metal Remediation From Water/Wastewater Using Bioadsorbents - A Review. Tewari A., Bhutada D.S., Wadgaonkar V.,Nature Environment And Pollution Technology. An International Quarterly Scientific Journal 2023, 22(4), 2039-2053.
4. Joseph, L., Jun, B., Flora, J., Park, C. M., Yoon, Y. Removal Of Heavy Metals From Water Sources In The Developing World Using Low-Cost Materials: A Review', Chemosphere, 2019, 229, 142–159. Doi: 10.1016/J.Chemosphere.2019.04.198.
5. Chakraborty R. ,Asthana A.,, Singh A.K.,Jain B., Susan A.B.H., Adsorption Of Heavy Metal Ions By Various Low-Cost Adsorbents: A Review.International Journal Of Environmental Analytical Chemistry , 2020, 1-39. https://Doi.Org/10.1080/03067319.2020.1722811
6. Yang, X., Jia, Z., Yang, X., Li, G. And Liao, X., Cloud Point Extraction-Flame Atomic Absorption Spectrometry For Pre-Concentration And Determination Of Trace Amounts Of Silver Ions In Water Samples', Saudi Journal Of Biological Sciences, 2017, 24(3), Pp. 589–594. Doi: 10.1016/J.Sjbs.2017.01.030.
7. Shakar G.. Das B., Patel B., Chemical Analysis Of Surface Water Of Raipur, Chhattisgarh To Evaluate The Consequences Of Industrial Effluents SAMRIDDHI : A Journal Of Physical Sciences, Engineering And Technology, 2021, 13 (2), 1-7.
8. Liu, J., Xue, J., Yuan, D., Wei, X. And Su, H., Surfactant Washing To Remove Heavy Metal Pollution In Soil: A Review', Recent Innovations In Chemical Engineering (Formerly Recent Patents On Chemical Engineering, 2019, 13(1), 3–16. Doi: 10.2174/2405520412666190912151737.

9. Szymczyk, K. And Taraba, A. 'Properties Of Aqueous Solutions Of Nonionic Surfactants, Triton X-114 And Tween 80, At Temperatures From 293 To 318 K: Spectroscopic And Ultrasonic Studies', Chemical Physics, 2017, 483, 96–102. Doi: 10.1016/J.Chemphys.2016.11.015.
10. Benderrag, A. Haddou, B., Daaou, M., Benkhedja, H., Bounaceur, B. And Kameche, M. 'Experimental And Modeling Studies On Cd (II) Ions Extraction By Emulsion Liquid Membrane Using Triton X-100 As Biodegradable Surfactant', Journal Of Environmental Chemical Engineering, 2019, 7(3), 103166. Doi: 10.1016/J.Jece.2019.103166.
11. West, C. C., Harwell, J. H. 'Surfactants And Subsurface Remediation', Environmental Science And Technology, 1992, 26(12), 2324–2330. Doi: 10.1021/Es00036a002.
12. Elouzi A A , Akasha A.A, , Elgerbi A.M. , El-Baseir M , Bassam A. E Gammudi, Removal Of Heavy Metals Contamination By Bio-Surfactants (Rhamnolipids), Journal Of Chemical And Pharmaceutical Research, 2012, 4(9):4337-4341,
13. Jiménez-Castañeda M E, Medina D I, Use Of Surfactant-Modified Zeolites And Clays For The Removal Of Heavy Metals From Water. Water 2017, 9, 235; 1-12, Doi:10.3390/W9040235
14. Yaqub M, Lee S. H., Heavy Metals Removal From Aqueous Solution Through Micellar Enhanced Ultrafiltration: A Review Environ. Eng. Res. 2019; 24(3): 363-375.
15. Https://Doi.Org/10.4491/Eer.2018.249
16. Saxena N, Islam M M., Baliyan S. Sharma D. Acomprehensive Review On Removal Of Environmental Pollutants Using A Surfactant Based Remediation Process, RSC Sustainability, 2023, 1, 2148–2161.
17. Ziaee .M, Taseidifar M, Pashley R.M., Ninham B W. Selective Removal Of Toxic Ions From Water Wastewater: Using A Novel Surfactant Substantia. An International Journal Of The History Of Chemistry 2020 4(2) , 79-88, DOI: 10.36253/Substantia-830
18. Mungray A.A., Kulkarni S. V., Mungray A K.,Removal Of Heavy Metals From Wastewater Using Micellar Enhanced Ultrafiltration Technique: A Review Cent. Eur. J. Chem., 2012 10(1) , 27-46 .DOI: 10.2478/S11532-011-0134-3
19. Peng Z., Chen H., Li Y., Feng K,Wang C., Liao F., Deng H., Huang Y., Chelating Surfactant For The Removal Of Heavy Metals From Wastewater And Surfactant Recovery, Desalination And Water Treatment, 2020, 206, 229–234
20. Sahu, O.P. Chaudhari P.K., Removal Of Color And Chemical Oxygen Demand From Sugar Industry Wastewater Using Thermolysis Processes. Desalination And Water Treatment 2015, 56, 1758–1767.
21. Bhatt C., Verma R. Physico-Chemical Analysis Of Sugar Mill Effluent Of Kabirdham (C.G.) International Journal Of Scientific Engineering And Research (IJSER) 2015, 129-131.
22. Ghafar H.H.A., Radwan E.K., El-Wakee S.T., Removal Of Hazardous Contaminants From Water By Natural And Zwitterionic Surfactant-Modified Clay. ACS Omega2020, 5, 6834−6845.
23. Asweisi A., Hussein R., Bader N., Elkailany R., Propylene Oxide−Ethylene Oxide Block Polymer As A Surfactant For Cloud Point Extraction Of Some Metal Ions Advanced Journal Of Chemistry-Section A, 2020, 3(3), 259–263.
24. Bhatt C., Verma R., Physico-Chemical Analysis Of Sugar Mill Effluent And Their Impact On Soil Of Kabirdham (C.G.). International Journal Of Sciences & Applied Research, 2016, 3(11), 8-13.
25. Goyal S., Shrivastava S., Physico-Chemical Analysis Of Kharun River Water In Raipur, CG, India. International Research Journal Of Environmental Science 2020, 9(3), 72-74.

26. Sahu S K., Ghosh M.K., Monitoring The Quality Of Drinking Water In Various District Of Chhattisgarh, International Journal Of Science And Technology Research Archive, 2023, 05(02), 052–059.
27. Biswas S., Nayak A K., Pal A., Surfactant-Influenced Biosorption As A Sustainable And Effective Way For The Eradication Of Environmental Pollutants: A Review. RSC Sustainability, 2025, 3, 112–133
28. Latef S E., AL-Azawey A S. N., Study Of Effect Of Some Surfactants On Water Quality Of Al-Hilla River, Iraq Plant Archives 2020, 20 (1) . 99-105.
29. Algheryani K. , Asweisi A., Cloud Point Extraction Of Trivalent Chromium From Aqueous Solutions Using Different Nonionic Surfactants J. Eng. Ind. Res.2023, 4 (2), 68-76.
30. Lindman, B., Medronho, B. And Karlström, G., Clouding Of Nonionic Surfactants', Current Opinion In Colloid And Interface Science, 2016, 22, 23–29. Doi: 10.1016/J.Cocis.2016.01.005.
31. Azizinezhad F., Comparative Investigation Of Some Non-Ionic Surfactants In The Removal Of Pb^{2+} Ions Using. Cloud Point Extraction, Iranian Journal Of Chemistry And Chemical Engineering (IJCCE), 2025, 44(03): 766-774.
32. Khan, S., Kazia, T. G, Baig, J. A., Kolachi, N. A., Afridi, H. I., Wadhwaa, S. K., Shah, A. Q., Kandhro, G. A., Shah, F. Cloud Point Extraction Of Vanadium In Pharmaceutical Formulations, Dialysate And Parenteral Solutions Using 8-Hydroxyquinoline And Nonionic Surfactant', Journal Of Hazardous Materials, 2010, 182(1–3), Pp. 371–376. Doi: 1516 10.1016/J.Jhazmat.2010.06.042.
33. Hazrina HZ, Noorashikin MS, Beh SY, Loh SH, Zain N N M. Formulation Of Chelating Agent With Surfactant In Cloud Point Extraction Of Methylphenol In Water.R. Soc. Open Sci., 2018, 5: 180070. Http://Dx.Doi.Org/10.1098/Rsos.180070
34. Ahmadi F.,Mohaghegheyan M , Khanmohammadi A. , Z.Ghezelbash, Determination Of Copper And Nickel In Real Samples By Rubeanic Acid In Micelle-Mediated. ACAIJ, 2008, 7(7) , 475-479
35. Mortada, W. I. 'Recent Developments And Applications Of Cloud Point Extraction: A Critical Review', Microchemical Journal, 2020, 157, 105055. Doi: 10.1016/J.Microc.2020.105055.
36. Kluk D., Steliga T., Eben D B.,Jakubowicz P., Study On Surfactants For The Removal Of Water From Deliquification Natural Gas Wells To Enhance Production Energies 2024, 17, 5924, 1-18. https://Doi.Org/10.3390/En17235924
37. Dubey V., Singh N., Singh S., Shukla A., Pandey A., Effect Of Detergent Use On Water Quality In Rewa City Of M.P. (India), IOSR Journal Of Applied Chemistry (IOSRJAC). 2012, 1(4), 28-3.
38. Hanif N.M., Adnan S N. N., Latif M.T., Zakaria Z., Othman M. P.A. M. R, The Composition Of Surfactants In River Water And Its Influence To The Amount Of Surfactants In Drinking Water. World Applied Sciences Journal 17 (8): 970-975, 2012 ISSN 1818-4952
39. KURUP P.S., Surfactant Based Analysis Of Pond Water -A Statistical Approach, Ijcrt 2024, 12(8), 785-791
40. Ullah I. , Shah A , Khan M., Khan S Z., Zia-Ur-Rehman, Badshah A., Synthesis And Spectrophotometric Study Of Toxic Metals Extraction By Novel Thio-Based Non-Ionic Surfactant, Tenside Surf. Det. 2015, 52, 5 407-413
41. Paria, S. Surfactant-Enhanced Remediation Of Organic Contaminated Soil And Water', Advances In Colloid And Interface Science, 2008, 138(1), 24–58. Doi: 10.1016/J.Cis.2007.11.001.17
42. Jaiswal, A., Verma, A. And Jaiswal, P., 'Detrimental Effects Of Heavy Metals In Soil, Plants, And Aquatic Ecosystems And In Humans', Journal Of Environmental Pathology, Toxicology And

Oncology, 2018, 37(3), 183–197. Doi:10.1615/Jenvironpatholtoxicoloncol.2018025348.

43. Lee, D. H., Kim, E. S. And Chang, H. W., ‘Effect Of Tween Surfactant Components For Remediation Of Toluene-Contaminated Groundwater’, Geosciences Journal, 2005, 9(3), 261–268. Doi: 10.1007/BF02910586. 268
44. Sohaimi, N. M., Suda, N., Aziz, H. Z., Zaini, S. R. M., Kandasamy, S. And Suresh, K. The Application Of Cloud Point Extraction 2017, 12(1), Pp. 79–95.
45. Wang, L. L., Wang, J. Q., Zheng, Z. X. And Xiao, P. ‘Cloud Point Extraction Combined With High-Performance Liquid Chromatography For Speciation Of Chromium(III) And Chromium(VI) In Environmental Sediment Samples’, Journal Of Hazardous Materials, 2010, 177(1–3), 114–118. Doi: 10.1016/J.Jhazmat.2009.12.003.
46. Varshney, K. G., Rafiquee, M. Z. A. And Somya, A. ‘Effect Of Surfactants On The Adsorption Behaviour Of Tin(IV) Phosphate, Cation Exchanger For Alkaline Earths And Heavy Metal Ions’, Colloids And Surfaces A: Physicochemical And Engineering Aspects, 2007, 301(1–3), 224–228. Doi: 10.1016/J.Colsurfa.2006.12.061