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PHYTOREMEDIATION OF SOIL CONTAMINATED WITH TEXTILE DYE AND EFFLUENT USING *Corchorus olitorius* L.

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ABSTRACT

Industrial effluents, particularly from the textile sector, contribute significantly to environmental pollution through the discharge of complex chemical dyes. This study aims to evaluate the physicochemical properties and Fourier Transform Infrared (FTIR) spectral profiles of untreated textile dye effluent, soil, and to assess their remediation potential using *Corchorus olitorius* L. The dye wastewater was collected from the channel of flow over 6 months from five sampling points and the soil samples were also collected at Department of Agricultural Technology, Kwara State Polytechnic, Ilorin. The phytoremediation potential of *C. olitorius* was also carried out using the standard method of analysis. Plants were cultivated in contaminated water systems under controlled conditions using buckets and loamy soil with different concentration of dye solution. Results revealed elevated levels of pH, chloride, nitrate, chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), and heavy metals in the effluent. FTIR spectra indicated the presence of alcohols, aromatic amines, carbonyls, ethers and sulfonic groups in the dye. *Corchorus olitorius* showed significant remediation potential, indicated by reductions in pollutant load and structural alterations in FTIR spectra post-treatment. These findings highlight the potential of *C. olitorius* as an eco-friendly solution for mitigating textile dye pollution.

Keyword: Physicochemical; Fourier Transform Infrared Spectroscopy; phytoremediation; Dyes; *Corchorus olitorius* L.

INTRODUCTION

Water is a vital component of life, covering approximately 71% of the Earth's surface, with 97.5% comprising seawater and only 2.5% available as freshwater [1]. Industrial wastewater is a major environmental concern, exerting numerous harmful effects on ecosystems. Significant amounts of wastewater are produced by industries such as textiles, cosmetics, printing, paper, and rubber manufacturing [2]. Dyes, commonly used in these industries, are classified according to their properties and applications [3,4]. Among them, the textile industry is a major contributor to pollution, releasing substantial quantities of highly toxic chemicals during various stages of production [5]. Furthermore, extensive studies have shown that untreated textile dyes pose serious eco-toxicological risks to living organisms [6,7].

Textile dye-containing wastewater is a major contributor to water pollution, significantly impacting the environment by disrupting aquatic ecosystems, inhibiting photosynthesis in aquatic plants, and posing serious health risks to humans, including breathing difficulties, irregular heartbeats, skin rashes, dizziness, and cancer [4,6,8]. The textile industry employs various types of dyes, such as sulphur, azo, acid, and basic dyes, with azo dyes being the most widely used [9,10].

Dyes have been known and utilized by humans since ancient times [11]. Across numerous industries—such as the paper sector and others—various methods have been developed to effectively remove dyes from wastewater [12-14].

However, the dyes commonly used in the textile sector are often highly toxic and potentially carcinogenic [8,15]. Overall, the textile industry exerts a considerable environmental impact [16], with textile dyes linked to a range of health issues, from dermatitis to disorders of the central nervous system [17]. As a result, the treatment of toxic wastewater containing different textile dyes has become an urgent and critical concern [18-20]. Azo dyes, characterized by the presence of one or more azo groups, represent 60–70% of all known dye structures [21-23].

The treatment of dye-containing wastewater employs a variety of methods, including physical, chemical, and biological approaches, as well as emerging advanced technologies such as nanotechnology, microbial biosorbents, microbial films, genetic engineering, and plant–microbe-mediated techniques [4,14]. Recent studies have highlighted the application of chemical-based methods for the removal of pollutants from wastewater [24-26]. Additionally, metal–organic frameworks have been utilized as sensitive and selective sensors for detecting hazardous contaminants [27]. Nevertheless, physical and chemical treatment methods are often not cost-effective [6].

There are several strategies used to overcome these dye pollutants that includes chemical method, physical methods and biological methods. We can also use combination of more than two methods for remediation of dye pollutants. The chemical methods required costly chemicals which can produce secondary pollutants also. The physical methods do not require chemicals but they are costly and time taking. The biological methods used plants or microorganism for the degradation of dyes, these methods do not require costly chemicals and machinery.

This approach represents one of the biological methods employed for dye degradation. It involves the use of plants, along with the microbes associated with their root systems, to remove pollutants from the environment. Several studies have shown that plants growing in polluted areas develop an enhanced ability to survive by undergoing genetic modifications that enable them to accumulate contaminants such as dyes [28]. As a result, these plants can function as self-sustaining bioreactors for the remediation of environmental pollutants [29,30].

Corchorus olitorius L. (Jute) is an economically significant plant commonly cultivated for its fiber, which is used in the production of various textiles and agricultural materials. Additionally, *Corchorus olitorius* is a rich source of nutritional value, particularly in its young leaves, which are consumed as a vegetable in various regions [31]. Given its widespread cultivation, it is crucial to understand the potential impacts of textile effluent contamination on this plant species. Thus, this research was conducted to investigate the physicochemical assessment of dye effluent and fourier transform infrared analysis of textile dye, and evaluate their phytoremediation potential using *Corchorus olitorius* L.

MATERIALS AND METHODS

Collection and Preparation of Samples

A 10 mL of dye effluent was collected from Itoku local dyeing industry in Ogun State, Nigeria, in a sterile polypropylene container and were collected over 6 months from five sampling points. A 5 cm³ of nitric acid per litre was added and stored at 4 °C in refrigerator prior to analysis. The wastewater was collected from the channel of flow unto the land and sieved in order to avoid debris, paper twigs and other small floating materials [32]. Dyes used (mint green and orange colour dyes) was obtained from the Itoku market where the local industry purchased dyes used for their production. The experimental plant seeds (*Corchorus olitorius* seeds) was obtained from Yoruba market, Challenge, Ilorin, Kwara State. The soil used was obtained from Department of Agriculture Technology, Kwara state Polytechnic, Ilorin and transported to the laboratory using buckets where dead plants and stones were removed.

Experimental Plant Preparation

Corchorus olitorius seeds were soaked in hot water (90 °C) for five minutes to break its dormancy. Buckets were punctured at the bottom and sides to allow for aeration for root and dislodgement of excess water. Buckets were filled with approximately 5 kg of loamy soil. Those contaminated with different concentrations of dye solution, effluent and tap water (control) were labelled accordingly. *Corchorus olitorius* seeds were spread over the surface of each buckets and covered up with soil and were put outside in the sun. Each group were irrigated with 250 mL of the prepared concentrations daily. Weeds growing were uprooted by hands every 2 weeks and applied to the surface of the soil in order to prevent evaporation and further weed growth [33].

Physicochemical Analysis of Wastewater

The physicochemical analysis of dye effluent wastewater was determined using the method reported by [34]. The properties determined includes pH, temperature, conductivity, dissolved oxygen (DO), biochemical oxygen demand

(BOD), chemical oxygen demand (COD), total solids, total dissolved solids, total suspended solids, nitrates, sulphates, chlorides, phosphates and heavy metals.

Physicochemical Analysis of Soil

The physicochemical properties of soil determined includes pH, organic carbon, organic matter, total nitrogen content, phosphate-phosphorus content, potassium content and heavy metal content. It was carried out to determine the nutrient status of the soils as problems in growth and germination are not only a function of possible phytotoxic substance but also of soil nutrients too.

Phytoremediation Studies

The degree of heavy metals accumulation in effluent contaminated and control soil was analysed prior to planting. The amount of heavy metals accumulated in the plant was determined at the end of 60 days (harvesting period). The plant was separated into root, stem and leaf and amount of heavy metals accumulated in each tissue was determined. A 0.1 g of each dried plant tissue was weighed into 250 mL conical flask and 5 mL concentrated nitric acid added and heated on hot plate for 1h. It was allowed to cool and 1 mL 30% H₂O₂ added and another 5 mL of concentrated nitric acid added and heated until solution is clear [35].

Determination of Enrichment Factor

The degree of soil pollution by the effluent (contaminated soil) with respect to uncontaminated soil (control) site was determined using the enrichment factor (EF) which was according to Gupta and Sinha, [36]. The enrichment factor EF was calculated thus:

$$EF = \frac{\text{Concentration of metal in soil in contaminated site}}{\text{Concentration of metal in soil in uncontaminated site}}$$

Determination of Translocation Factor

Translocation factor TF was used to evaluate the metabolic activities and health of individual plants growing on polluted site. It was calculated according to Gupta and Sinha, [36]

$$TF = \frac{\text{Concentration of metals in the shoot (stem+leaves)}}{\text{Concentration of metals in the root}}$$

Determination of Bioaccumulation Factor

The bioaccumulation factor (BAF) was used to evaluate metals phytoextraction potential of *Corchorus olitorius* L. BAF was calculated according to Yoon et al. [37]

$$BAF = \frac{\text{Metal concentration in plant tissue } (\frac{mg}{kg})}{\text{Metal concentration in soil } (\frac{mg}{kg})}$$

RESULT AND DISCUSSION

Table 1: Physico-chemical characteristics of effluent, dye solution and tap water (control)

Parameters	Effluent	Dye solution	Tap water	Maximum permissible limit for irrigation purpose FAO (1985)	Maximum permissible limit for irrigation purpose BIS (1991)
Colour	Blue-black	Orange	Clear	colourless	colourless
Odour	Offensive	Pungent	Odourless	odourless	odourless
Temperature (°C)	28.7±1.15	29±1	26.3±1.53	<30	25
pH	10.3±1.03	7.81±0.1	6.86±0.09	6.0-8.5	5.5-9.0
Turbidity (NTU)	73.3±1.53	38.3±2.08	0.47±0.005	NS	5
Electrical conductivity(dS/m)	8.85±0.05	0.015±0.005	0.307±0.001	3	3
Total dissolved solids (TDS) (mg/l)	4384±14.42	0.57±0.04	99.63±0.40	2000	2000
Total suspended solids (TSS) (mg/l)	266.7±11.55	7.0±2.0	23.3±5.77	50	10
Total solids (mg/l)	4650±10.07	7.57±2.03	122.97±5.84	700	2000

Biological oxygen demand (BOD) (mg/l)	57.3±2.31	54.0±2.0	30.0±3.46	<30	<30
Chemical oxygen demand (COD) (mg/l)	7346.7±11.5	7294±5.29	886.7±11.55	NS	250
Chlorides(mg/l)	1268±20.5	310.3±9.73	156±19.5	1065	500
Nitrates (mg/l)	584.7±0.58	396.1±2.9	41.96±0.34	10	100
Sulphates (mg/l)	843.7±3.84	105.45±4.74	18.56±6.45	960	1000
Phosphates (mg/l)	59.9±0.56	32.26±1.11	1.17±0.41	2	
Lead (mg/l)	0.01±0.005	ND	0.01±0.007	5.0	1.0
Zinc (mg/l)	0.9±0.877		0.7±0.015	2.0	15
Cadmium (mg/l)	0.02±0.011		0.01±0.007	0.01	2
Copper (mg/l)	0.32±0.3	ND	0.23±0.006	0.2	3
Chromium (mg/l)	0.05±0.01		0.01±0.006	0.1	2
		ND			

ND= Not determined

The physico-chemical properties of the dye, its effluent and tap water (control water) are shown in Table 1. The properties determined includes; temperature, pH, turbidity, electrical conductivity, total dissolved solid, total suspended solid, chloride, nitrate, sulphate phosphate, biological oxygen demand (BOD), chemical oxygen demand (COD) and heavy metals.

Temperature is one of the most vital ecological features that controls behavioral characteristics of organisms such as respiration, solubility of gases and salts in water. The basis of all life functions is a complicated set of biochemical reactions that are influenced by physical factors such as temperature. Disease resistance and increased rate of microbial activity are linked to temperature [38]. The temperature of the effluent and dye solution was the same (28°C) while that of the control water was 25°C (Table 1).

pH is a measure of acidity or alkalinity of water and is one of the vital parameters used to determine the usefulness of water as a source of irrigation. The solubility and bioavailability of many plant nutrients and potentially toxic constituents are highly dependent on pH. Since soil is more strongly buffered against changes in pH than water, irrigation water will cause soil pH to change slowly and is seldom a problem in itself [39]. For agricultural sector, pH value plays an important role in plant growth. If the pH value is higher than standard value, then it will affects plants growth [40]. The pH of the effluent was found to be highly basic (10.3). This can be attributed to the use of high concentrations of caustic chemicals. The pH of the dye solution and control water was slightly basic. The pH of dye solution and control water was within the maximum permissible limit while that of the effluent exceed the maximum permissible limit as shown in Table 2 above.

Electrical conductivity is a measure of the salinity of the water. High electrical conductivity alters the chelating properties of receiving water bodies thereby creating a condition for free metal availability to flora and fauna [41]. High conductivity obtained for the effluent (8.85 mS/cm) could be attributed to high dissolved solids presence in the effluent

Chloride is the anion of the element chlorine. Chloride is an essential plant micronutrient. Unlike most other micronutrients, it is however relatively non-toxic to most crops. Chlorides are very soluble and are not adsorbed to any significant degree by soil, but are readily transported with the soil water, and are taken up by roots and conveyed in the transpiration stream, where they accumulate in the leaves. Plants vary in their ability to restrict the transport of chloride to the shoots [39]. Presence of high chloride is responsible for high salinity and high eutrophication. The chloride content of the effluent was higher than the recommended FAO and BIS values (Table 1). This could be attributed to residual sodium chloride used in the manufacturing process.

Nitrogen occurs predominantly as nitrate in irrigation water. Being an anion, nitrate is only very weakly sorbed by the soil exchange complex (which is mainly a cation exchanger) and its movement in the soil is considered to be unaffected by exchange reactions. Therefore, nitrates leach freely [39]. The nitrates content of the effluent, dye solution and tap water were 584.7, 396.1 and 41.96 mg/l respectively (Table 1). However, the nitrate content of the effluent and dye solution was found to be above the recommended limit set by BIS.

Suspended solids in water consist of inorganic and organic matter such as, clay particles or suspended mineral matter and a combination of decay products and living organisms respectively. Suspended solids are mostly comprised of particulate matter of inorganic origin with no inherent toxic effect for plants or soil and effects are of a physical nature. Because of the particle size distribution found in the suspended solids fraction, and the small size orifices (emitters) used in drip (and to a lesser extent microjet) irrigation systems, partial to complete clogging or plugging of orifices occurs. This leads to a decrease in uniformity of water application and subsequent yield decreases. When present in sufficiently high concentrations, deposition of suspended solids on the soil surface can lead to the formation of a depositional surface crust which inhibits water infiltration and seedling emergence, and reduces soil aeration [39]. The suspended solids value for effluent, dye solution and tap water were 266.7, 7.000 and 23.00 mg/l respectively. That of the effluent was above the 200mg/l maximum recommended value set by BIS.

The total dissolved solids (TDS) are a measure of the quantity of various inorganic salts dissolved in water. The TDS concentration is directly proportional to the electrical conductivity (EC) of water. Irrigation with water containing salt introduces salt into the soil profile. When no or little leaching of salt takes place from the soil profile, salt accumulates and a saline soil is formed. High TDS can have adverse impact on plants by decreasing crop yield [39]. The effluent TDS value of 4384 ± 14.42 from the effluent was several folds higher than the FAO and BIS recommended value. This may be attributed to the large presence of inorganic salts.

Biological oxygen demand BOD represents the amount of oxygen required by microorganisms to decompose organic matter. The BOD obtained for the effluent and dye were 57.3 and 54 mg/L respectively which were within permissible limit as shown in table 3.

Chemical oxygen demand COD represent the amount of oxygen required to oxidize all organic material to carbondioxide and water. The dye solution, effluent and control water all have their COD values between 886.7-7346.7 mg/L which are higher above permissible limits. High BOD, COD and TS in effluent indicate high inorganic and organic loads [42].

Most physicochemical parameters measured for the effluent were above the FAO and BIS standards for irrigation. However, after dilution, the pollution load were reduced.

Table 2: Physicochemical characteristics of contaminated and control soils

PARAMETERS	CONTROL SOIL	EFFLUENT CONTAMINATED SOIL
pH	6.5333 ± 0.0577	7.0 ± 0.1
% Nitrogen	7.9133 ± 0.0808	8.1567 ± 0.0404
Phosphates (mg/l)	52.154 ± 0.1502	23.3477 ± 0.130
Potassium (mg/l)	10.16 ± 0.0361	10.84 ± 0.08
% Organic carbon	0.4 ± 0.087	0.65 ± 0.087
% Organic matter	0.68 ± 0.1472	1.105 ± 0.147
Pb (mg/kg)	ND	0.5 ± 0
Cd (mg/kg)	8.5 ± 2.64	20.000 ± 5.0
Cr (mg/kg)	1.1667 ± 0.2887	0.6667 ± 0.2887
Zn (mg/kg)	35.833 ± 3.82	54.167 ± 5.06
Cu (mg/kg)	27.000 ± 3.46	46.667 ± 5.77

ND= Not determined

The need to set up more industries have led to disposal of industrial wastes onto the lands thereby polluting agricultural soils and groundwater. The soil properties were modified when it gets contaminated with the effluent. The pH, organic content, phosphates, nitrogen and potassium content were all altered on contamination. The control and contaminated soil have an average pH of 6.53 and 7.0 respectively. pH is one of the important parameters because nutrients uptake by plants depends on soil pH and it limit bioavailability and mobility of metals. The soil pH was optimal for efficient growth of vegetables exhibiting moderate organic matter of 0.68 and 1.105% for uncontaminated and contaminated soil to provide micronutrients [43,44]. Irrigation with the effluent was found to cause an increase in nitrogen and potassium content while there was a decrease in phosphate content in the contaminated soil (Table 2). All the heavy

metals were within recommended values. The cause in the change in properties of the contaminated soil maybe due to effect of Base Exchange capacity and nature of the content present in the effluent.

FTIR Characterization of Industrial Dyes Used

FTIR spectrum of mint green coloured dye

The possible functional groups and chemical compounds in mint green dye is shown in Table 3 and the spectrum was shown in figure 1.

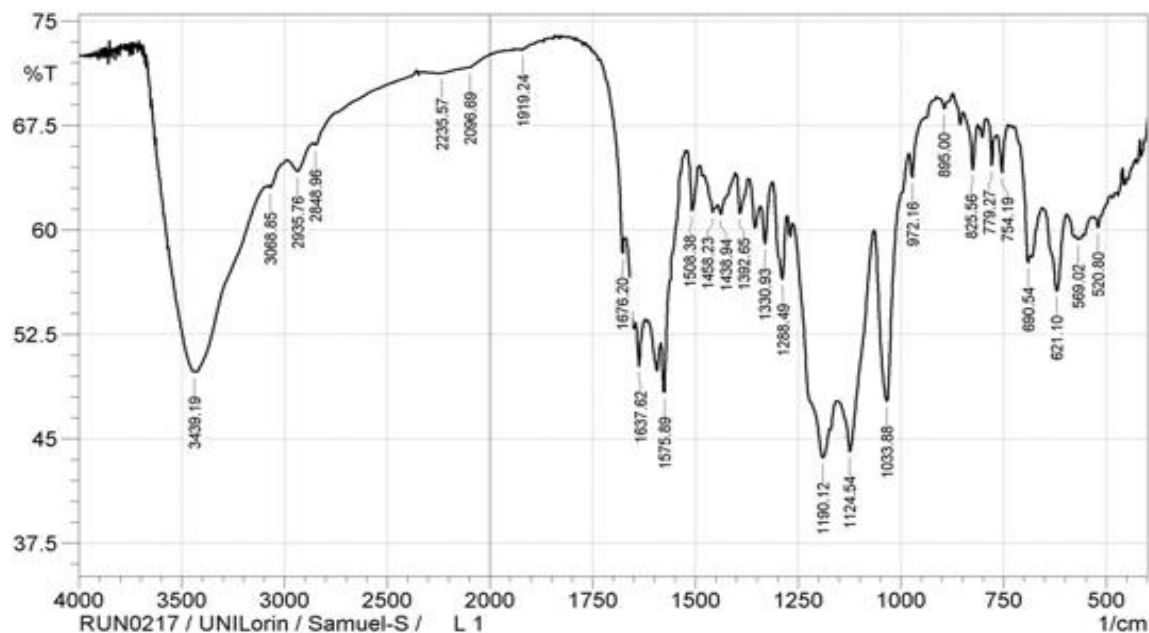


Figure 1: FTIR spectrum of mint green dye

Table 3: Possible functional groups and compounds present in mint green dye

Region (cm ⁻¹)	Functional groups	Possible compounds present
3439.19	O-H stretching vibrations	Alcohols
3068.85	=C-H	Alkenes, Aromatic groups
2935.76, 2848.96	C-H sp ³ stretching	Alkanes
2235.57	≡C-C, -N=N-, -C≡N	Alkynes, nitriles, azides
1637.62	-C=C-, -C=N-, -NH	Alkenes, Aromatic, amines, azides
1458.23, 1392.65	C-H sp ³ , NO ₂	Aliphatic groups, aromatic groups, nitro groups
1288, 1190.12	C-O-C, C-OH, S=O, P=O, C-F bend	Ethers, alcohols, phenols, sulphur, phosphorus and fluorine compounds
972.16	Geminal disubstituted sp ² C-H	Alkenes, aromatic
895	Disubstituted sp ² C-H bend	Alkenes, aromatic, halogen groups
754.19, 690.54	Monosubstituted sp ² C-H bend, C-X	Alkynes
621.1	C-H sp bend	

FTIR spectrum of orange dye

The possible functional groups and chemical compounds in orange dye is shown in Table 4 and the spectrum was shown in figure 2.

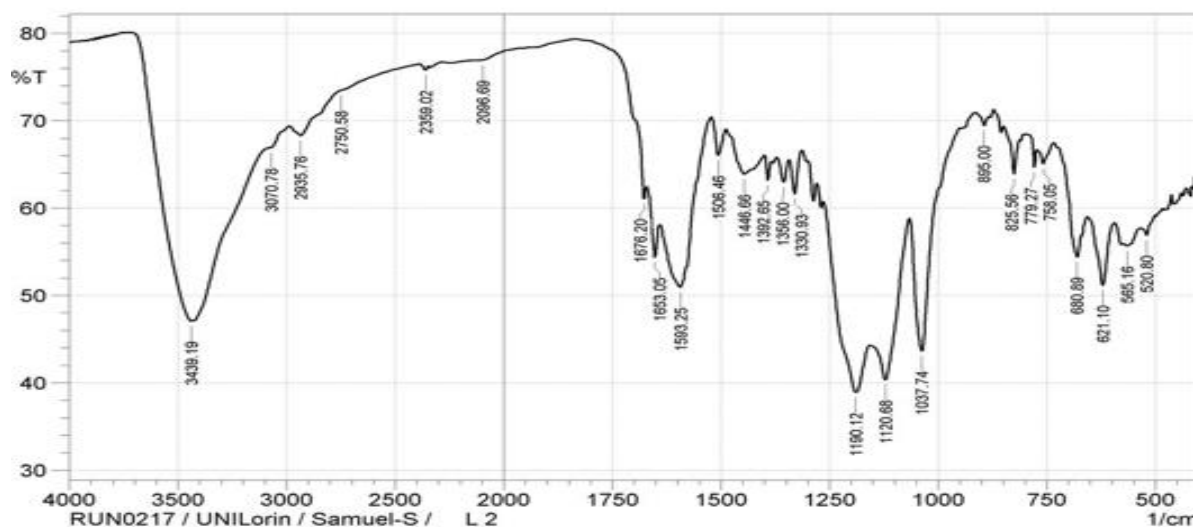


Figure 2: FTIR spectrum of orange dye

Table 6: Possible functional groups and compounds present in orange coloured dye

Region (cm ⁻¹)	Group	Possible compounds present
3439.19	O-H stretching vibrations	Alcohols
3070.85	=C-H stretching	Alkenes, Aromatic groups
2935.76, 2750.58	-C-H sp ³ stretching	Alkanes
2359.02	≡C-C, -N=N-, C≡N stretching	Alkynes, nitriles, azides
1653.62	-C=C-, C=N, NH	Alkenes, aromatic, amines
1446.66, 1392.65	C-H sp ³ , NO ₂	Aliphatic groups, aromatic groups, nitro groups
1330.93, 1190.12	C-O-C, C-OH, S=O, P=O, C-F bend	Ethers, alcohols, phenols, sulphur, phosphorus and fluorine compounds
895	Disubstituted sp ² C-H bend	Alkenes, aromatic
758.05, 680.89	Monosubstituted sp ² C-H bend, C-X	Alkenes, aromatic, halogen groups
621.1	C-H sp bend	Alkynes

The resulting bands obtained from the FTIR spectrum of mint green dye were very similar to that of orange dye. However, a prominent difference between them was the absence of 972.16 cm⁻¹ band in orange coloured which shows lack of germinal disubstituted alkene in the orange coloured dye.

Phytoremediation Studies

Enrichment factor EF is used to assess level of soil contamination. The Enrichment factor of Zn, Cu and Cd were 1.5139, 1.7376 and 2.722 respectively. The EF calculated for Zn and Cd were <2 indicating minimal enrichment while that of Cd calculated was >2, which indicates moderate enrichment [45], as shown in Figure 3

Translocation factor is an indication of the ability of plant to translocate metals from roots to the aerial parts of plants [46]. The translocation factor of Zn, Cu and Cd were 1.7354, 3.0502 and 0.3889 respectively. The translocation factor TF calculated for Zn and Cu were >1 which indicates that there was effective translocation of these metals from the roots to the shoot system of the plant. However, the translocation factor calculated for Cd was <1, indicating that the plants have the ability to accumulate Cd and largely store it in its root rather than translocating it to the aerial part of the plant (Figure 4).

Bioaccumulation factor also known as transfer factor can be defined as the ratio of heavy metal content of soils and corresponding plants. It is used to assess the plants capability to absorbed heavy metals from the soil [47]. Bioaccumulation factor BAF is a good determinant of the potential mobility of metals in soils to plants. This study have confirm the hypothesis that metals are absorbed and utilized by vegetables in dissolved and exchangeable phase as shown in figure below. The plant phyto remediate metals in order of $Zn > Cu > Cd$. The ability of plant tissue to accumulate Zn was in the order of leaves > root > shoot; for Cd it was in the order root > shoot > leaves while for Cu it was in the order of leaves > shoot > root (Figure 5)

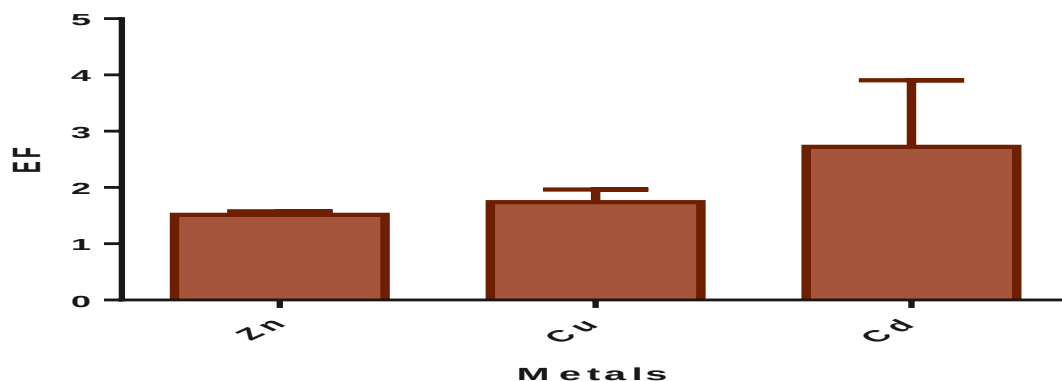


Figure 3: Graph showing Enrichment factor

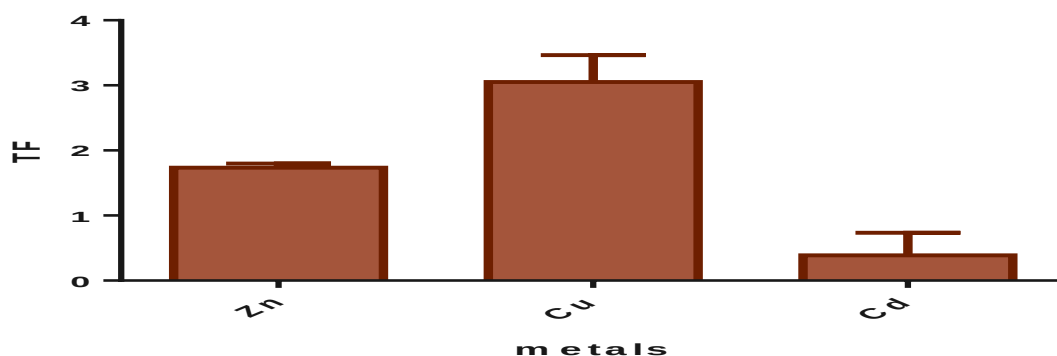


Figure 4: Graph showing Translocation factor

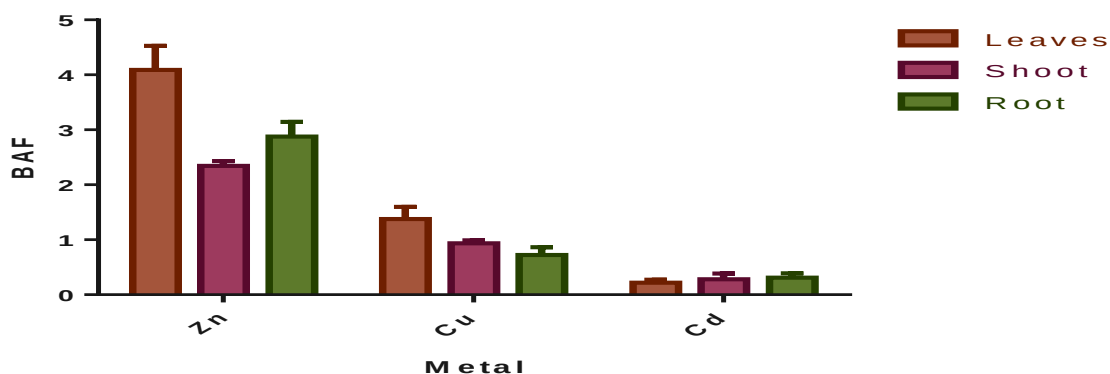


Figure 5: Graph showing bioaccumulation factor

The bioaccumulation factor of Zn and Cu was >1 indicating to be hyper-accumulator of these metals. However the bioaccumulation factor calculated for cadmium was <1 indicating the plant (*C. olitorius*) to be a poor phytoaccumulator of Cd [47].

CONCLUSION

Overall, *Corchorus olitorius* L. shows promising phytoremediation potential, particularly for Zn and Cu, through efficient uptake and translocation mechanisms, and for Cd through root-based immobilization. This makes the plant a viable candidate for remediating soils impacted by textile dye and effluent contamination. The significant reduction in physicochemical analyses of the effluent compared to the control and changes in FTIR spectral features affirm its potential for large-scale application in wastewater management strategies. Further studies are recommended to elucidate the molecular mechanisms involved in pollutant degradation and to optimize phytoremediation protocols for field conditions.

Competing Interest

We have none to declare.

Authors Contribution

Jamio W: Conceptualization, performed experiments, data collection, preparation of draft manuscript and data analysis; Oseni, T.O: Performed experiments, data analysis, editing and review of the manuscript; Ibrahim, I.A: Performed experiments, data analysis, editing and review of the manuscript.

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