

Characterization of Water Hyacinth Powder Using FTIR Spectroscopy and the Adsorption Behaviour of Pb^{2+} , Cd^{2+} , Zn^{2+} , Ni^{2+} and Cr^{2+} in Aqueous Solution

ABSTRACT

The adsorption behavior of selected metal ions on water hyacinth powder was investigated by Fourier Transform Infrared (FTIR) analysis. Water hyacinth powder was used as an adsorbent due to its popularity, low cost and ease of availability. Water hyacinth stem was dried and ground to a powder. Batch adsorption experiments were conducted at room temperature by adding known concentrations of Pb^{2+} , Cd^{2+} , Cr^{3+} , Zn^{2+} and Ni^{2+} to 5g of water hyacinth powder in different test tubes and allowed to stand for the same time respectively. Adsorption is one of the methods used to remove heavy metals from aqueous solutions and wastewaters. FTIR analysis was performed to identify the functional groups in the water hyacinth powder according to the KBr disc method. The study showed a strong broad absorption band in the region of 3200cm^{-1} to 3300cm^{-1} which is characteristic of O-H stretching vibrations of the adsorbed water molecules at the surface of raw water hyacinth powder particles. Other peaks were observed at 1732cm^{-1} which corresponded to C=O stretching vibrations while the band at 1396cm^{-1} could be attributed to C-H bonds. The functional groups identified were: C-H; O-H; C=O or C-O. After adsorption there was a disappearance, reduction or a shift in the adsorption bands depending on the type of metal ion. Lead for example showed a strong absorption band in the region of 1732cm^{-1} which is characteristic of C=O stretching bond structure which is found in esters and carboxylic acids. The disappearance of the peaks indicated that the H atom present in the functional groups of the raw water hyacinth powder could have been substituted with lead ion. The intensity of the adsorption bands reduced for all the metals confirming that functional groups were responsible for adsorption of the heavy metal ions on to the material.

Key words: Water hyacinth powder, Characterization, biosorption, functional group, heavy metal

1. INTRODUCTION

FTIR spectroscopy is a powerful technique that can be used in diagnostic analysis of water hyacinth powder before and after adsorption of metal ions. It is a rapid and non-destructive technique that has been used to characterize the functional groups responsible for adsorption of heavy metal ions [1, 2]. The hazardous heavy metals can affect the human physiology and biological systems [3] hence it is important to frequently evaluate their occurrence in the environment. FTIR technique helps to elucidate the functional groups that participate in the heavy metal adsorption. The use of plant materials in the remove of heavy metals from wastewaters has been reported [4]. Water

hyacinth (*Eichhornia crassipes*) is a common aquatic plant in Lake Victoria and dams in Kenya. It is readily available and therefore in this study it has been used a low cost adsorbent to evaluate its adsorption behaviour in the presence of metal ions in aqueous solution.

FTIR spectroscopy was used to identify the functional groups in water hyacinth powder that are responsible for heavy metal adsorption. FTIR was used because it has a high reliability even with small amounts of material and is analytically sensitive.

The objective of this study was to characterize the water hyacinth powder before and after heavy metal absorption using FTIR spectroscopy. The spectra of the water hyacinth

powder (unloaded) and that which is loaded with the heavy metal ions (Pb^{2+} , Cd^{2+} , Cr^{3+} , Zn^{2+} and Ni^{2+}) were compared in order to establish any structural changes in the functional groups due to adsorption.

2. MATERIALS AND METHOD

Water hyacinth (*Eichhornia crassipes*) was collected from a beach point on Lake Victoria and the stems were sliced into pieces and cleaned thoroughly with tap water in order to remove dust and any other contaminants. The stems were then rinsed with distilled water and dried until sufficiently dry. The water hyacinth pieces were further oven dried at 110°C for a day to remove moisture completely. The dry fractions of the water hyacinth stem were ground into powder using mortar and pestle and the particles were sieved using $300\mu\text{m}$ sieve and stored for subsequent use.

2.1 FTIR analysis of raw water hyacinth powder

A 0.5g water hyacinth powder was ground until it was fine. The sample plates were wiped using analytical grade KBr. The sample was placed on the face of the sample plate. The second plate was placed on top of the first plate allowing the sample to form a thin film between the sample plates. The sandwiched plates were placed on the sample holder. The sample was scanned in the range of $400\text{-}4000\text{ cm}^{-1}$ wavenumbers using FTIR instrument (Model: IR Afinity IS Class 1). The FTIR spectra of the samples were recorded and identified as belonging to different functional groups.

2.2 FTIR analysis of metal loaded water hyacinth powder

The water hyacinth residue after adsorption of metal ions (Pb^{2+} , Cd^{2+} , Cr^{3+} , Zn^{2+} and Ni^{2+}) was

filtered and further dried in an oven at 110°C for a day to remove moisture completely. A 0.5 g of dry fractions of metal loaded water hyacinth were ground into fine powder using mortar and pestle and used in the FTIR diagnostic analysis. The sample plates were wiped using analytical grade KBr. The finely ground sample was placed on the face of the sample plate. The second plate was placed on top of the first plate allowing the sample to form a thin film between the sample plates. The sandwiched plates were placed on the sample holder. The sample was scanned on the FTIR instrument in the range of $400\text{-}4000\text{ cm}^{-1}$. The structural changes in the spectra were recorded and compared with those of the raw water hyacinth powder to assess the adsorption behavior of the different heavy metal ions.

3. RESULTS AND DISCUSSION

The spectra of raw water hyacinth powder and treated (metal loaded) water hyacinth powder for the metal ions; Ni^{2+} , Cd^{2+} , Pb^{2+} , Zn^{2+} and Cr^{3+} are presented in Figures 1-5. The spectra of the raw and metal loaded water hyacinth powder were compared for example the Pb^{2+} ion adsorption is given in Figures 1a and 1b.

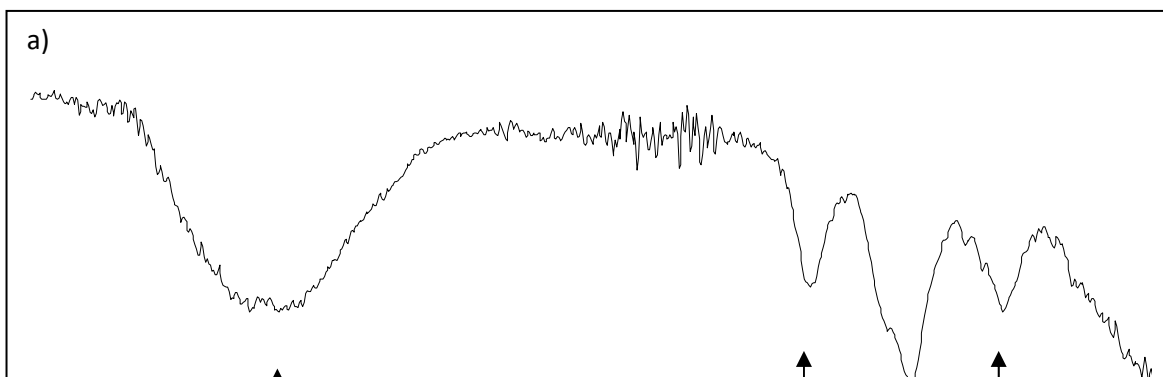


Figure 1: a= Water hyacinth powder; b= spectrum of water hyacinth loaded with Pb²⁺ ions

The study showed that there was a strong broad absorption band in the region of 3200 cm⁻¹ to 3300 cm⁻¹ (Figure 1a) for the raw water hyacinth powder. The presence of this band is characteristic of O-H stretching which is attributed to alcohol, water, acid and phenols [5]. This peak is absent in Figure 1b. The strong absorption band in the region of 1732 cm⁻¹ (Figure 1a) is characteristic of C=O stretching bond structure which could be attributed to esters and carboxylic acids [6]. This peak is

The strong band at 1033 cm⁻¹ is characteristic of C-O stretch in structures which contain carboxylic acids, ethers, ethers and alcohol [10]. It is observed that the band reduced in intensity upon adsorption of lead ions. The strong band at absorption band 1396 cm⁻¹ is characteristic of bending of the C-H bonding in structures that contain alkanes or C-O stretch and deformed O-

absent in Figure 1b. The disappearance of the peaks could be attributed to H atom in the functional groups which has been substituted with Pb²⁺ ion [7]. The strong band at absorption band 1396 cm⁻¹ is characteristic of bending of the C-H bond in structures that contain alkanes or both C-O stretch and O-H deformation in carboxylic acids [8]. The disappearance of this peak could be because lead ions are bound to hydroxyl, carboxyl and carbonyl functional groups [9].

H in the structure which contains carboxylic acids [11]. It was observed that upon adsorption of Pb²⁺ ions the band reduced in intensity. The spectra for Cd²⁺ ions adsorbed on the water hyacinth powder (Figure 2b) showed that the bands for O-H (3200-3300 cm⁻¹) and C-H (1396 cm⁻¹) band disappeared. This could be due to

participation of both alkyl and hydroxyl groups during cadmium adsorption [8].

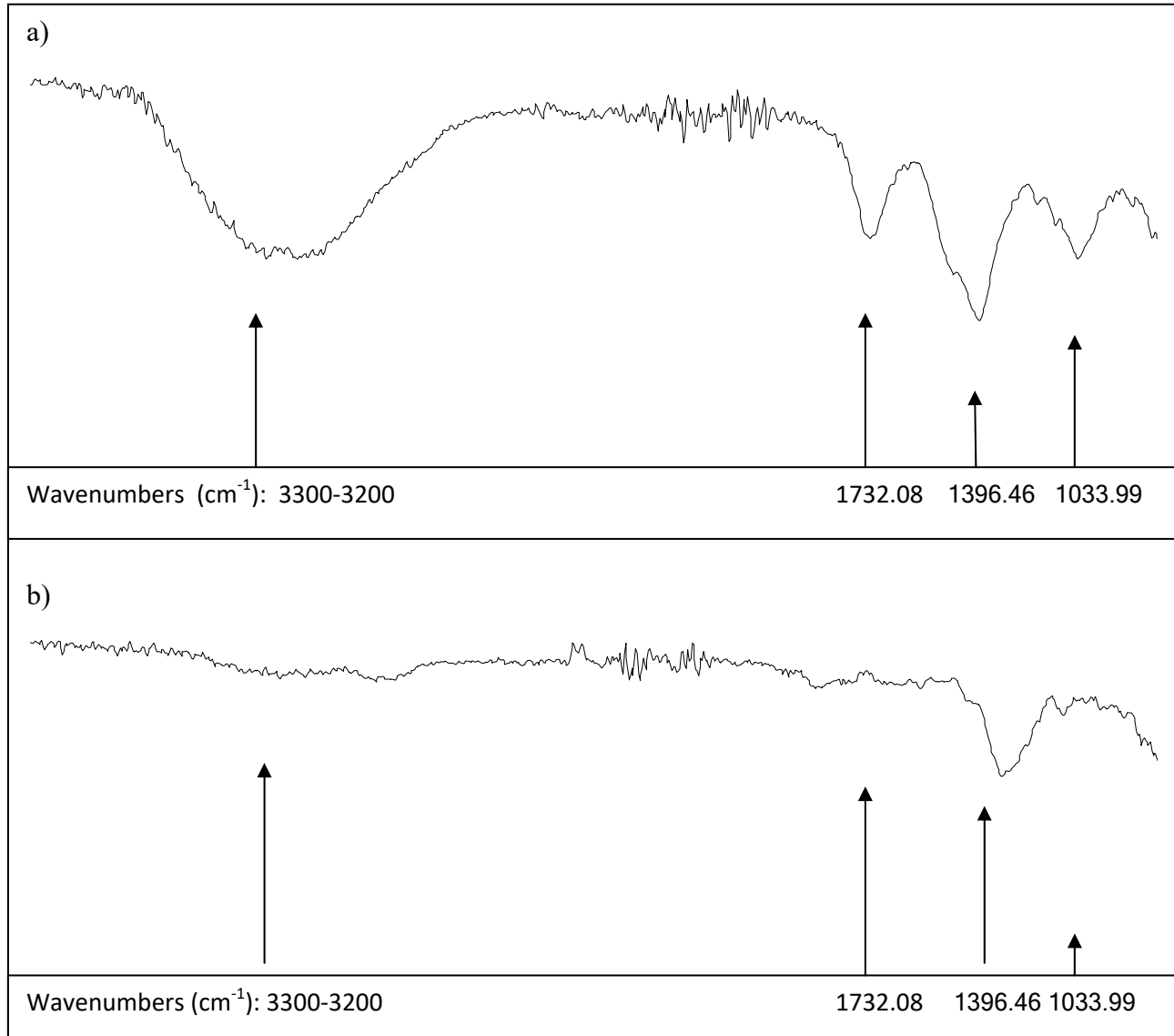


Figure 2: Water hyacinth powder; b= spectrum of water hyacinth loaded with Cd²⁺ ions

The strong peak at 1033 cm⁻¹ is ascribed to the C-O stretch in structures which contained carboxylic acids, ethers, ethers and alcohol [12; 13]. The band reduced in intensity upon

adsorption of cadmium ions. The spectra of the water hyacinth powder before and after adsorption of Ni²⁺ ions are presented in Figure 3.

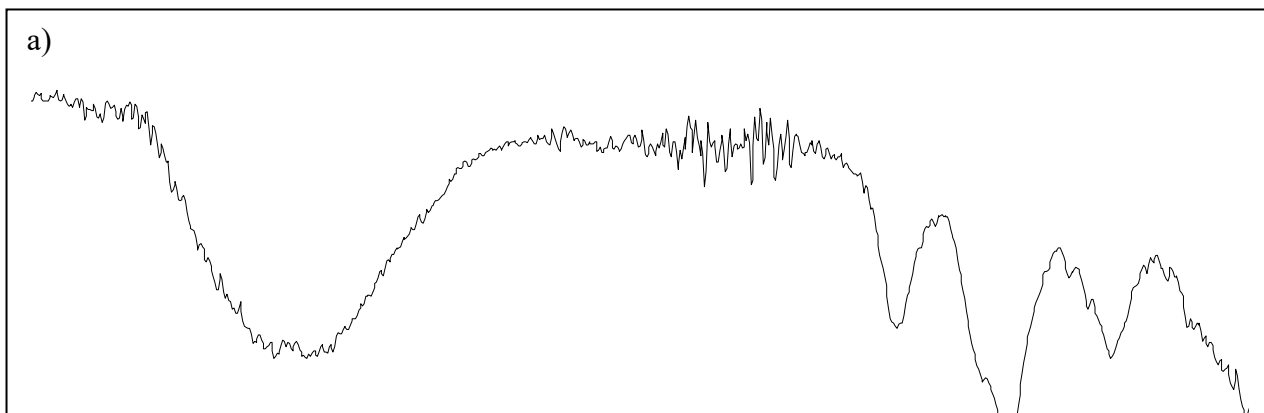


Figure 3: Water hyacinth powder; b= spectrum of water hyacinth loaded with Ni²⁺ ions

Figure 3a is the spectra of the raw water hyacinth powder. It showed a strong broad absorption band in the region of 3200cm⁻¹ to 3300 cm⁻¹. The adsorption of Ni²⁺ ions caused O-H band to disappear and hence there was a shift of the C=O peak from 1732 cm⁻¹ to 1724

cm⁻¹. The adsorption peaks 1396 cm⁻¹ and 1033 cm⁻¹ were reduced in intensity after adsorption of nickel ions. The spectral changes during the adsorption of Cr³⁺ ions are shown in Figure 4.

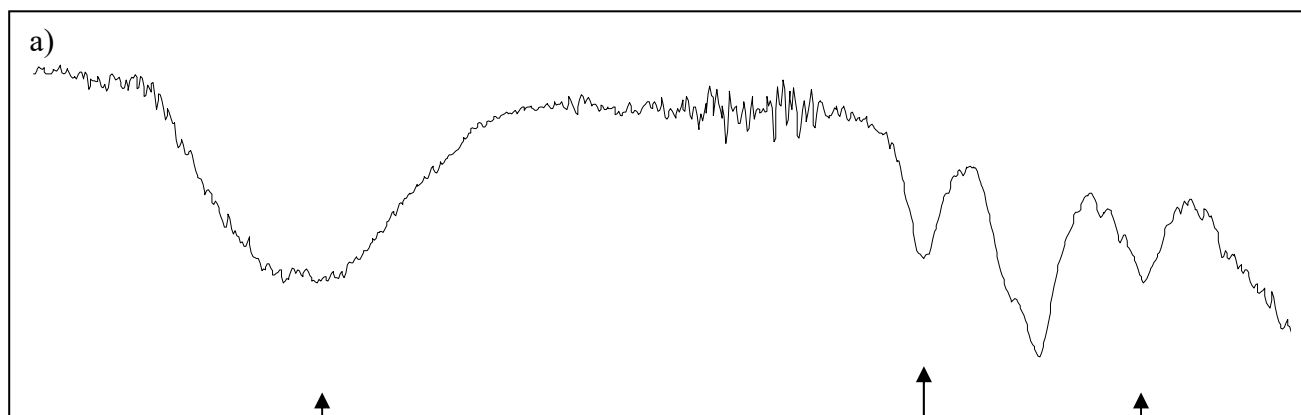


Figure 4: Water hyacinth powder; b= spectrum of water hyacinth loaded with Cr^{3+} ions

The study showed that adsorption of Cr^{3+} caused the O-H band peak at $3300\text{-}3200\text{ cm}^{-1}$ to disappear (Figure 4b). Further, it was observed that the peak at 1396 cm^{-1} disappeared while the C=O peak reduced in intensity. The observation

was in agreement with the studies conducted by [14] using other biological materials. The changes in the spectral bands for Zn^{2+} ions are shown in Figure 5.

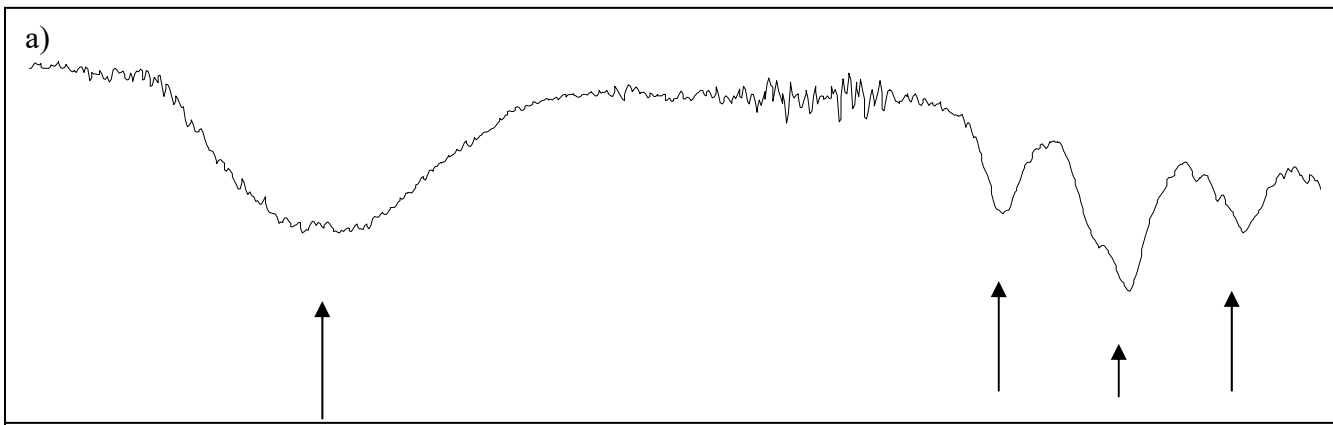


Figure 5: Water hyacinth powder; b= spectrum of water hyacinth loaded with Zn²⁺ ions

The O-H band in the region of 3200-3300 cm⁻¹ (Figure 5a) reduced in intensity after adsorption of Zn²⁺ ions (Figure 5b). The reduction in intensity could be attributed to zinc ions being attached to the functional groups at the region 3300-3200 cm⁻¹ which reduced the peak height hence the absorption band stretching to a lesser degree [15]. The adsorption of Zn²⁺ ions caused C=O to shift from 1732 to 1720 cm⁻¹ while the band at 1396 cm⁻¹ shifted to 1395 cm⁻¹. The

shifting of bands showed that Zn²⁺ ions were adsorbed by the relevant functional groups [4]. The adsorption of zinc ions caused the C-O band to reduce in intensity [16]. The use of FTIR spectroscopy has shown that during adsorption of heavy metal ions by water hyacinth powder, absorption bands either disappeared or reduced in intensity. The observations are summarized in Table 1.

Table 1: Changes in Spectral structure when various heavy metals adsorbs on the on the water hyacinth

Wave - number (cm ⁻¹)	Functional groups identified in the Raw water hyacinth	Changes in spectral structure after adsorption of the metal				
		Pb	Ni	Zn	Cd	Cr

3200 - 3300	O-H carboxylic acid, alcohol, water, phenols	Disappeared	Disappeared	Reduced intensity	Disappeared	Disappeared
1732	C=O acid, esters	Disappeared	Shifted (1724 cm ⁻¹)	Shifted (1720cm ⁻¹)	Reduced intensity	Reduced intensity
1396	C-H bending (alkanes) or C-O stretch and O-H deformation (acids)	Disappeared	Reduced intensity	Shifted (1395cm ⁻¹)	Disappeared	Disappeared
1033	C-O Alcohols, Acids, Esters, Ether	Reduced intensity	Reduced intensity	Reduced intensity	Reduced intensity	Reduced intensity

In Table 1, it is observed that during the heavy metal adsorption on the water hyacinth powder, there was a reduction in the intensity, disappearance or a shift in the functional groups which confirmed that the functional groups are responsible for the metal ion adsorption.

4. CONCLUSION

FTIR technique showed in this study that water hyacinth powder contains various functional groups which are capable of adsorbing metal ions and that the spectral intensities depended on the nature of the metal. The spectral bands were reduced, disappeared or shifted their positions depending on the metal. This could be attributed to the size of the metal ion, availability of metal ions at the site or on the electronegativity of the metal. The spectral intensities were observed at different frequencies indicating that bonds formed could have different energies. The study established that for all the metals the spectral intensities were reduced which is attributed to adsorption process.

REFERENCES

- [1] Csernaton, F., Socaciu, C., Pop, M.R. and Bunghez, F. (2013). Application of FTIR Spectroscopy for Fingerprinting Bioactive Molecules in a Nutraceutical PROMEN, comparatively with Plant ingredients. *Journal of Food Science and Technology*, 70:(1) 68-69.
- [2] Sahira Joshi and Bhadra Prasad Pokharel (2012). Preparation and Characterization of Activated Carbon from Lapsi (*Choerospondias axillaris*) Seed Stone by Chemical Activation with Potassium Hydroxide. *Journal of the Institute of Engineering*. 9 (1) 79–88.
- [3] Ayhan, D. 2008. Heavy metal adsorption onto agro-based waste materials: A review. *J. Hazard. Mater.* **157**: 220-229.
- [4] Njoki, M.A., Mercy, G., Nyagah, G. and Gachanja, A. (2016) Fourier transform infrared

- spectrophotometric analysis of functional groups found in *Ricinus communis*. L and *Cucurbita maxima* Lam. Roots, Stems and Leaves heavy metal adsorbent. *International journal of science environment*. **5**:861-871
- [5] Ibrahim, M, Nada, A. and Kamal, D.E. (2005) DFT and FTIR spectroscopic study of carboxyl group. *Indian journal of pure and applied physics* **43**:911-917
- [6] Ibrahim, M., Kuhn, O. and Scheytt, T. (2009) Molecular spectroscopic study of water hyacinth dry matter. *The open chemical physics journal* **2**:1-6
- [7] Mathias, E., Evangelou, M.W.H. and Scaeffler, A. (2007) A cyanide phytoremediation by water hyacinth (*Eichhornia crassipes*). *Chemosphere* **66**:816-823.
- [8] So, L.M., Chu, L.M. and Wong P.K. (2003) Microbial enhancement of Cu²⁺ removal capacity of *Eichhornia crassipes* (Matt) *chemosphere* **52**:1499-1503
- [9] Nuhoglu, Y. and Malkoc, E. (2009). Thermodynamics and kinetics studies for the environmental friendly Ni (II) biosorption using waste pomace of olive oil factory. *Bioresources technology* **100**:2375-2380
- [10] Hasan, S.H., Talat, M. and Rai, S. (2007) Sorption of Cadmium and zinc from aqueous solution by water hyacinth (*Eichhornia crassipes*) *Bioresources technology* **98**:918-928
- [11] Gobran, A., Siddig, T., K. and Hago, A. (2017) Determination of heavy metals in soil samples from Tuti Island Khartoum, Sudan. *Red sea university journal of Basic and Applied science* **2**(3):1-12.
- [12] Hasan, S.H., Talat, M. and Rai, S. (2007) Sorption of Cadmium and zinc from aqueous solution by water hyacinth (*Eichhornia crassipes*). *Bioresources technology* **98**:918-928.
- [13] Durwe, A. and Chandra, N (2014). FTIR analysis of bacteria biomass in response to heavy metals stress. *International journal of Biotechnology Photon* **112**:386-391.
- [14] Śliwińska, A, Smolinski, A. and Kucharski, P. (2019). Simultaneous analysis of heavy metals concentration in the soil samples. *Journal of applied science* **9**(21):4707-4716.
- [15] Liu, T., Hou, J.H., Wang, J.B., Wang, W. Wang, X.Y. and Wu, J.L. (2017) Bio-sorption of Heavy metals from Aqueous solution by the novel *Biosorbent pectobacteriu*
- [16] D'Souza L, Devi P, Shridhar DM, Naik CG (2008). Use of Fourier Transform Infrared (FTIR) spectroscopy to study Cadmium-induced changes in *Padina tetrastratica* (Hauck) *Analytical Chemistry Insights* **3**:135–143