DOI : <http://doi.org/10.22438/jeb/42/1/MRN-1397>

## Biosorption of chromium ions through modified *Eichhornia crassipes* biomass form the aqueous medium

 E. Parameswari<sup>1\*</sup>, R.P. Premalatha<sup>2</sup>, V. Davamani<sup>1</sup>, P. Kalaiselvi<sup>1</sup>, S. Paul Sebastian<sup>1</sup> and K. Suganya<sup>1</sup>
<sup>1</sup>Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore - 641 003, India<sup>2</sup>Department of Soil science Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore - 641 003, India\*Corresponding Author Email : [parameswariphd@gmail.com](mailto:parameswariphd@gmail.com)

Received: 15.01.2020

Revised: 05.05.2020

Accepted: 24.10.2020

### Abstract

**Aim:** To explore the potential of water hyacinth biomass as a low cost adsorbent for sequestering chromium ions from aqueous solution.

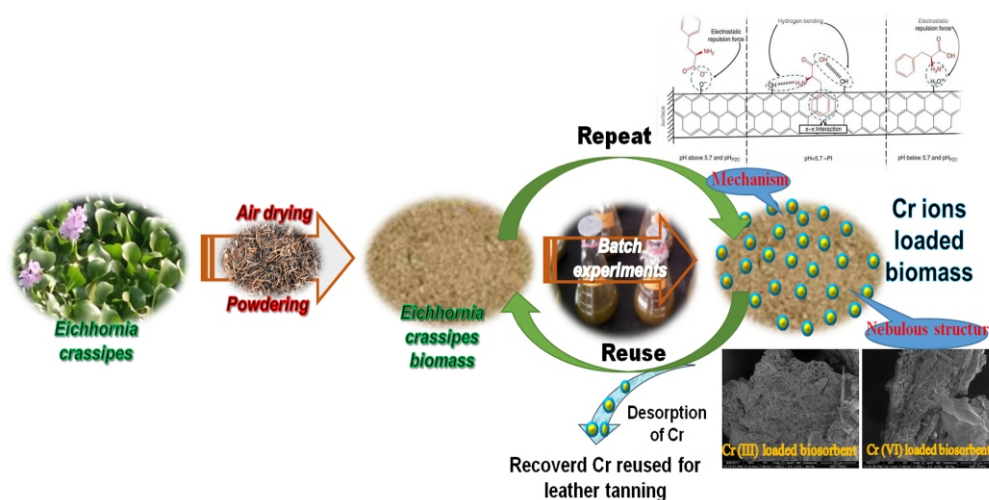
**Methodology:** The biosorption behavior of chromium ions (Cr(III) and Cr(VI)) from aqueous solution by powdered water hyacinth biomass was assessed through series of batch experiments using advanced instrumentation techniques like Scanning Electron Microscopy with Energy Dispersive X-ray analysis and Fourier Transform Infra-Red spectroscopy, pH zero point charge. The equilibrium relationship between sorbent and sorbate was determined in solution by using the isotherms Langmuir, Freundlich and Temkin models.

**Results:** The optimum pH for Cr(III) and Cr(VI) adsorption was 5.0 and 2.0 whereas the maximum Cr(III) and Cr(VI) adsorption was 99.80 and 89.15%, respectively. Langmuir isotherm fitted the data well with R<sup>2</sup> value of 0.999 for both Cr(III) and Cr(VI) by the biosorbent.

Adsorption kinetics showed that the experimental data fitted the pseudo second order kinetic model with R<sup>2</sup> value of 0.999 for both Cr(III) and Cr(VI). The EDX spectra peaks of Ca, O, C indicated the presence of functional groups such as –OH and –COOH in the biosorbent. The zeta potential analysis depicted that water hyacinth biomass had negative surface charge of (-) 23.5mV.

**Interpretation:** Water hyacinth based biosorbent can be utilized for the removal of Cr ions from industrial waste water. Further, water hyacinth has additional advantage that it reduces or even eliminates the diverse impact of weeds on the environment.

**Key words:** Biosorption, Chromium removal, Water hyacinth



**How to cite :** Parameswari, E., R.P. Premalatha, V. Davamani, P. Kalaiselvi, S. Paul Sebastian and K. Suganya: Biosorption of chromium ions through modified *Eichhornia crassipes* biomass form the aqueous medium. *J. Environ. Biol.*, **42**, 62-73 (2021).

## Introduction

Heavy metal pollution is a serious threat to the aquatic environment. Heavy metals also known as trace metals are the most persistent and non-biodegradable pollutants discharged from various industries (Akpör *et al.*, 2014). Chromium is a heavy metal that exists in several oxidation states, but the most stable and common forms are trivalent Cr(III) and hexavalent Cr(VI) species. Chromium in oxidation state +6 (Cr(VI)) is very harmful, even the quantum intake is abysmally low whereas intake of Cr(III) in moderate amount is considered essential for human formaintaining the glucose level in the blood (Rajeshwari and Sailaja, 2014). The major anthropogenic sources of Cr are from a wide spectrum of industrial processes like alloying, plating, tanning of hides, refractory, metallurgy, paint, textile dyes, chemical and petroleum refinement industries (Avudainayagam *et al.*, 2003). Tannery industry is considered as one of the most polluting industry. They are the major contributors of chromium pollution in the environment. Tanning industries have mushroomed in India for last several years. Almost 50% of these industries exist in Tamil Nadu. A total number of 2,161 tanneries are located in India and approximately 2000–3000 tonnes of chromium escapes into the environment annually from the industries.

The minimum effluent produced during leather processing is 2500 to 5000 l 100 kg<sup>-1</sup> of hide. For every 100 kilogram of skin tanned, 3200 l of freshwater is required (Murali and Rajan, 2012). Unfortunately, a part of chromium salt alone reacts with skin during tanning process. The remaining quantity is retained in the tanning exhaust bath. During this process it releases enormous quantity of Cr rich effluent (100 to 300 mg l<sup>-1</sup>). The permissible limit of Cr(VI) in the industrial effluent is 0.05 mg l<sup>-1</sup> as per the guidelines of World Health Organization, whereas the maximum permissible limit for total Cr is 0.05 mg l<sup>-1</sup> in drinking water. Among various industrial sources, leather tanning industry needs a relook as 40% of total Cr used in leather processing is retained in sludge (Kamaludeen *et al.*, 2003). Disposal of these compounds on land and in water is inevitable, thereby increasing pressure on the environment.

The disastrous effect of Cr dates back to 1890 when the elevated risk of cancer was reported among the workers of chrome dye company (Newmann, 1890). Adding this, during the second world war the aircraft workers suffered from chromate induced dermatitis. To protect the environment and living organisms from the hazardous effect of Cr, it is essential to remove Cr from wastewater. Conventional methods including membrane filtration, chemical precipitation, reduction, ion exchange, chelation, reverse osmosis and electro dialysis are available for its removal (Khatoon *et al.*, 2013). Nevertheless, these technologies exhibit high energy requirements and generates toxic sludge which calls for economically sound, ecologically safe technology for Cr management. In this context, biosorption received attention. Biosorption is a biochemical process where biomass binds to the contaminant on its cellular level by various mechanisms like adsorption,

absorption, precipitation, surface complexation and ion exchange (Fomina and Gadd, 2014). Biosorption of pollutants mainly nutrients and heavy metals in the water by dried plant based biomass or biomass derived carbon material are being widely utilized. In India, water hyacinth (*Eichhornia crassipes*) has been reported to remove 99.5% of Cr(VI) from the processed water of Sukinda chromite mines area, Orissa (Saha *et al.*, 2017). Dubey (2014) investigated the biomass derived from *Portulaca* species used for adsorption of cadmium ions from contaminated water and achieved the sorption capacity upto 72% with the standardization of all the parameters for adsorption. Bioremediation of Cd(II), Mn(II), Cu(II), Zn(II) and Pb(II) by *Potamogeton malaianus* and *P. pectinatus* recorded 92% the absorption effectiveness (Peng *et al.*, 2008).

The current study focus on removal of chromium ions by utilizing water hyacinth biomass as an adsorbent. Water hyacinth (*Eichhornia crassipes*) is the world's most important paramount noxious aquatic plant covering lakes, ponds, streams, ditches and backwater areas (Ghosh, 2010). This dreaded weed poses a serious challenge to aquatic inhabitants and is often blamed for choking water bodies. Under favorable conditions water hyacinth can grow up to 17.5 metric tons of wet biomass ha<sup>-1</sup> day. Normal yield of water hyacinth is reported to be 150 MT fodder ha<sup>-1</sup> year in India (Malik, 2007; Sebastian *et al.*, 2009). Availability in larger quantities, presence of many polyfunctional metal binding sites for both cationic and anionic metal complexes, high biosorption capacity, renewability and low cost makes water hyacinth a biosorbent for suitable sequestration of chromium species in aqueous solution.

## Materials and Methods

**Sample collection and preservation:** Water hyacinth plants collected from Vaigai dam, located in Theni district of Tamil Nadu, India (10°03'12"N 77°35'23"E) were washed to remove the sediments and other small floating fresh water aquatic weeds, dried, grounded and sieved through 0.2 mm sieve for further analysis.

**Adsorbate:** The stock solutions of Cr(III) and Cr(VI) was prepared by using analytical grade Cr<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> and K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>, in 1000 ml of double distilled water. Appropriate dilution of the above stock was done to obtain the standards of required concentration. The pH of metal solution was adjusted with 1.0N NaOH or 1.0N HCl.

**Characterization of biosorbent:** The structural orientation of biosorbent was analyzed with scanning electron microscopy (M/s. FEI-Quanta 20, Czech Republic) at 7.00 kV equipped with back scattered electron detector. Energy dispersive spectroscopy was used to analyze the elemental constituents of biosorbent sample. The functional groups present in the biosorbent were identified through Fourier transform infrared spectrometry equipped with a diamond tipped ATR accessory (Shimadzu, Japan) at 4000 to 400 cm<sup>-1</sup> wavelength. The spectra were arranged on transmittance axis before and after Cr adsorption onto the biosorbent.

**Zeta potential:** The surface charge of water hyacinth biomass was determined by measuring zeta potential. About 0.5 mg of biosorbent was mixed with 20 ml of deionized water and the suspension was shaken at 180 rpm for 2 hr on a mechanical shaker. In order to shatter the particles into colloids, the suspension was left in sonic bath, and suspension was then filtered through Whatman no. 42 filter paper. Zeta potential was determined from the supernatant by zeta potential analyzer (Horiba Scientific)

**Batch experiment:** A set of preliminary experiments were conducted to determine the kinetic and equilibrium sorption behaviour of Cr(III) and Cr(VI). The trials were carried out at 25°C in 250 ml conical flasks on a revolving shaker at 250 rpm. At the end of shaking period, the samples were centrifuged at 8000 rpm for 10 min and filtered through Whatman no. 42 filter. The left over concentration of Cr ion was determined by Atomic Absorption Spectroscopy (Perkin Elmer 400).

**Point of zero charge of biosorbent:** Solid addition method was used to determine the point of zero charge ( $pH_{PZC}$ ) (Oladoja and Aliu, 2009).  $pH_{PZC}$  was calculated by plotting the differences in pH value ( $\Delta pH = pH_{initial} - pH_{final}$ ) against  $pH_{initial}$  and the point of intersection gave  $pH_{PZC}$ .

**Effect of pH on biosorption:** A set of preliminary experiments were conducted with 4 replicates. The concentration of Cr ion taken was 200 mg l<sup>-1</sup> and the pH was adjusted from 1 to 9 using 1.0N NaOH or 1.0N HCl. The pH was measured using pH meter.

**Kinetic study:** The chromium adsorption rate and its mechanisms were elucidated through kinetic studies. To analyse the adsorption kinetics of Cr(III) and Cr(VI), the elovich, intra particle diffusion, pseudo first order and pseudo second order models were applied. In 250 ml conical flask, 2% water hyacinth biomass was added in 200 mg l<sup>-1</sup> of Cr(III) and Cr(VI) solutions with the pH adjusted to 5 and 2, respectively with 1.0N NaOH or 1.0N HCl. The suspension was maintained in a revolving shaker at 250 rpm for 6 to 48 hr at 25°C. The suspension was centrifuged, filtered and measured as described above. From deducting the remaining quantity from initial concentration, the quantity adsorbed was calculated. The adsorption kinetics was analyzed for Cr (III, VI), the pseudo first order, pseudo second order, elovich and intra particle diffusion models were applied as described by Lagergren (1898); Ho and McKay (1999).

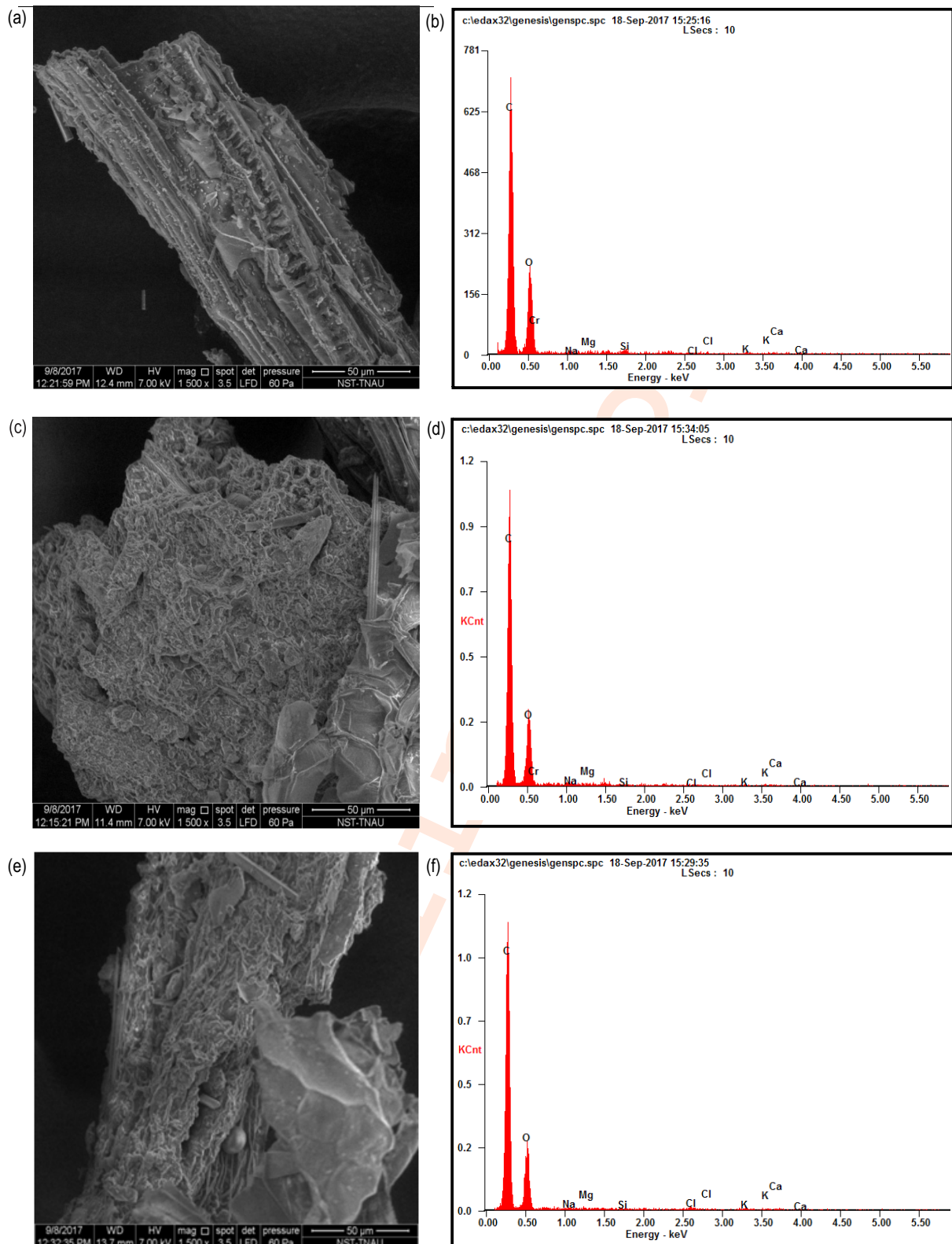
**Isotherm study:** The symmetrical relationship between sorbate and sorbent were determined by using the solution concentrations from 100 to 2000 mg l<sup>-1</sup> through 100 mg l<sup>-1</sup> interval with pH 2 and 5 for Cr(VI) and Cr(III), respectively. Then the mixture of 100ml of each solution and 2.0g of adsorbent were agitated on a rotating shaker at 250rpm and 25°C for 24 hr. The data obtained were fitted to Langmuir, Freundlich and Temkin isotherms as defined by Langmuir (1918), Dada et al. (2012) and Tempkin and Pyzhev (1940), respectively.

## Results and Discussion

The morphology of adsorbent was analysed with Scanning Electron Microscope before and after the adsorption of Cr ions at 7.00 kV equipped with back scattered electron detector. Fig.1 (a, e) shows the scanning electron micrograph of biomass with clear striated and nebulous structure which transformed to an aggregated structure after the adsorption of Cr (III) and Cr (VI) ions. This difference in surface structure of Cr (III) and Cr (VI) loaded adsorbent could be due to the deposition of chromium ions on the surface of the adsorbent (Balarak et al., 2014; Premalatha et al., 2019). EDAX spectra were recorded to assess the elemental composition of adsorbent before and after Cr adsorption. After Cr (III) and Cr (VI) adsorption, the composition of Ca reduced from 2.19% to 0.96 and 1.99%, respectively. Similarly, the composition of Mg, Cl, K decreased after Cr (III and VI) adsorption. Especially in consideration with Na, initially it was found to be 0.49% which decreased to 0% after Cr (III) adsorption. Chromium peaks were found only after subjection to Cr (III and VI) loading. The peaks of Ca, O, C indicated the existence of functional groups like -OH and -COOH in the adsorbent (Jain et al., 2013). The EDAX spectra of biomass before Cr adsorption showed no prominent peaks of chromium whereas spectra after Cr (III) and Cr (VI) adsorption produced prominent Cr peaks with the reduction in Ca peaks (Das and Guha, 2007). Similar reducing trend in composition of Mg, Na, K and Cl was also observed.

The FTIR peaks of powdered biomass at 3332.39, 2919.70, 2291.02, 2111.67 and 1615.09 cm<sup>-1</sup> showed the presence of -OH, C-H, N-H, C≡C and C=O groups, respectively. The peak at 3332.39 cm<sup>-1</sup> was shifted to 3284.18 and 3282.25 cm<sup>-1</sup> after the sorption of Cr (III) and Cr (VI), respectively, onto the biomass. Similar shift in the peaks corresponding to C≡C group was also recorded. Especially, the peaks at 2291.02 and 2111.67 cm<sup>-1</sup> observed in unloaded biomass disappeared in Cr (VI) loaded biomass but peaks at 2919.70 cm<sup>-1</sup> remained unchanged after Cr (III) and Cr (VI) adsorption which confirmed that C-H groups were not involved in adsorption. This chemical shift and disappearance of peaks corresponding to groups confirmed their contribution towards adsorption.

FTIR results of water hyacinth biomass in advance and after Cr (III and VI) adsorption are shown in Fig. 2. The FTIR spectra before Cr adsorption (Fig. 2a) showed intense peaks at 2700-3500 cm<sup>-1</sup> which represent -OH group stretching and -NH bonds (Jain et al., 2014) indicating the existence of amine and hydroxyl groups with the broad peak at 3332.39 cm<sup>-1</sup>. A strong spectral peak at 1024.98 cm<sup>-1</sup> showed C-O bonds stretching. The FTIR spectra of Cr(III) loaded biosorbent (Fig. 2b) had broad peaks at 3284.18 cm<sup>-1</sup> and 1019.19 cm<sup>-1</sup> showing the presence of hydroxyl, amine and C-O bonds stretching. Fig. 2c represents the water hyacinth biomass after Cr (VI) adsorption, in which broad peak at 3321.78 cm<sup>-1</sup> was due to -OH and N-H groups. The strong peak at 1581.34 cm<sup>-1</sup> has been attributed to NH<sub>3</sub> group antisymmetric deformation, and peak at 1024.02 cm<sup>-1</sup> was due to



**Fig. 1:** (a) Scanning electron micrographs of water hyacinth biomass; (b) EDX of water hyacinth biomass; (c) Scanning electron micrographs of Cr (III) loaded biomass; (d) EDX of Cr (III) loaded biomass; (e) Scanning electron micrographs of Cr (VI) loaded biomass; (d) EDX of Cr (VI) loaded biomass.

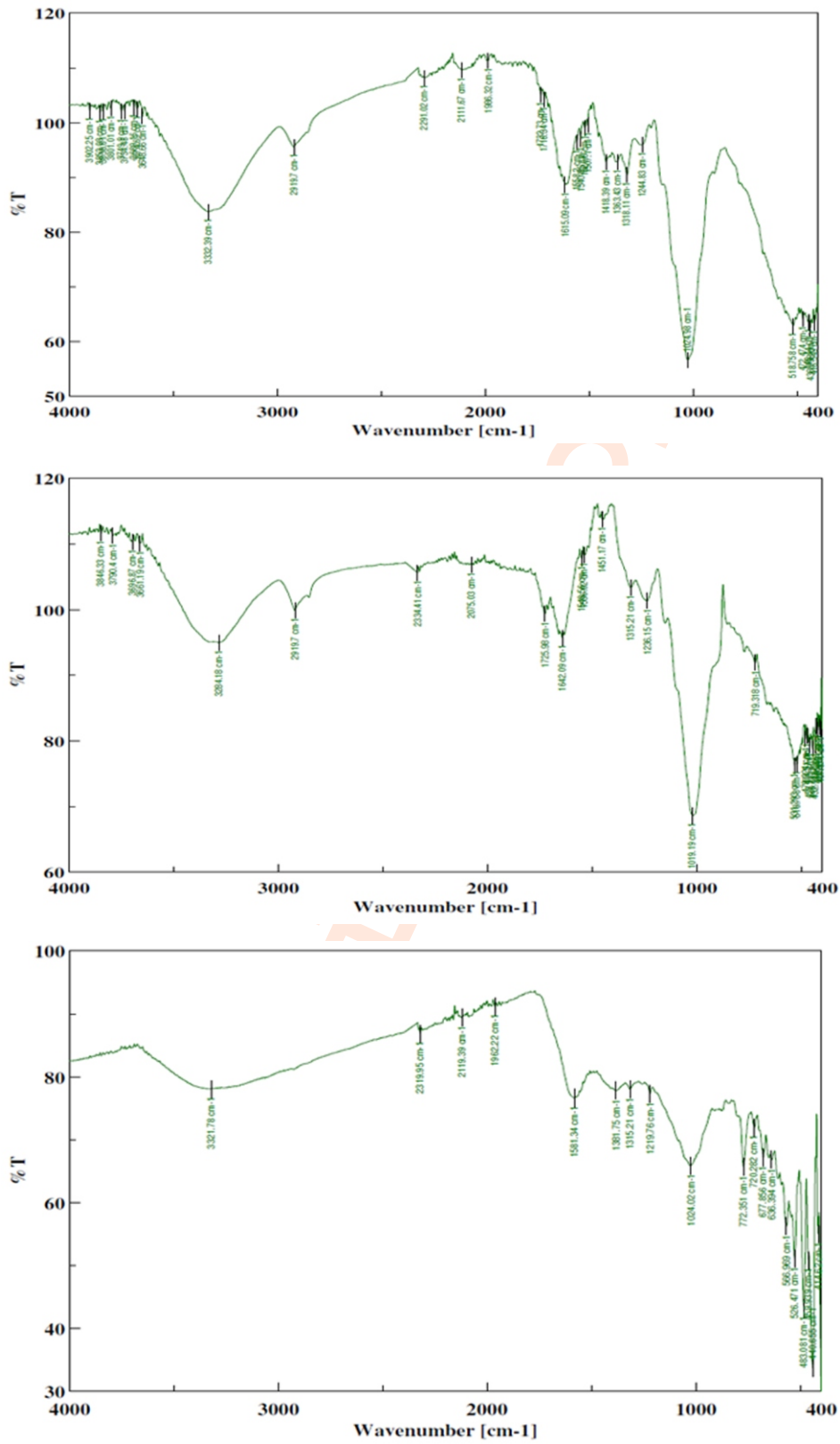


Fig. 2: FTIR spectra of water hyacinth biomass: (a) before Cr adsorption; (b) after Cr(III) adsorption and (c) after Cr(VI) adsorption.

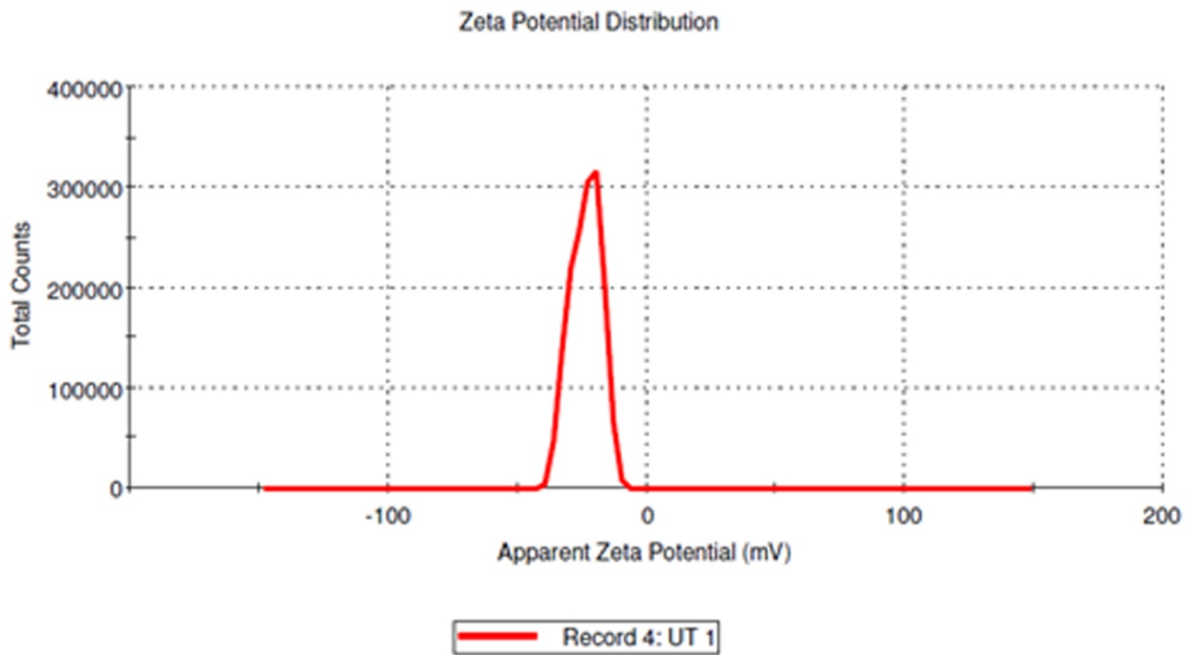


Fig. 3: Zeta potential distribution of water hyacinth biomass.

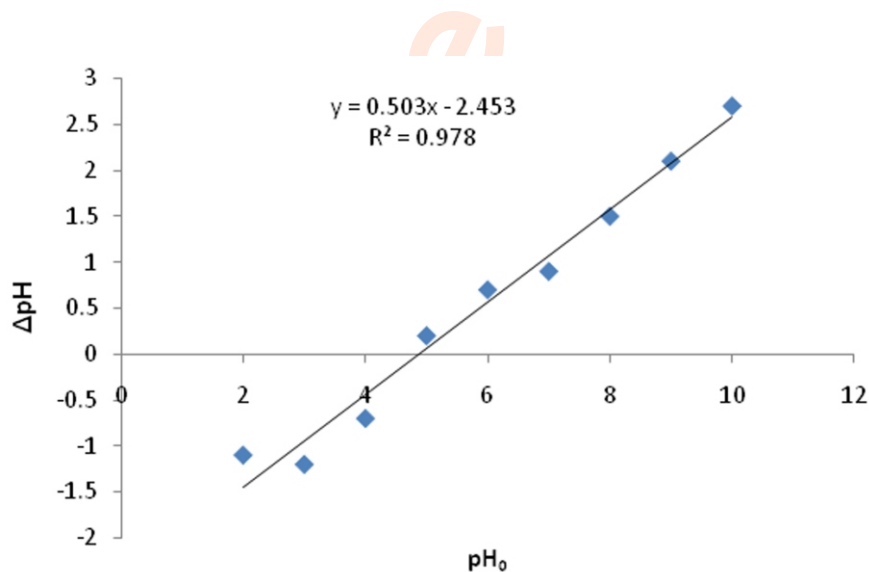


Fig. 4: Point of zero charge of water hyacinth biomass.

C-O functional groups. The distinct changes were recorded in spectra of biomass after Cr(III and VI) adsorption compared to spectra before Cr adsorption. The chemical shift in the positions of -OH, N-H and C-O group peaks indicate their involvement in the biosorption of Cr(III) and Cr (VI). Biosorption process occurs due to smaller shift in the series of peak indicating the

involvement of NH, OH, C=O groups for binding the metal ions (Madhusudhanan *et al.*, 2019). Zeta potential of water hyacinth biomass had negative surface charge of (-) 23.5mV (Fig.3.). The adsorbent recorded a negative zeta potential which indicated predominance of negative charges on the adsorbent surface, so cation like Cr (III) can be adsorbed more favourably compared to

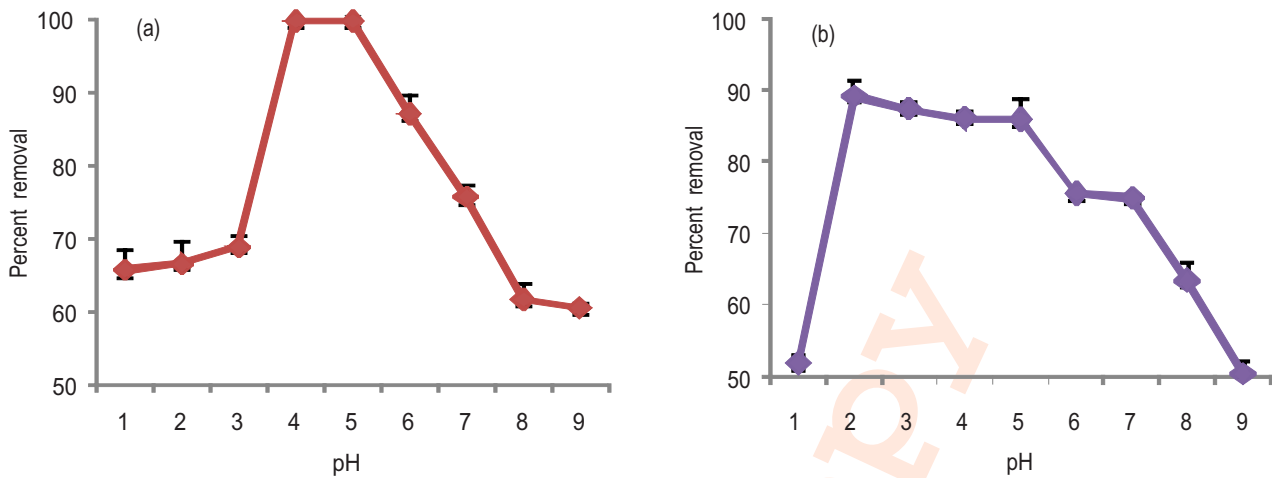


Fig. 5A: Effect of solution pH on: (a) Cr(III) and (b) Cr(VI) adsorption.

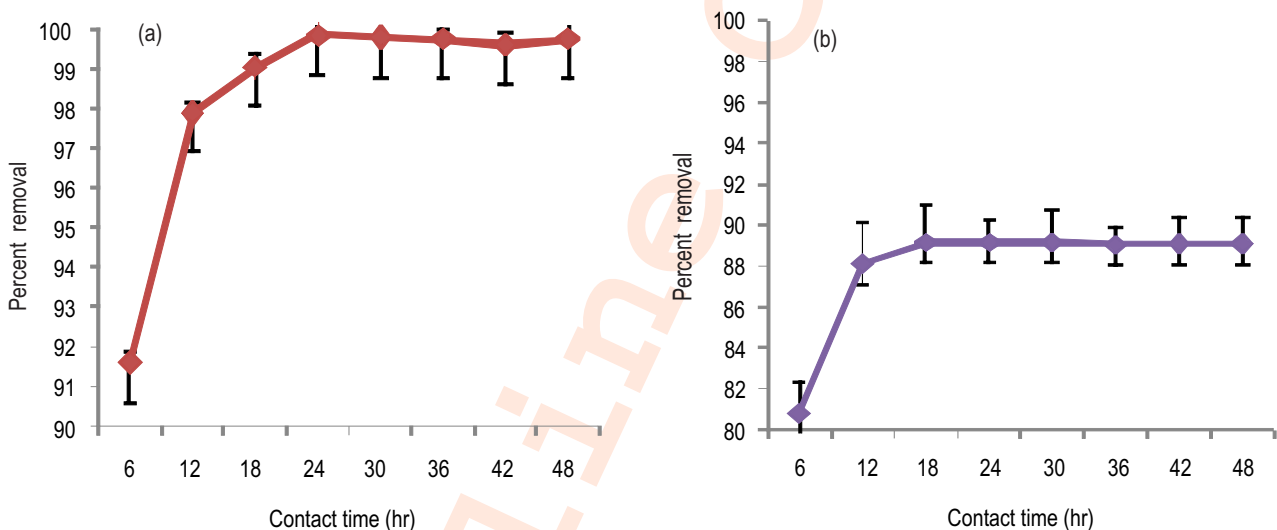


Fig. 5B: Effect of equilibrium period (hours) on: (a) Cr(III) and (b) Cr(VI) adsorption.

Cr (VI), which exists as anion. Based on the zeta potential measurements it seems that the adsorption process also includes the complexation reaction (Ghanbariana *et al.*, 2018). The point of zero charge (PZC) means the pH where the net charge on surface of the bioadsorbent is zero, having higher positive charge functions as that of negative charge functions on the surface. Point of zero charge of an adsorbent is a useful parameter for determining the sorption of metal ions.

The plot between  $\Delta$  pH and pH<sub>0</sub> (Fig.4) shows that the point of zero charge of water hyacinth biomass was 4.8. The sorption of metal ions depends on the surface chemistry of the adsorbents (He and Tebo, 1998). The adsorbent surface modifies

its polarization according to the pH of the solution (Do Nascimento *et al.*, 2013). At pH >pH<sub>PZC</sub>, the surface of the adsorbent become negatively charged due to the sorption of OH<sup>-</sup> ions by electrostatic attractive force, favouring the adsorption of cations whereas when pH <pH<sub>PZC</sub>, adsorbent surface attains positive charge due to the adsorption of H<sup>+</sup> ions (Uddin *et al.*, 2014). Hence, the adsorption of anionic metals (Cr (VI)) favors pH <pH<sub>PZC</sub> (Ebrahimian *et al.*, 2014). The adsorbent characteristics and level of ionization of metal ions in aqueous solution depends on the pH of the solution (Xu *et al.*, 2008; Puentes-Cárdenas *et al.*, 2012). As the pH of the aqueous solution is a prime variable pertaining to the metals adsorption on the adsorbent, the effect of pH on removal of chromium by adsorbents was studied with pH

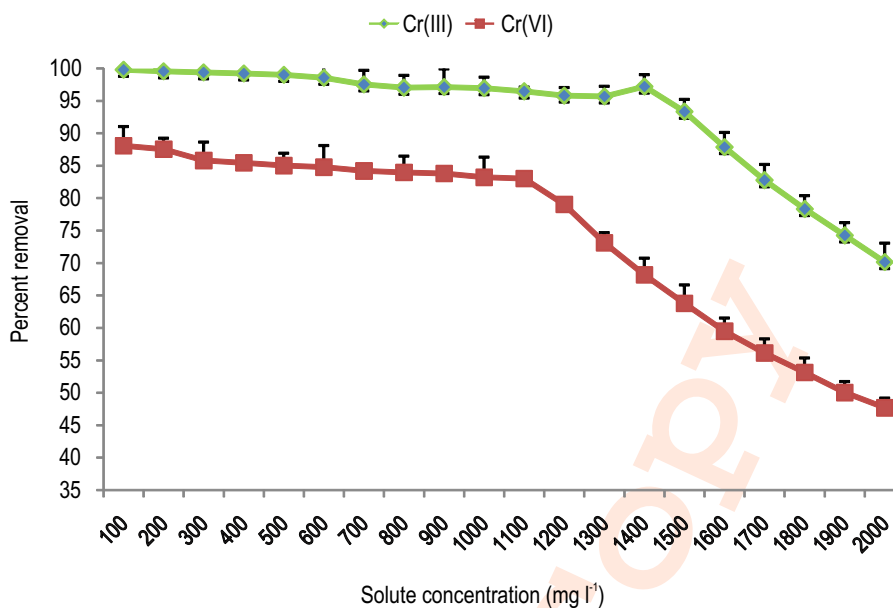


Fig. 5C: Effect of solute concentration on removal of Cr (III, VI).

range of 1 to 9 (Fig. 5A). The results showed that the maximum removal of Cr (VI) (89.2%) was achieved at pH 2.0. Similarly, Cr (III) removal by the biomass (99.8%) was maximum at pH 5.0. Variation in the removal of Cr (III) and Cr (VI) at different pH may be attributed to the factors like charge of metal ions in aqueous solution and charge on the adsorbent surface at particular pH. In aqueous solution, trivalent Cr is present as a cation whereas hexavalent Cr is present as anion (Bedemo *et al.*, 2016). It has been inferred that, at lower pH the surface of the adsorbent acquires a positive charge which can easily bind negatively charged Cr (VI) through electrostatic force of attraction (Tarley and Arruda, 2004; Mohanty *et al.*, 2006). In addition, lower adsorption of cations (Cr (III) at low pH may be due to the competition of H<sup>+</sup> and metal ions (Banat *et al.*, 2007) and electrostatic repulsion (Jeon and Höll, 2003).

At moderate pH (3 to 6), the H<sup>+</sup> ions linked with active sites of adsorbent are released favouring the adsorption of metal cations but at higher pH (> 6.0), the precipitation of metals and hydroxide formation dominates restricting the metal sorption (Salehzadeh, 2013). At higher pH, the surface charge of the adsorbent becomes negative and increases the percent removal of Cr (III) (Chathuranga *et al.*, 2013). The solute concentration and contact time has profound influence on the adsorption phenomenon which is depicted in Fig. 5. (B,C). The major adsorption of Cr(III) (91.60%) and Cr(VI) (80.80%) occurred at 6 hr and at equilibrium 99.85 and 89.14% of Cr(III) and Cr(VI), respectively were adsorbed. The initial rapid adsorption of cations could be due to large number of active sites available for adsorption and later the balance active sites were hard to be engaged due to repulsive action between solute molecules of

both bulk and solid phases (Alsaibi *et al.*, 2014). The unit Cr adsorption increased markedly with increase in solute concentration, the percent removal was found to decrease with higher adsorbate concentration. The results showed that the maximum removal of Cr (III) (99.8%) and Cr (VI) (88.1%) by the biomass was recorded with 100 mg l<sup>-1</sup> solute concentration, beyond which the metal removal decreased. On increasing the solute concentration, the sorption capacity increased but decreased the removal percent, which might be due to lack of active binding sites required at higher solute concentration of aqueous solution (Martinez *et al.*, 2006; Freitas *et al.*, 2008).

The kinetics involved in the Cr (III) and Cr (VI) adsorption onto the biomass was tested with kinetic models namely pseudo first order, pseudo second order, elovich and intra particle diffusion model (Fig. 6 A,B). The high R<sup>2</sup> value of 0.999 each for Cr (III) and Cr (VI) was obtained from pseudo second order kinetic model. Also, the calculated value of q<sub>e</sub> was closer to the experimental q<sub>e</sub> value in pseudo second order model. For instance, the q<sub>e</sub> value calculated for Cr (III) and Cr (VI) adsorption onto biomass was 10.1 and 9.01 mg g<sup>-1</sup>, were in close agreement with experimental q<sub>e</sub> value of 9.99 and 8.91 mg g<sup>-1</sup> for Cr (III) and Cr (VI), respectively, but for pseudo first order model. The calculated q<sub>e</sub> value differed greatly from the experimental q<sub>e</sub> value. The elovich equation was also employed to study the adsorption phenomena, but low R<sup>2</sup> was recorded. From elovich kinetics, α which denotes the initial adsorption rate was found maximum for adsorption of Cr (III) onto biomass (2.926 x 10<sup>10</sup> mg g<sup>-1</sup> min<sup>-1</sup>). In addition, the number of binding sites accessible for Cr adsorption related to the parameter 1/β showed higher values of 0.35 and



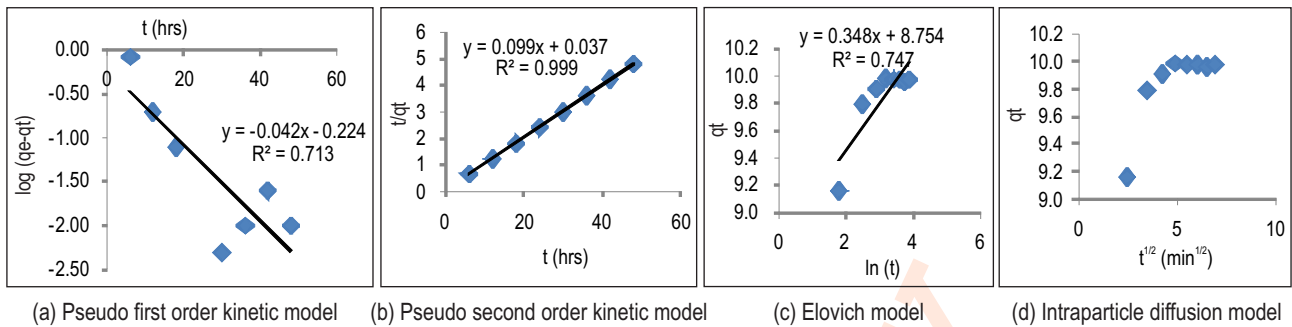


Fig. 6A: Adsorption kinetics for Cr(III) adsorption by water hyacinth biomass.

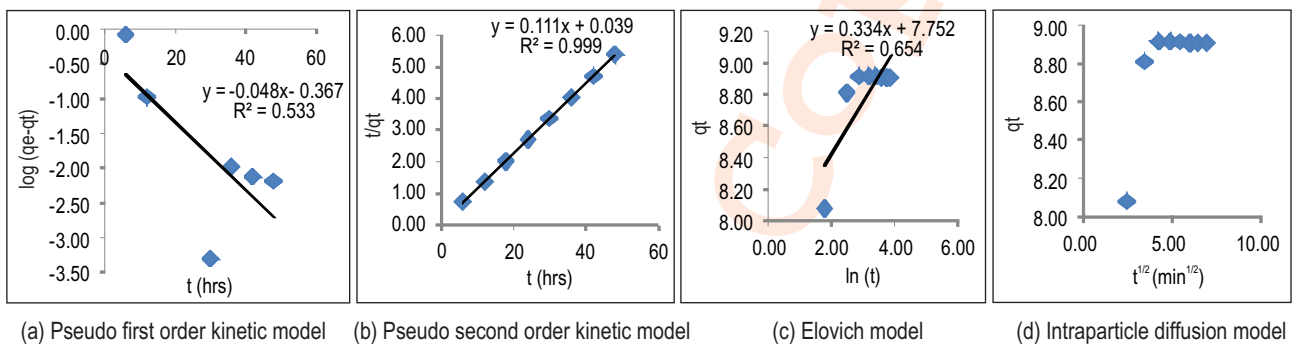


Fig. 6B: Adsorption kinetics for Cr(VI) adsorption by water hyacinth biomass.

0.81 mg g<sup>-1</sup> for Cr (III) and Cr (VI), respectively. The R<sup>2</sup> and q<sub>m</sub> value of pseudo second order model suggests that Cr (III) and Cr (VI) adsorption could be better described by chemisorption (Bernard and Jimoh, 2013; Chakraborty *et al.*, 2020) which involves sharing of electrons between adsorbents and adsorbate (Deng *et al.*, 2009). To obtain valid information pertaining to process involved in the adsorption mechanism, the data were further examined by intra particle diffusion model.

The multi linear plots were obtained from diffusion model which revealed that two or many steps were associated with the sorption of Cr onto the adsorbent (El-Said, 2010). From the plots of intra particle diffusion model, twin linearity was observed which confirmed that adsorption process involved two steps. The first linear portion represents the boundary layer diffusion of metal ions to the exterior surface of the adsorbent, while the next linear portion represents the intra particle diffusion (Abdel-Ghani *et al.*, 2015). To understand the adsorption mechanism at solid/liquid interface, Langmuir, Freundlich and Temkin isotherm models were studied. The isotherm plots for Cr (III) and Cr (VI) adsorption are shown in Fig. 7 A,B. For adsorbent and Cr species, the maximum R<sup>2</sup> value was obtained in Langmuir isotherm which confirmed that adsorption of Cr (III, VI) onto adsorbents occurred onto the active sites as monolayer (Abdel-Aty *et al.*, 2013). The Langmuir dimensionless constant (K<sub>f</sub>) for each of the solute

concentration was found between 0 and 1, indicating favourable adsorption of Cr (III & VI) onto the adsorbents (Kadirvelu *et al.*, 2001). For Cr (III), the maximum monolayer adsorption capacity (q<sub>m</sub>) of 76.9 and 41.7 mg g<sup>-1</sup> was reported. Similarly, the q<sub>m</sub> for Cr (VI) was 53.2. For Cr (III) adsorption, KL values of 0.084 whereas opposite trend was noticed for Cr (VI) adsorption. From the constants (q<sub>m</sub> and KL), it was clear that biomass had higher sorption capacity of Cr (III) than Cr (VI). Freundlich isotherm model showed R<sup>2</sup> value of 0.864 and 0.821 for Cr (III) and Cr (VI), respectively.

The calculated isotherm data revealed that adsorption intensity given by Freundlich coefficient (1/n) was <1, indicated positive adsorption of Cr(III) and Cr(VI) onto the water hyacinth biomass as biosorbent (Varank *et al.*, 2012; Erhayem and Sohn, 2014). Adding this, the higher sorption capacity (K<sub>f</sub>) was achieved (12.02mg g<sup>-1</sup>) for Cr (III) than Cr (VI) (2.45 mg g<sup>-1</sup>), which confirmed greater sorption of Cr (III) onto the biosorbent than Cr (VI) (Ismail *et al.*, 2013). The outcome represents that the higher R<sup>2</sup> value of 0.999 (Cr(III)) and 0.989 (Cr(VI)) were obtained from Langmuir isotherm model, which confirmed that biosorption of Cr(III) and Cr(VI) onto biosorbent occurred onto the active sites as monolayer (Abdel-Aty *et al.*, 2013). Adsorption of metal ions on biosorbent surface was found over unity (n values), indicating active adsorption (Singh *et al.*, 2018). Considering Freundlich isotherm, the R<sup>2</sup> value was less compared to Langmuir and

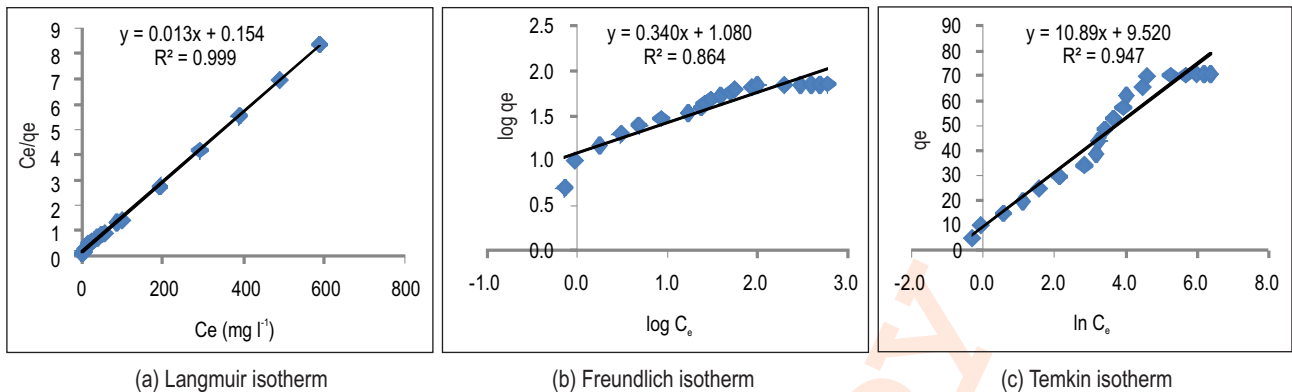


Fig. 7A: Adsorption isotherms for Cr(III) adsorption by water hyacinth biomass.

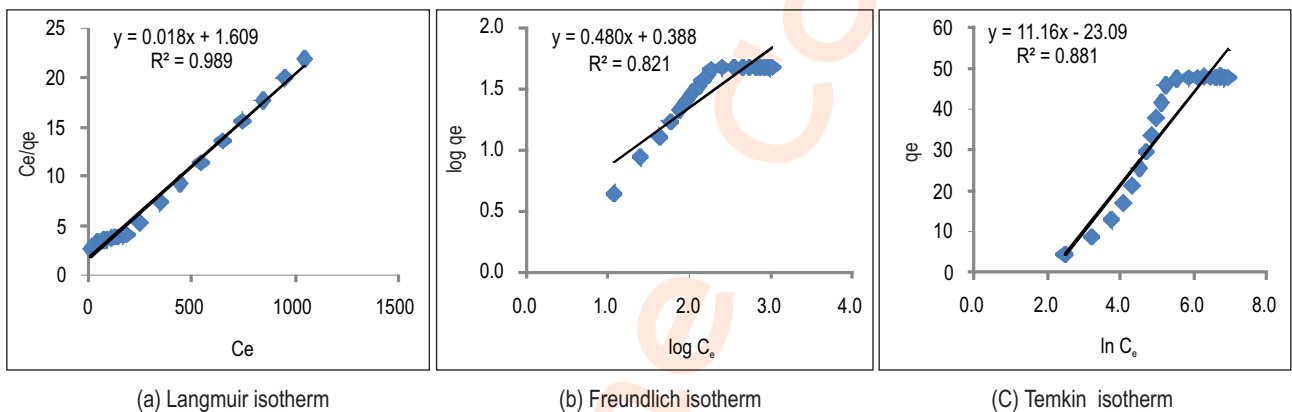


Fig. 7B: Adsorption isotherms for Cr(VI) adsorption by water hyacinth biomass.

Temkin isotherms and the 'n' value for both adsorbents and Cr species ranged between 2-3, indicated favourable adsorption (Mckay *et al.*, 1980). Adding this, the Freundlich constant related to sorption capacity (KF) was found maximum ( $12.0 \text{ mg g}^{-1}$ ) for Cr (III) than Cr (VI) ( $2.45 \text{ mg g}^{-1}$ ) for biomass. From this study it is concluded that water hyacinth biomass is a potential biosorbent with variable capacity to remove Cr (III) and Cr (VI). SEM with EDX and FTIR analysis confirmed the adsorption reaction on biosorbent surface. Hence, water hyacinth biomass is more efficient in Cr (III) adsorption than Cr (VI). From this study, it is evident that water hyacinth based biosorbent will act as an ecofriendly biosystem for the management of chromium contamination while considering the economic aspects of wastewater treatment. Hence, this technology may be upgraded to larger scale in the industries.

#### Acknowledgment

The authors deeply acknowledge the Science and Engineering Research Board (YSS/2015/001432), Department of Science and Technology, New Delhi for financial assistance.

#### Add-on Information

**Authors' contribution:** E. Parameswari: Designed & Executed the study; R.P. Premalatha: Wrote the protocol & conducted the experiment; V. Davamani: Wrote the first draft of the manuscript; P. Kalaiselvi: Statistical analysis & draft editing; S. Paul Sebastian: Manage the analyses of the study; K. Suganya: Manage the literature search.

**Research content:** The research contents is original and has not been published elsewhere

**Ethical approval:** Not Applicable

**Conflict of interest:** The author declare that there is no conflict of interest.

**Data from other sources:** Not Applicable

**Consent to publish:** Author agree to publish the paper in *Journal of Environmental Biology*.

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