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Introduction

About 71% of total surface of earth covered with salty water and remaining 29% are fresh water required to maintain life of people living on earth. According to the estimate of World Health Organization, more than 1 billion people are not getting clean water. Approximately every day death of 4000 children caused around worldwide are due to the diseases resulted from water contamination (Suhas et al., 2019). Discharge of wastewater into environment composed of water along with numerous chemicals of organic, inorganic and heavy metals resultant from industry, domestic and commercial activities (Dixit et al., 2011). Toxic heavy metals are discharged into environmental from different industrial sectors includes electroplating, mining battery manufacture, tanneries, petroleum refining, paint manufacture, dye manufacture, printing, photographic industries, etc. These industries effluent associated with heavy metals of arsenic, lead, chromium, cadmium, copper, zinc, nickel, lead, mercury, etc. The toxic heavy metals are major challenge for treatment due to their property of recalcitrance and persistence nature (Kadirvelu et al., 2001; Williams et al., 1998). In comparison of toxic heavy metals, hexavalent chromium is one of the highly toxic metals and considered as main concern pollutant. The oxidation state of chromium in the aqueous systems are trivalent and hexavalent chromium. The trace concentration of trivalent chromium found essential for metabolism of glucose in the living systems. Trivalent chromium is immobile and less toxic compared to hexavalent chromium. The characteristic feature of hexavalent chromium includes easy penetration into the cell wall, exhibits toxicity and causes carcinogenic diseases (Miretzkya et al., 2010). The synthetic dyes used in the industries of textile, paper, plastics, etc., and their various use in industrial operations generates large amount of colored effluent. Industrial effluent holding synthetic textile dyes are hard for treatment/disposal because of their synthetic origin and complex structures. The synthetic dyes absorb sunlight, which in turn affects phytoplankton, and aquatic system through declined photosynthesis as well diminished dissolved oxygen concentration. Dye wastewaters are difficult to treat due to larger volume, and constituted with chemicals of organic and inorganic. Synthetic dyes are toxic in nature and exhibits carcinogenic effects (Sun and Yang 2003; Banat et al., 1996; Kroschwitz and Howe-Grant 1993). Considering the major hazardous effects of water pollutants on living systems and environment, the pollutants must be removed before discharge into the water bodies. The conventional industrial effluent treatment methods are associated with drawbacks of requirement of more investments and sludge generation (Table 1). The method of biosorption considered as potential and sustainable solution for the elimination of wastewater pollutants due to their inexpensive factor, higher removal efficiency/uptake capacity and environmental friendliness (Rangabhashiyam et al., 2014).

Table 1 Conventional treatment technologies for the removal of water contaminants from aqueous solutions (Rangabhashiyam et al., 2019; Mohamad Amran et al., 2011).

Technology	Advantages	Disadvantages
Coagulation and flocculation	Good settling and dewatering characteristics	Higher sludge volume generation
Chemical precipitation	Simple process and low capital investment	High maintenance costs for disposal of sludge, Ineffective at lower concentration
Membrane filtration	Operates at low pressure, occupies less space and selective process	High cost requirement and membrane fouling
Flotation	Higher removal efficiency and more selective	Requires high maintenance and operation cost
Photocatalysis	Simultaneous removal of metal and dye pollutant	Longer duration time
Ion-exchange	Highly selective	Higher cost of synthetic resins and limited pH tolerance
Adsorption using activated carbon	Fast and higher removal efficiency	Higher cost of activated carbon
Ozonation	Does not increase volume of wastewater and sludge	Short half-life
Electrochemical destruction	No consumption of chemicals and no sludge buildup	High flow rates affects removal efficiency

Lignocellulosic biomass and biosorption

Lignocellulosic biomass mainly consists of cellulose, hemicellulose and lignin. The residues resultant from agricultural practice and forests are the major resource for the lignocellulosic biomass (Karolina et al., 2018). Our research focuses on precursors sourced from the different lignocellulose biomass are used for the removal of hexavalent chromium, methylene blue, malachite green, etc. The biosorption potential of *Caryota urens* inflorescence, *Ficus auriculata* leaves powder, *Swietenia mahagoni* shell, *Sterculia guttata* shell and *Enteromorpha* sp., was carried out the removal of hexavalent chromium from the aqueous solution. Removal of methylene blue and malachite green tested using Carica papaya wood. Biodiesel extracted seeds of *Jatropha* sp., *Ricinus* sp., and *Pongamia* sp., assessed for biosorption of hexavalent chromium. Removal behaviors of methylene blue and hexavalent chromium on *Pterospermum acerifolium* shells reported. Macroalgae, *Cladophora* sp., employed for the biosorption of hexavalent chromium and malachite green from aqueous solutions. The biosorption process investigation performed using the characterization techniques of C–H–N analyzer, surface area analyzer, Fourier transform infrared spectroscopy, X-ray

Powder Diffractometer, scanning electron microscope and Energy-dispersive X-ray spectroscopy, respectively. The investigation of biosorption carried out using the analysis of process parameters, isotherms and kinetics modeling. The lignocellulosic biomass of *Caryota urens* inflorescence and *Pterospermum acerifolium* shells considered for the further elaborate discussion towards elimination of hexavalent chromium and methylene blue from aqueous system.

***Caryota urens* inflorescence as biosorbent for the removal of hexavalent chromium** (Rangabhashiyam and Selvaraju 2015)

Caryota urens widely distributed in India, Malaysia, Myanmar, Nepal and Sri Lanka. The inflorescence biomass of *Caryota urens* cleaned using distilled water, and further dried in hot air oven. The dried biomass subjected to blender and sieved to the suitable particle size ranges. The prepared biosorbent used for the removal of hexavalent chromium without any further modifications. In the batch biosorption system, the parameters of initial solution pH, biosorbent particle size, biosorbent dosage, agitation speed, initial metal concentration and temperature were analyzed. The next level of study performed in a glass column under continuous biosorption process using 1 g of biosorbent at the optimal process conditions.

The results of scanning electron microscope image of biosorbent showed that the surface morphology was smooth surface areas with long ridges and offers large surface area for biosorption of hexavalent chromium. The reusability of the biosorbent carried out using recycles of biosorption–desorption up to five times. The results showed decrease in biosorption capacity of the biosorbent was with the increase of recycles from one to five. Revealed that structural changes on the biosorbent surface as well retention of Cr(VI) ions in biosorbent intrapores caused the decrease in biosorption capacity. The continous biosorption process performed with initial hexavalent chromium concentration of 100 mg/L, packed with the biosorbent of 1 g and initial solution pH 2.0. Biosorbent of 1 g found potential to treat 175 mL of influent hexavalent chromium solution.

Caryota urens inflorescence as biosorbent found effective towards the elimination of hexavalent chromium from aqueous solutions. In comparison of other biosorbents reported in literature, the biosorbent prepared using *Caryota urens* inflorescence showed higher biosorption capacity of 100 mg/g (Table 2) for treating hexavalent chromium. The process of hexavalent chromium removal using the *Caryota urens* inflorescence biosorbent influenced by parameters of initial solution pH, initial Cr(VI) concentration, biosorbent size, biosorbent dosage, agitation speed and temperature. The equilibrium data better fitted with the isotherms of Langmuir and Redlich–Peterson. The experimental data followed pseudo-second-order kinetics model.

Table 2

Comparison of uptake capacities of different reported biosorbents with *Caryota urens* inflorescence waste biomass for the removal of hexavalent chromium.

	Initial	Biosorption

Biosorbent	solution pH	capacity (mg/g)
Sal sawdust	3.5	9.55
Hevea Brasilinesis	2.0	44.05
Lathyrus sativus husk	2.0	44.5
Sugarcane bagasse	2.0	1.76
Eupatorium adenophorum	1.0	55.19
Acacia albida	2.0	2.98
Euclea schimperi	2.0	3.94
Neem sawdust	2.0	58.82
Mango sawdust	2.0	37.73
Mangrove leaves	4.5–5.5	8.87
Water lily	4.5–5.5	8.44
Swietenia mahagoni fruit shell	3.0	2.30
Caryota urens inflorescence waste biomass	2.0	100

Removal of methylene blue and hexavalent chromium using native and modified *Pterospermum acerifolium* shells (Rangabhashiyam and Balasubramanian 2018)

The *Pterospermum acerifolium* belongs to Sterculiaceae family, distributed in the Southeast Asia, sub-Himalaya and outside Himalayan valley. The common names of this plant includes are Matsakanda, Muchukunda, Karnikara and Kanakchampa. *Pterospermum acerifolium* reported in some of medical applications in the treatment of leucorrhoea, leprosy, smallpox, haemostasis, tumors, etc (Preety et al., 2012; Manisha et al., 2011). The shells of *Pterospermum acerifolium* were used in three different forms of native, modified with sulfuric acid and phosphoric acid, respectively and tested for the removal of Methylene blue and hexavalent chromium from aqueous solutions. The scanning electron microscope image of native adsorbent showed heterogeneous structure without presence of pores. The sulfuric acid activated biomass showed higher pores with different shapes and sizes. The activation of biomass using phosphoric acid presented honeycomb structure.

The adsorption efficiencies and uptake capacities by the adsorbents found influenced by the process parameters of solution pH, adsorbent dosage, initial adsorbate concentration, and temperature. The isotherm model of Langmuir better described the equilibrium data of the batch adsorption towards the removal of Methylene blue and hexavalent chromium. The maximum adsorption capacity of 125, 166 and 250 mg/g using native, sulfuric acid and phosphoric acid modified biomass were found towards Methylene blue removal. In case of hexavalent removal, adsorption capacity of 76.92, 142 and 111 mg/g, were found using native, sulfuric acid and phosphoric acid modified biomass, respectively.

Conclusions

The contamination of environment due to synthetic dyes and heavy metals discharge from the industrial effluents are major concern in developing countries. The industrial sectors are backbone for the country economy as well. Therefore, proper treatment technology needs to be adopted to combat the issue of environmental deterioration. The technology must be economical, eco-friendly and sustainable. Considering these factors, our research explored biomasses of *Caryota urens* inflorescence, *Ficus auriculata* leaves, *Swietenia mahagoni* shell, *Sterculia guttata* shell, *Enteromorpha* sp., Carica papaya wood, deoiled cakes of *Jatropha* sp., *Ricinus* sp., and *Pongamia* sp., *Pterospermum acerifolium* shells, *Cladophora* sp., Musa sp. peel (MSP), *Aegle marmelos* shell, etc. for the sequestration of wastewater pollutants. The utilization of waste biomass facilitate the reduction of cost associate with disposal of waste and also transform to adsorbents, which can be substituted for commercial activated carbon towards application of industrial wastewater treatment.

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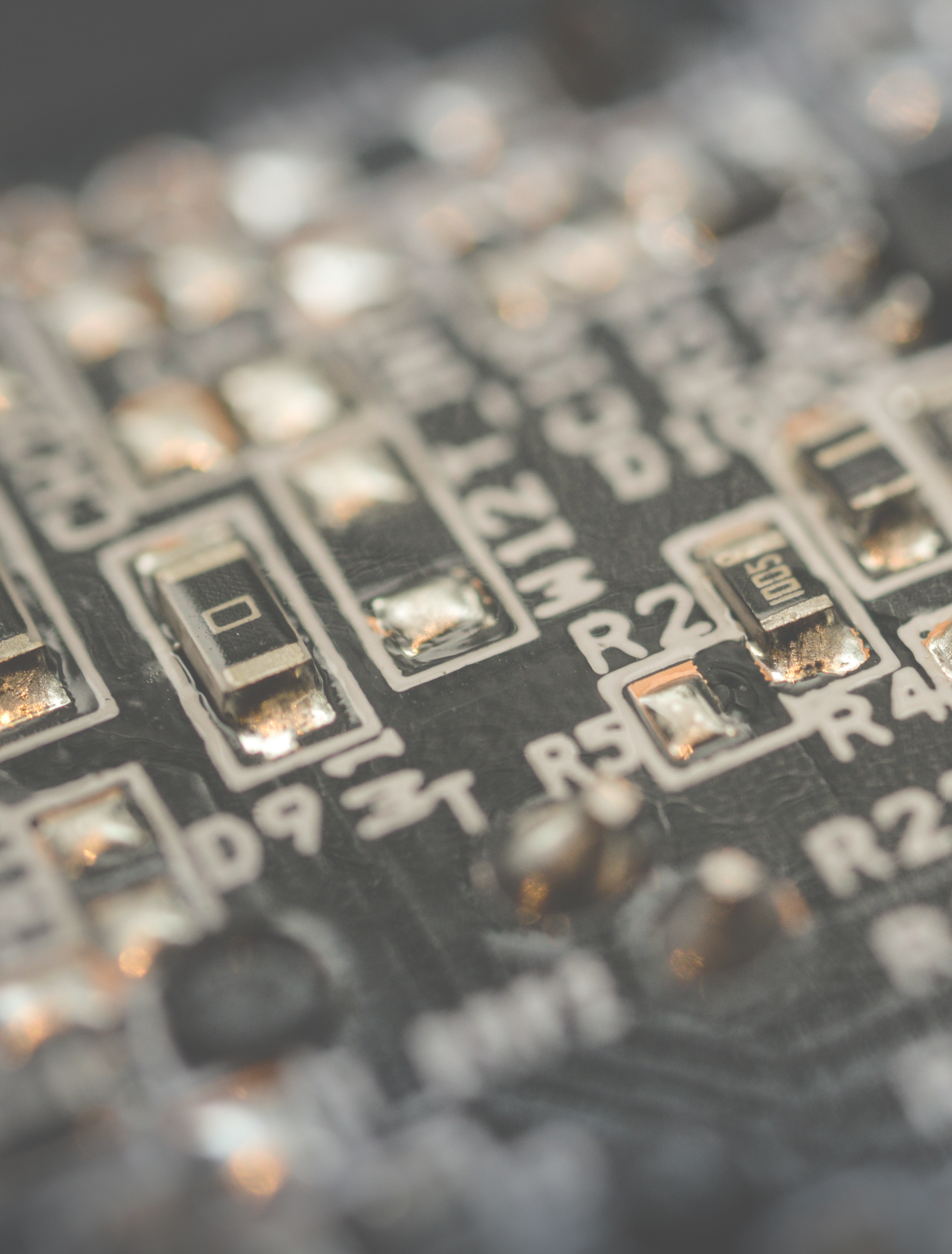
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