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PLANT EXTRACTS FOR PURIFICATION OF INDUSTRIAL WASTE WATER- A REVIEW

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Abstract

The present review provides a comprehensive analysis of metal ions being removed from industrial wastewater by using plant extracts. This review contains several plant parts such as bark, seeds, flower, fruits, plant wastes such as fruit wastes, vegetable peels, rice husk and shells etc. which have been used for purification of water. These organic materials show good participation for removing Cd, Pb, Ni, Zn and Cu metal ions and these plant products are biodegradable. These plant products have stimulated new gateways for the production of renewable, low cost and sustainable adsorbents for water treatment applications. The present review compiles data for last decade.

Introduction

Recent days numerous industries are growing to boost their economic competitiveness. Several industries like textile, fertilizer, paper, tanneries, batteries and pesticides etc. release their waste into water. This waste water is contaminated with heavy metals. These toxic metals are released in water during various processes of industries as well as mining like activities. This contaminated water causes serious threat to humans, plants and aquatic life which leads to several diseases like dermatitis, mutations, nausea, chronic asthma, human carcinogen, coughing, kidney damage and renal disorder etc. mainly due to their non-degradability and toxicity. Therefore, removal of these toxic metals from waste water is essential before these are mixed up with unpolluted natural waterbodies. The objective of removing toxic metals from wastewater has grown day by day due to rapid industrialization. The development of new industrial technologies and modernization of society means more discharge of waste water. Various methods such as ion-exchange (Alyu *et al.*, 2009), chemical precipitation (Tangahu *et al.*, 2011), reverse osmosis (Shahalam *et al.*, 2002), coagulation (Samrani *et al.*, 2008) etc. had been used to remove toxic metal ions from wastewater. But these methods are expensive and have the inability to remove metals at low concentration and maintaining wastewater treatment system especially in the case of rural areas. So, recently attention is towards a method which is less expensive and ecofriendly. Plant products are used to remove toxic metal ions from wastewater. Plant products such as fruits, leaves, seeds and wastes like peels, bark is used to remove Pb, Cr, Cu and Ni like toxic metals from waste water. Various researchers have proved the potential of plants to decrease the levels of toxic metals ions from contaminated water (Table 1).

Purification of water by Using leaves extract of various plants

B.V. Babu *et al.* in 2008 used neem leaves to remove Cr (VI) ions from aqueous solution (Babu *et al.*, 2008). Research revealed that activated neem leaves was added to stock solution of Cr (VI) in conical flask, allowed to work at desired temperature and pH. The result showed that removal capacity of neem leaves for Cr ions increases at given conditions of batch experiment.

P. Goyal *et al.* used *Saraca indica* leaf powder to remove Pb ions from water (Goyal *et al.*, 2008). This was done by adding powdered form of bio material in Erlenmyer flask containing contaminated water containing lead ions at specific temperature, pH. Then solution was filterate by whatsman filter paper to determine the amount of lead ions from filterate by AAS after experiment.

Oboh *et al.* used low cost biomaterial such as neem leaves to remove toxic metals viz. Zn (II), Cu (II), Pb (II) and Ni (II) ions from wastewater (Oboh *et al.*, 2009). The removal of heavy metal ions was done by adding powdered form of neem leaves in conical flask containing metal ions allow to shaken on magnetic stirrer at room temperature, specific pH. After contact time solution undergo filtration to determine removal efficiency of metal ions by AAS. Research stated that neem leaves had great efficiency to remove copper ions and low removal efficiency for lead ions.

Yuru Chen *et al.* used leaves of tobacco to remove Cr (VI) ions from contaminated water (Chen *et al.*, 2009). The experiment done by extracting dry mass of tobacco leaves with volatile solvent, which continue to added in stock solution containing heavy metal ion for batch studies. Experimental result showed that tobacco leaves has a great potential to form complex with metal ions analyzed by FTIR.

Boudrahem *et al.* in 2011 (Boudrahem *et al.*, 2011) used leaves of Date tree to treat contaminated water containing Pb (II). The experiment was conducted by adding powdered dried form of leaves of date tree in contaminated water containing lead ions for desired time and temperature. Then solution was filtered and analyze its filterate for determine the concentration of metal ions in it.

Ruchi Pandey *et al.* in stated that Kush grass (Desmostachya bipinnata) and bamboo leaves (Bambusa arundinacea) had great efficiency to remove Cd (II) ions from aqueous solution (Pandeya *et al.*, 2015). The chemically modified dried form of bio material was adding to conical flask containing stock solution of heavy metal ions on thermostatic stirrer for desired time period, temperature. AAS technique used for filterate of resultant solution to determine % removal of cadmium ions from water. The experimental result showed that Kush grass leaves has comparatively high uptake capacity of cadmium ions as compared to bamboo leaves.

Shinomol George *et al.* stated that leaves of *Moringa oleife*ra had great efficiency to remove toxic metal ions i.e. Cr, Cd, Pb and Ni ions from industrial effluent (George *et al.*, 2016). To remove these toxic metal ions, dried form of citric acid modified leaves of Moringa added to conical flask, that contain contaminated wastewater. Further, apparatus allowed to work at desired temperature and pH. UV and AAS technique used for filterate of resultant solution to determine % removal of toxic metal ions from it.

Sreelakshmi C.D *et al.* showed that leaves of Ocimum Sanctum (Tulsi) had great efficiency to treat water containing Fe (II) and Pb (II) ions (Sreelakshmi *et al.*, 2017). Dried form of biomaterial added to different glass tubes containing stock solution of different metal ions at magnetic stirrer for desired time period, temperature and pH. Metal removal efficiency was determined by AAS. The experimental result showed that tulsi leaves had comparatively high removing capacity of lead ions as compared to iron ions from water.

Priyanka Tiwari *et al.* used inexpensive biomaterial leaves of Urtica dioica to treat water containing Cu (II), Zn (II) and Pb (II) ions (Tiwari *et al.*, 2017).

D.Sai Seetha Rama Raj *et al.* used low cost-effective biomaterial leaf powder of papaya to treat wastewater containing Pb (II) ions. To remove toxic metal ions from water dried mass of bio material added in contaminated water for batch experiment. AAS technique used for filterate of resultant solution showed that papaya leaves had great efficiency to bind lead ions (Seetha *et al.*, 2012).

Using bark of plants

Shinomol George K *et al.* stated that bark of Moringa oleifera had great efficiency to remove toxic metal ions i.e. Cr, Cd, Pb and Ni ions from industrial effluent. To remove these toxic metal ions, dried form of citric acid modified bark of Moringa added to conical flask, that contain contaminated wastewater. Further, apparatus allowed to work at desired temperature and pH. UV and AAS technique used for filterate of resultant solution to determine % removal of toxic metal ions from it (George *et al.*, 2016).

Use of fruit and vegetable peel

Tehseen Aman *et al.* used potato peel for treatment of wastewater containing Cu (II) ions released by industries. For this work dried carbonized form of potato peel was added to conical flask containing stock solution of copper ions, which allowed to shaken at desired stirring speed, temperature and pH. Suitable spectroscopic technique used on resultant solution revealed that potato peel had great efficiency to remove copper ions from wastewater (Aman *et al.*, 2008).

Dhiraj Sud *et al.* in 2008 used agricultural wastes such as peels of banana, apple, orange, shells of coconut, hazelnut, groundnut, walnut, stalks of cotton, grapes, sunflower, seed hulls of cotton, soybean and waste tea leaves etc. to remove toxic metals viz. Pb(II), Cu(II), Cd(II), Zn(II), Cr(VI) from wastewater. Removal of metal ions from wastewater was due to formation of complex with functional groups of agricultural waste products. The complex formation done by FTIR spectroscopy technique (Sud *et al.*, 2008).

El-ashtoukhy *et al.* used peel of pomegranate to reduce Pb (II) and Cu (II) from waste water, by adding treated pomegranate peel in stock solution of metal ion solution (El-ashtoukhy *et al.*, 2008).

Flavio A. Pavan *et al.* reported that Ponkan peel had great efficiency to remove Pb (II) ions from contaminated water (Pavan *et al.*, 2008). Muhammad Iqbal *et al.* stated that peel of grapes fruit had great efficiency to remove Ni (II) and Zn (II) from wastewater. Powdered form of bio material added to aqueous solution containing metal ions in conical flask on magnetic stirrer for particular time at specific temperature and pH. The resultant mixture allows to undergo filteration and then metal concentration in filterate analyzed by AAS. FTIR technique used in this research stated that functional groups such as carboxylic and hydroxyl groups had great efficiency to bind Ni and Zn ions from wastewater (Iqbal *et al.*, 2009).

Muhammad Iqbal *et al.* used peel of mango to remove Cu (II), Ni (II) and Zn (II) ions from contaminated water. Experiment was carried by adding dry form of mango peel to conical flask containing stock solution of heavy metal ions, which allowed to shaken on stirrer specific time, temperature and Ph. Result of experiment showed that maximum adsorption was showed towards copper ions and minimum towards zinc ions which was determined by FTIR technique which predict that functional groups of bio material had great efficiency to bind toxic metal ions from wastewater (Iqbal *et al.*, 2013).

Munusamy Thirumavalavan *et al.* used peels of fruit such as banana, lemon to remove toxic metal ions such as Ni (II), Cd (II), Cu (II), Zn (II) and Pb (II) ions from wastewater. The experimental result showed that lemon peel has comparatively high uptake capacity of heavy metal ions as compared to banana and orange peels. Copper and nickel ions adsorbed maximum by fruit peels (Thirumavalavan *et al.*, 2010).

Amit Bhatnagar *et al.* used waste lemon peel to treat aqueous solution containing toxic metal ions of cobalt. To remove these toxic metal ions from water dried form of lemon peel added to stoppered tubes containing this aqueous solution of cobalt. Which allow to shaken at stirrer for specific time at desired temperature and pH. Then resultant solution put for filtration using filter paper for AAS for determine the percentage removal of cobalt ions from water (Bhatnagar *et al.*, 2010).

Jamil Anwar *et al.* reported that banana peel is potent plant part to remove Pb and Cd ions from wastewater. Research carried out by preparing dried form of banana peel. Then this dried form was used for batch experiment to remove metal ions from contaminated water and used specific type of spectroscopic technique to determine the % removal of metal ions from water. This research showed that Cd was adsorbed more than Pb (Anwar *et al.*, 2010).

Hema Krishna *et al.* used peel of Mosambi fruit for removal of Ni (II) ions from wastewater. The process was done by adding dried form of mosambi fruit peel in conical flask containing contaminated water. The solution was analyzed by UV spectroscopy technique. Then conical flask stirrer for desired period of time at specific conditions of temperature (Krishna *et al.*, 2011).

Renata S. D. Castro *et al.* further used banana peel to remove Cu (II) and Pb (II) ions from wastewater. They added definite amount of fine minced banana peel added in aqueous solution of Cu and Pb ions in different centrifuge tubes centrifuge tubes. These tubes stirrer for desired time period at specific temperature. Experimental study showed that carboxyl and amine functional groups present in banana peel bind Cu and Pb metal ions from contaminated water, which was analyzed by DRIFT technique (Castro *et al*., 2011).

Mohamed R. Lasheen *et al.* studied the efficiency of orange peel for removal of Pb(II), Cd(II) and Cu(II) ions from contaminated water by adding chemically modified dried form of orange peel to glass tube containing aqueous solution of metal ions, which allowed to shaken for specific time limit at desired temperature and pH. Result indicate that orange peel is novel biomaterial for reduce heavy metal ions from contaminated water (Lasheen *et al*., 2012).

Parineeta Pandhram *et al.* reported that leaves of neem as low cost adsorbent had great potential to remove chromium ions from industrial wastewater. Experiment was done by adding suitable amount of dried form of neem leaves in flask containing contaminated water for batch studies at desired conditions of time period, temperature and pH. UV study reveals Cr removal capacity by bio material Pandhram *et al*., 2013).

Ruchi Pandey *et al.* reported that peel of Cucumis sativus (cucumber) has good Cd (II) ions removal capacity from wastewater. The acid modified form of dried mass of biomaterial added to stock solution of metal ions, which allow to stand for desired time period, temperature and pH. Spectroscopic study reveals Cd removal capacity by bio material (Pandey *et al*., 2014).

Ramakrishna Mallampati *et al.* stated that fruit peels of dragon fruit, avocado and hamimelon fruit has a great potential as an inexpensive biomaterial to treat water containing toxic metal ions such as Ni (II) and Pb (II). Dried form of fruit peel was treated with strong alkali to break ester bond of bio material, which further added to stoppered glass tube containing contaminated water at orbital shaker at desired range of temperature (Mallampati *et al*., 2015).

Zubera Naseem *et al.* reported that peel of Trapa bispinora (Singhara) is potant low cost effective bioproduct to remove uranium from waste water. Dried form of bio material added to conical flask containing wastewater. Experiment conducted on thermostatic shaker at specific temperature range. Suitable technique used to determine % removal of metal ions from wastewater r (Naseem *et al*., 2015).

Naba Kumar *et al.* used environmentally friendly biomaterial banana peel to remove fluoride from water. The work was carried out by adding dried form of bio material in conical flask containing fluoride ions, further allowed to stand at desired temperature and time. The % removal of ions from solution determined by Ion selective electrode method (Mondal *et al*., 2017).

Use of stem of plants

Monika Jain *et al.* stated that sunflower stem is a potent plant part to remove Cr(VI) ions from aqueous solution by adding dried mass of formaldehyde treated sunflower stem to it in conical flask. The apparatus allowed to shaken on magnetic stirrer at specific temperature and $_{P}$H for removal of toxic metal ions from water. The removal % of metal ions was determined by FTIR spectroscopy method (Jain *et al*., 2009).

A Arun Kumar *et al.* reported that stem of Vitex negundo had great efficiency to remove Cd (II) ions from wastewater by preparing activated carbon adsorbent for removal of Cd ions at specific temperature and pH (Kumar *et al*., 2017).

Use of husk of plants

Ajay Kumar Meena *et al.* used mustard husk to treat aqueous solution containing Pb (II) and Cd (II) ions. The powered dried form of bio material added to different conical flask containing different stock solution of different concentration of metal ions, which shaken on magnetic stirrer at definite temperature and pH. Removal of metal ions depend upon pH factor. At pH 6 maximum removal of Pb ions take place whereas at pH 4 maximum removal of Cd ions take place. Research concluded that capacity of mustard husk to remove heavy metal ions from its aqueous solution is maximum for Pb then for Cd ions (Meena *et al*., 2008).

Waleska E. Oliveira *et al.* used coffee husk to treat aqueous solution containing heavy metal ions such as Cu(II), Cd(II), Zn(II) and Cr(VI). They used formaldehyde treated coffee husk for removal of heavy metal ions from their stock solution. The chemically treated bio material added to contaminated water in conical flask at magnetic stirrer for specific temperature, pH. This review showed that coffee husk had maximum removal capacity for copper ions and minimum for Zinc ions determined by atomic adsorption spectroscopy method (Oliveira *et al*., 2008).

Li-Hua Wang *et al.* used hull of rice for removal of Cd ions from wastewater (Wang *et al*., 2010).

Muhammad Iqbal *et al.* used green bean husk to remove Sb (III) from wastewater. In experiment dried mass of bean husk was added in conical flask containing appropriate solution of antimony ions stirred at room temperature and desired pH. FTIR analysis stated that amino, Carboxyl and alcoholic functional groups of bio material responsible for removal of Sb ions from contaminated water (Iqbal *et al*., 2013).

Kailash P. Patel *et al.* used husk of pigeon and rice pea to remove Cd (II) and Zn (II) ions. To remove toxic metal ions from water dried mass of pigeon husk and husk of rice pea added in different conical flask of contaminated water containing Cd and Zn ions. Which allow to shaken on magnetic stirrer at desired temperature and pH conditions. AAS technique used for filterate of resultant solution which determine the removal concentration of metal ions. Comparative result showed that husk of pigeon pea had maximum potential to remove Zn and Cd ions from wastewater as compared to rice husk (Patel *et al*., 2013).

Haitham Ahmed El-Araby *et al.* reported use of inexpensive biomaterial Sesame husk to remove Cu (II) ions from wastewater by adding dried form of husk in conical flask containing stock solution of copper ions at specific stirring rate, temperature, time. Then filtration done to determine % removal of metal ions by AAS technique (El-araby *et al*., 2017).

Use of seeds of plant

Egila *et al.* studied that agricultural waste such as African spinach and papaya seed had a great potential to treat wastewater containing heavy metal ions viz. Mn (II) and Pb (II). Experiment was conducted by adding these dry masses of bio material in different stoppered bottles containing aqueous solution of Mn and Pb metal ions. Which further shaken for desired temperature and pH. Then its filterate analyze by AAS. Experimental result showed that papaya seed had high removal capacity than African spinach (Egila *et al.*, 2011).

Jonathan Gonzalo Flores-Garnica *et al.* in 2013 used cost effective biomaterial i.e. seeds of Litchi to treat wastewater containing Ni (II) ions. Dried form of biomaterial added to conical flask containing stock solution of nickel ions at magnetic stirrer for desired time period, temperature and pH. Metal removal efficiency was determined by UV spectroscopy.

Kailash P. Patel *et al.* used husk of pigeon and rice pea to remove Cd (II) and Zn (II) ions. To remove toxic metal ions from water dried mass of pigeon husk and husk of rice pea added in different conical flask of contaminated water containing Cd and Zn ions. Which allow to shaken on magnetic stirrer at desired temperature and conditions. AAS technique used for filterate of resultant solution which determine the removal concentration of metal ions. Comparative result showed that husk of pigeon pea had maximum potential to remove Zn and Cd ions from wastewater as compared to rice husk (Flores-garnic *et al.*, 2013).

Ravikumar *et al.* stated that Seeds of *Moringa oleifera* had great efficiency to remove heavy metal ions viz. Cd, Cr, Cu and Pb ions from contaminated water. For removal of metal ions from contaminated water, dried form of bio material added to it, which allowed to shaken on magnetic stirrer for desired temperature, pH. Result showed that copper ions were maximum removed by Moringa oleifera (Ravikumar *et al.*, 2013).

Samiksha V. Ashtikar *et al.* stated that seeds of mango had great potential to treat wastewater containing Cu (II) ions. The dried mass of mango seeds added to stock solution of metal ions, which allow to shaken on magnetic stirrer at desired time period, temperature and pH. Spectroscopic study reveals that seeds of mango has good Cu removal capacity than other ions (Ashtikar *et al.*, 2014).

Use of shells of plants

Erol Pehlivan *et al.* used shells of almond, walnut and hazelnut to remove Cr (VI) from wastewater. Batch studies done by adding of different type of dried powdered form of bio material in suitable amount of aqueous solution containing chromium ions in conical flask on magnetic stirrer at desired pH and temperature. Then resultant mixture allows for filtration and analyzed with AAS. Which showed that Hazelnut had great capacity to remove Chromium ions from wastewater then walnut and almond shells (Pehlivan *et al.*, 2008).

Vazquez *et al.* stated that chesnut shell is potent plant part to remove Cd ions from industrial wastewater. Powdered form of chestnut shell added to aqueous solution containing cadmium ions in conical flask on magnetic stirrer for particular time at specific temperature and pH. The resultant mixture was allowed to undergo filtration and then metal concentration in filterate analyzed by AAS (Vazquez *et al.*, 2010).

Anna Witek-Krowiak *et al.* used peanut shell to remove Cr (III) and Cu (II) ions from contaminated water. The experimental result showed that peanut shell has high uptake capacity for chromium ions (Witek-krowiak *et al.*, 2011).

Koel Banerjee *et al.* in stated that watermelon shell was low cost-effective biomaterial to remove Cu (II) ions from contaminated water by adding dry powdered form of shell in conical flask containing copper ions for shaken at desired range of temperature and pH (Banerjee *et al.*, 2012).

Tasrina Rabia Choudhury *et al.* stated that groundnut shell had great potential to remove Cr (III) ions from contaminated water. The experiment was carried out by adding dried form of bio mass to conical flask containing industrial wastewater which allowed to shaken for given conditions of temperature, stirring speed, contact time and pH. Then AAS technique used for filterate of resultant solution to calculate the % removal of metal ions from industrial wastewater (Choudhury *et al.*, 2012).

Ponnusamy Senthil Kumar *et al.* stated that shell of cashew nut had great efficiency to treat wastewater containing Cd (II), Zn (II), Ni (II) and Cu (II) ions (v *et al.*, 2012).

Chandran Prince Jebadass Isaac *et al.* stated that shell of Annona squamosal is great potent plant part for removal of Pb (II) and Cd (II) ions from contaminated water (Isaaca *et al.*, 2013).

Galeshi *et al.* reveals that shell of kiwi had great potential to remove Ni (II), Cd (II) and Pb (II) ions from contaminated water. Chemically modified dried form of biomaterial added to different glass tubes containing stock solution of different metal ions at magnetic stirrer for desired time period, temperature and pH. Metal removal efficiency was determined by AAS. The experimental result showed the order of maximum adsorption capacity of these toxic metal ion as Pb > Ni > Cd by kiwi shell from water (Galeshi *et al.*, 2017).

Use of roots of plant

Jia-Chuan Zheng *et al.* used roots of water hyacinth for removal of Cu (II) from wastewater. For the removal of heavy metal ions from water, dried mass of water hyacinth added to conical flask containing stock solution of copper metal ions allowed to shake for specific time on stirrer at desired temperature and pH. Removal of copper ions from water was due to formation of metal complex with functional group of water hyacinth root which was determined by FTIR and XPS techniques (Zheng *et al.*, 2009).

Bieby Voijant Tangahu *et al.* used cost effective material such as roots of Brassica, Populus and Pteris to treat wastewater containing As, Hg and Pb metal ions. Result showed that these inexpensive biomaterials is an attractive and low-cost bio sorbent for removal of toxic metal ions (Tangahu *et al.*, 2011).

Satya Narain *et al.* examined the efficiency of aquatic plants such as Water hyacinth in removal of Cr and Cd ions from wastewater. Result showed that water hyacinth has maximum potential to remove Cr ions as compared to Cd ions from contaminated water (Narain *et al.*, 2011).

Jothi Ramalingam *et al.* used roots of Calotropis Procera to treat wastewater containing Cd (II) and Pb (II) ions. To remove toxic metal ions from water dried mass of bio material added in different conical flask of contaminated water containing Cd and Pb ions. Which allow to shaken on magnetic stirrer at desired temperature and pH conditions. UV technique used for filterate of resultant solution which determine the removal concentration of metal ions (Ramalingam *et al*., 2013).

Use of straw/bran

Bo Zhu *et al.* used soybean straw to remove Cu (II) ions from wastewater. In experiment dried mass of citric acid treated soyabean straw added in conical flask containing appropriate solution of copper ions stirred at room temperature and desired pH. Research stated that with the increase in pH of aqueous solution, Adsorption capacity of soybean straw increases for copper ions. The concentration of metal ions after experiment were determined by atomic adsorption spectrophotometer (Zhu *et al*., 2008).

Erol Pehlivan *et al.* used barley straw to treat aqueous solution containing Cu (II) and Pb (II). Review showed that dried mass of barley straw added to aqueous solution containing heavy metals ions in conical flask on magnetic stirrer for particular time at specific temperature and pH. The result showed that with the increase in pH of aqueous solution, removal efficiency for metal ions also increases and removal capacity of barley straw was maximum for lead ions as compared to copper ions determined by atomic adsorption spectroscopy method (Pehlivan *et al*., 2009).

V.B.H. Dang *et al.* used straw of to remove Cd (II) and Cu (II) ions from wastewater. The experiment done by adding prepared dried form of straw to conical flask containing stock solution allowed to shaken on stirrer for desired time, temperature and pH. Result showed wheat straw had great efficiency to remove cadmium ions as compared to copper ions from wastewater, which was determined by AAS (Dang *et al*., 2009).

Crystian Gonclaves *et al.* used rice straw to remove Hg (II), Cu (II), Cd (II) and Zn (II) ions. Review showed that dried mass of rice straw added to aqueous solution containing heavy metals ions in conical flask on magnetic stirrer for particular time at specific temperature and pH. The removal capacity of bio material increased for metal ions which was determined by atomic adsorption spectroscopy method (Goncalves *et al*., 2009).

Umar Farooq *et al.* studied wheat bran for removal of toxic metal ions such as Pb (II), Cu (II), Cd (II), Zn (II), Cr (II), Ni (II) ions from aqueous solution (Farooq *et al*., 2010).

Use of flower of plants

Rupal Sharma *et al.* used dried mass of cotton plant flower (*Gossypium herbacium*) in conical flask containing Cr (III) ions from wastewater. To remove these ions from water, apparatus shaken for given time period at desired temperature and pH. IR technique used for analyze complex of metal ions with functional group of bio material (Sharma *et al*., 2011).

Jimoh, T.O. *et al.* used dried form of Flamboyant Flower to remove Co (II), Pb (II) and Cu (II) from industrial wastewater. The dried form of bio mass added to conical flask containing industrial wastewater which allowed to shaken for given conditions of temperature, stirring speed, contact time and pH. Then AAS technique used for filterate of resultant solution to calculate the % removal of metal ions from industrial wastewater (v *et al*., 2012).

Use of fruit pulp/cortex

Kevin Kelly-Vargas *et al.* used different fruit cortex i.e. banana, orange and lemon to remove Cu, Pb and Cd ions from wastewater. Experiment was done by adding dried mass of different fruit peel in different glass column containing aqueous solution of metal ions. Then, elution was done to determine % removal of metal ions from water. This process repeated again to decrease the metal concentration from water. Experimental result showed that banana cortex has great efficiency to remove lead ions and least efficiency for copper ions from wastewater (Kelly-vargas *et al*., 2012).

Lauren *et al.* used curcurbita (Pumpkin) to remove toxic metal ions from water. Result showed that pumpkin has good Pb ions removal capacity than Cr ions (https://www.amnh.org/ learn-teach / curriculum-collections / young-naturalist-awards/winning-essays/2012/pumpkin-purifier-removal-of-toxic-metals-from-water-using-curcurbita-agricultural-waste).

Khairia Al-Qahtani *et al.* used fruit cortex of kiwi, tangerine and banana to treat water containing Zn (II), Cd (II) and Cr (III) ions. The dried form of bio material added to conical flask containing contaminated water on magnetic stirrer at desired temperature. Further ICP technique used to determine the concentration of metal ions from filterate. Result reveals that kiwi and tangerine fruits cortex remove more heavy metal ions as compared to banana fruit cortex. The order of maximum adsorption capacity of these toxic metal ions on kiwi and tangerine was Cd > Cr > Zn and on banana was Cr > Cd > Zn (Al-Qahtani *et al*., 2016).

Use of grass

Adesola Babarinde *et al.* studied that Elephant grass has a great potential as a low-cost biomaterial to treat decontaminated water containing Pb (II) ions. For removal of metal ions from water dried form of bio material added to it, allowed to stand on water bath for desired temperature, pH. Their result showed that elephant grass had great efficiency to form metal complex, which was determined by FTIR technique on resultant solution (v *et al*., 2010).

Piyush Gupta *et al.* studied aquatic plants such as water hyacinth, vetiver grass and water lettuce for removal of water contaminants from water bodies (Gupta *et al*., 2012).

Hassan *et al.* reported that jute fibers have good potential for removal of toxic metal ions such as Cu (II), Ni (II), Pb (II) and Fe (II) ions from wastewater. Result reveals that Iron metal ion was removed maximum by jute fibers (Hassan *et al*., 2015).

Mario H. Gonzaleza *et al.* stated that coconut coir has great potential to remove Cr (VI) ions from contaminated water. This was done by adding powdered form of bio material in Erlenmeyer flask containing contaminated water containing Cr ions at specific temperature, pH. Then solution was filterate by Whatman filter paper to determine the amount of lead ions from filterate by ICP-OES after experiment. Research reveals that treatment of contaminated water done by coir at pH at 1,2,3,4 and 5 using sulphuric acid solution. Result showed that Cr (VI) adsorption increases with decreasing pH (Gonzaleza *et al*., 2008).

Leila Chebil Ajjabi *et al.* used dried marine green macroalgae to treat wastewater containing Zn (II) and Cu (II) ions. From paper it is reviewed that desired amount of dry powdered form of bio material added to solution containing toxic metal ions, which allowed to shaken for desired time on stirrer by giving appropriate conditions of temperature and pH . Review paper stated that Zinc ions were maximum removed from water as compared to copper ions, which was determined by filtering the resultant solution and its filterate analyzed by AAS to determine the percentage removal of metal ions from contaminated water (Chebil *et al*., 2009).

Gurgel Leandro Alves Vinicius *et al.* in 2009 used sugarcane bagasse to remove Pb (II), Cd (II) and Cu (II) ions from contaminated water. Dried mass of bio material allowed for Soxhlet apparatus with volatile solvents to remove its lignin. Then desired amount of dried form of modified agricultural material added in contaminated water at specific time, temperature and pH. The AAS result of resultant solution showed that maximum removal capacity by sugarcane bagasse towards lead ions from contaminated water (Gurgel *et al*., 2009).

Lina Agoubordeet *al.* used saw dust to remove Cu (II) and Zn (II) ions from industrial wastewater. FTIR technique showed that carboxylic and alcoholic functional groups present in it binds metal ions present in wastewater. Result showed that maximum adsorption was done with zinc by sawdust as compared to copper ions (Agouborde *et al*., 2009). Ali Ahmadpour *et al.* used almond green hull to remove Cr (VI) ions from wastewater (Sahranavard *et al*., 2011).

Egila *et al.* studied that agricultural waste such as African spinach and papaya seed had a great potential to treat wastewater containing heavy metal ions viz. Mn (II) and Pb (II). Experiment was conduct by adding these dry masses of bio material in different stoppered bottles containing aqueous solution of Mn and Pb metal ions. Which further shaken for desired temperature and pH. Then its filterate analyze by AAS. Experimental result showed that papaya seed had high removal capacity than African spinach (Egila *et al*., 2011).

Sachin M. Kanawade *et al.* studied that cork powder has a great efficiency to treat industrial wastewater containing Zn (II) ions by adding sample of bio material in conical flask containing contaminated water, which further shaken at desired time period, temperature. Then % removal of metal ions from water determined by suitable spectroscopic technique (Kanawade *et al*., 2011).

Anirudhan *et al.* used coconut buttons to remove ions of toxic metal viz. Cu (II), Pb (II) and Hg (II) from industrial wastewater. Experiment was conducted by preparing carbonized form of sulphuric acid treated coconut buttons in muffle furnace. Further carbonized form of bio material added to conical flask containing stock solution of metal ions, which allow to shaken at magnetic stirrer for desired conditions i.e. temperature, time and pH. FTIR and AAS technique used for determine the % removal of metal ions from water. Experimental result stated that Pb was removed maximum and copper was least removed from wastewater (Anirudhan *et al*., 2011).

Rahul Negi *et al.* used onion and garlic waste for removal of heavy metal ions and FTIR was used. The onion and garlic wastes were used to remove Sn, Fe, Hg, As, Cd ions from wastewater. Dried form of agricultural material added to conical flask containing different stock solution of different metal ions on magnetic stirrer at desired range of temperature. Result of ICP technique reveals that removal of metal ions take place in order of $Pb^{2+} > Sn^{2+} > Fe^{2+} > Hg^{2+} > As^{2+} > Cd^{2+}$ by bio products from wastewater (Negi *et al*., 2012).

Archana Dixit *et al.* used dry weeds of Eichhornia crassipes to remove various toxic metal ions Cd, Pb, Cr and Zn ions from aqueous solution. Experiment was conducted by preparing the extract of dried form of bio material in Soxhlet apparatus in suitable solvent, which further converted to dried form and added in conical flask containing aqueous solution of metal ions. Then, solution was studied for batch experiment by giving desired conditions of temperature, pH. FTIR technique analyze the complex of metal ions with functional groups of bio material (Dixit *et al*., 2015).

Aravind *et al.* reported use of environmentally friendly Pigeon pea pods for removal of Ni (II) ions from contaminated water. Dried form of pigeon pods was added to conical flask containing stock solution of nickel ions on thermostatic stirrer at specific stirring speed, desired temperature and pH conditions. Further FTIR technique was used for filterate of resultant solution (Aravind *et al*., 2015).

Donadkar *et al.* reported that Datura Stramonium is potent plant for removing toxic metals from wastewater or water bodies. Finely divided dried mass of bio material used in wastewater containing heavy metal ions for batch studies for adsorption of metal ions (Donadkar *et al*., 2016).

Use of other parts of plants

Mario H. Gonzaleza *et al.* stated that coconut coir has great potential to remove Cr (VI) ions from contaminated water. This was done by adding powdered form of bio material in Erlenmyer flask containing contaminated water containing Cr ions at specific temperature, pH. Then solution was filterate by Whatman filter paper to determine the amount of lead ions from filterate by ICP-OES after experiment. Research reveals that treatment of contaminated water done by coir at pH at 1,2,3,4 and 5 using sulphuric acid solution. Result showed that Cr (VI) adsorption increases with decreasing pH (Gonzaleza *et al*., 2008).

Leila Chebil Ajjabi *et al.* used dried marine green macroalgae to treat wastewater containing Zn (II) and Cu (II) ions. From paper it is reviewed that desired amount of dry powdered form of bio material added to solution containing toxic metal ions, which allowed to shaken for desired time on stirrer by giving appropriate conditions of temperature and pH. Review paper stated that Zinc ions were maximum removed from water as compared to copper ions, which was determined by filtering the resultant solution and its filterate analyzed by AAS to determine the percentage removal of metal ions from contaminated water (Chebil *et al*., 2009).

Leandro Vinicius Alves Gurgel *et al.* used sugarcane bagasse to remove Pb (II), Cd (II) and Cu (II) ions from contaminated water. Dried mass of bio material allowed for Soxhlet apparatus with volatile solvents to remove its lignin. Then desired amount of dried form of modified agricultural material added in contaminated water at specific time, temperature and pH. The AAS result of resultant solution showed that maximum removal capacity by sugarcane bagasse towards lead ions from contaminated water (Gurgel *et al*., 2009).

Lina Agouborde*et al*. used saw dust to remove Cu (II) and Zn (II) ions from industrial wastewater. FTIR technique showed that carboxylic and alcoholic functional groups of saw dust bind metal ions present in wastewater. Result showed that maximum adsorption was done with zinc by sawdust as compared to copper ions (Agouborde *et al*., 2009).

Sachin M. Kanawade *et al*. studied that cork powder has a great efficiency to treat industrial wastewater containing Zn (II) ions by adding sample of bio material in conical flask containing contaminated water, which further shaken at desired time period, temperature. Then % removal of metal ions from water determined by suitable spectroscopic technique (Kanawade *et al*., 2011).

Anirudhan *et al*. in 2011 used coconut buttons to remove ions of toxic metal viz. Cu (II), Pb (II) and Hg (II) from industrial wastewater. Experiment was conducted by preparing carbonized form of sulphuric acid treated coconut buttons in muffle furnace. Further carbonized form of bio material added to conical flask containing stock solution of metal ions, which allow to shaken at magnetic stirrer for desired conditions i.e. temperature, time and pH. FTIR and AAS technique used for determine the % removal of metal ions from water. Experimental result stated that Pb was removed maximum and copper was least removed from wastewater (Anirudhan *et al*., 2011).

Saman Khan *et al*. used peel of citrus to remove Cu (II). From paper it is reviewed that desired amount of chemically modified dried powdered form of bio material added to solution containing toxic metal ions, which allowed to shaken for desired time on stirrer by giving appropriate conditions of temperature and pH . Review paper stated that copper ions were maximum removed from water, which was determined by filtering the resultant solution and its filterate analyzed by AAS to determine the percentage removal of metal ions from contaminated water (Khan *et al*., 2013).

Anies Suhaida Mohd Naspu *et al*. used Salvinia (water moss) to remove Cd ions from aqueous solution. The citric acid modified dried form of bio material added to conical flask containing stock solution of Cd ions, which allow to stand at specific temperature. FTIR used for determine complex of metal functional group of bio material (Naspu *et al*., 2014).

Sneh Lata *et al*. reported the use of chemically modified rice husk for removal of toxic metal ions Pb, Cd, Zn, Ni and As from water taken in conical flask. Which allow to work at desired time period, temperature and neutral pH. Study reveals that husk of rice has good Cd removal capacity than other ions (Lata *et al*., 2014).

Archana Dixit *et al*. used dry weeds of *Eichhornia crassipes* to remove various toxic metal ions Cd, Pb, Cr and Zn ions from aqueous solution. Experiment was conducted by preparing the extract of dried form of bio material in Soxhlet apparatus in suitable solvent, which further converted to dried form and added in conical flask containing aqueous solution of metal ions. Then, solution was studied for batch experiment by giving desired conditions of temperature, pH. FTIR technique analyze the complex of metal ions with functional groups of bio material (Dixit *et al*., 2015).

Aravind *et al*. in reported use of environmentally friendly Pigeon pea pods for removal of Ni (II) ions from contaminated water. Dried form of pigeon pods was added to conical flask containing stock solution of nickel ions on thermostatic stirrer at specific stirring speed, desired temperature and pH conditions. Further FTIR technique was used for filterate of resultant solution (Aravind *et al*., 2015).

Donadkar *et al*. reported that *Datura Stramonium* is potent plant for removing toxic metals from wastewater or water bodies. Finely divided dried mass of bio material used in wastewater containing heavy metal ions for batch studies for adsorption of metal ions (Donadkar *et al*., 2016).

Ayhan Demirbas *et al*. used agriculture waste such as peanut hull, coconut husk, pine bark, rice hull and corncob etc. to remove heavy metal ions such as Cu (II), Cd (II), Ni (II), Cr (III), Cr (VI). Review showed that agriculture waste had maximum removal efficiency for Cu (II) among all heavy metal ions (Demirbas *et al*., 2008).

Wan NWS *et al*. stated that plant waste had great efficiency to remove heavy metal ions from wastewater. Result reveals that plants such as papaya wood, teak leaf powder etc. having low cost, good adsorption capacity. We review from this research that adsorption of Cu and Pb were done by these plant wastes (Wan *et al*., 2008).

O.K. Olayinka studies revealed that coconut husk had great potential to remove Ni (II) and Cr (VI) from wastewater. The removal of heavy metal ions was done by adding powdered form of chemically modified coconut husk in different conical flask containing Ni and Cr metal ions allow to shaken on magnetic stirrer at room temperature, specific pH. After contact time solution undergo filtration to determine removal efficiency of metal ions by AAS. The experimental result showed that coconut husk removes 90% for Cr (VI) and 97% for Ni (II) from contaminated water (Olayinka *et al*., 2009).

Sahranavard *et al*. used almond green hull to remove Cr (VI) ions from wastewater (Sahranavard *et al*., 2011).

Want qi *et al*. reported that low cost agricultural wastes such as potato peels, coffee husk, orange peels and black gram husk had great efficiency to remove toxic metal ions i.e. Pb (II), Ni (II) ions from aqueous solution (Wang *et al*., 2011).

M.A. Barakat *et al*. stated that inexpensive and environmentally friendly bio products such as coconut shell, rice husk etc. had good efficiency to remove toxic metal i.e. Zn (II), Cr (VI), Ni (II) from industrial wastewater (Barakat *et al*., 2011).

Mohamed H.H. Ali *et al*. used inexpensive biomaterial such as vegetables (turnip, carrot, spinach, potato), fruits (cucumber, tomato) and cereals (wheat, barley) etc. to remove heavy metal ions viz. Cu, Zn, Pb, Cd, Hg, Mn and Fe from water. Experimental result stated that leafy vegetables had greater efficiency to remove heavy metal ions from water (Ali *et al*., 2012).

Vikashni Nand *et al*. used seeds of Moringa oleifera, corn, urad, cowpeas and peanuts to remove toxic metal ions such as Pb (II), Cu (II), Zn (II), Cd (II) ions from contaminated water. Experiment was done by adding suitable amount of different seed paste in different flask containing contaminated water at room temperature. Result showed that seeds of Moringa oleifera had maximum potential to remove heavy metal ions from wastewater as compared to other seeds. Cu were the maximum metal removed by *Moringa oleifera* (Nand *et al*., 2012).

Rahul Negi *et al*. used onion and garlic waste for removal of heavy metal ions and FTIR was used. The onion and garlic wastes were used to remove Sn, Fe, Hg, As, Cd ions from wastewater. Dried form of agricultural material added to conical flask containing different stock solution of different metal ions on magnetic stirrer at desired range of temperature. Result of ICP technique reveals that removal of metal ions take place in order of $Pb^{2+} > Sn^{2+} > Fe^{2+} > Hg^{2+} > As^{2+} > Cd^{2+}$ by bio products from wastewater (Negi *et al*., 2012).

Ideriah *et al*. used palm fruit fiber to treat water containing Cu, Cr, Pb and Ni ions (Ideriah *et al*., 2012). Nguyen *et al*. used agricultural wastes such as fruits, bark, leaves, flower, stem, shell etc. for removal of heavy metal ions from wastewater (Nguyen *et al*., 2013).

Nour T. Abdel-Ghani *et al*. reported the use of cost-effective biomaterial such as bark of Acacia, leaves of castor, sugarcane bagasse, almond leaves, ficus leaves, peels of pumice etc. to treat wastewater containing various heavy metal ions viz. Cu, Cd, Cr, Pb etc (Abdel-Ghani *et al*., 2014).

Sabreen Alfarra *et al*. showed the use of inexpensive bio products such as seeds of Litchi, Moringa oleifera, shells of coconut, leaves of Moringa, Cinnamomum camphora etc. to remove heavy metal ions from contaminated water. Study reveals that leaves of Moringa oleifera has good Cd removal capacity then other bio products (Alfarra *et al*., 2014).

Abdel-Raouf MS *et al*. reported that inexpensive biomaterial such as seeds of tulsi, waste tea, cotton seed hull etc. had great efficiency to remove heavy metal ions Cr, Pb and Hg from wastewater (Abdel-Raouf *et al*., 2017; Table 2 and 3).

Conclusions

It is evident from the review that plant biomaterials have great potential to remove heavy metals from industrial waste water. All research now a days is going towards herbal products i.e. use of plants biomaterials in various fields like cosmetics, purification of water etc. The results reveal that plants are better source to remove heavy metals as compared to engineering techniques. The engineering techniques developed are no doubt costly as well as waste a lot of water for example the present RO systems.

It has been revealed that use of plants or plant waste material such as bark, leaves, seeds, root, stem, flower, husk, peel etc. has great contribution to treat wastewater containing heavy metal ions i.e. Cu, Zn, Ni, Cd, Cr, Pb ions which are human health hazardous and harmful for aquatic life also. This further proves that these low cost and environment friendly agricultural wastes have been replacing earlier conventional water treatment techniques such as co-agulation, precipitation etc., which were expensive and cannot used in rural areas. It is evident that these natural products have great efficiency to remove toxic metal ions from industrial effluents before adding to water sources. The make shift of research from engineering towards plant materials is very evident and well proven from the above review.

Table 1: Sources and toxicities of various heavy metal ions.

Heavy metal ions	Sources of contaminaton	Toxicities	References
Cr	Electroplating, leather tanning, textiles industries.	Headache, vomiting, nausea, carcinogenic, diarrhea.	Gadd *et al*., 2010
Pb	Paint, Solder and consumer products	Damage the foetal brain, disease of kidney and nervous system	Chen *et al*., 1998; Papandreou *et al*., 2007
Cd	Mining, smelting, Ni-Cd batteries and plastics	Kidney damage, human carcinogen, renal disorder	Environmental Health Criteria 221: Zinc. World Health Organization Geneva 2001;11:171-176; Singh *et al*., 2006,
Cu	Mining, industries discharge	Wilson disease, Liver damage, insomnia	Sharma *et al*., 1995
Ni	Stainless steel, Ni-Cd batteries	Nausea, chronic asthma, human carcinogen, coughing	Robertson *et al*., 1989
Zn	Galvanization process, paints, batteries and alloys	Neurological signs and increased thirst, depression	Manohar *et al*., 2002

Table 2: Various plant parts used to remove different toxic metal ions from wastewater

Leaves		
Plant used	**Metal ions removed**	**Reference no.**
Azadirachta indica (Neem)	Cr (VI)	Babu *et al*., 2008; Nguyen *et al*., 2013
Saraca asoca (Ashoka tree)	Pb (II)	Goyal *et al*., 2008
Azadirachta indica (Neem)	Cu (II), Ni (II), Zn (II), Ni (II)	Oboh *et al*., 2009
Nicotiana tobacum (Tobacco)	Cr (VI)	Chen *et al*., 2009

Phoenix dactylifera (Date tree)	Pb (II)	Boudrahem *et al*., 2011
Bambuseae (Bamboo)	Cd (II)	Pandeya *et al*., 2015
Moringa oleifera (Munaga)	Cr, Cd, Pb, Ni	George *et al*., 2016
Ocimum sanctum (Tulsi)	Pb, Cd, Cu, Zn, Ni, Cd	Sreelakshmi *et al*., 2017
Urtica dioica (Stinging needle)	Zn (II), Pb (II), Cu (II)	Tiwari *et al*., 2017
Carica papaya (Papaya)	Cd (II)	Seetha *et al*., 2012
Bark		
Plant used	**Metal ions removed**	**Reference no.**
Moringa oleifera (Munaga)	Ni	George *et al*., 2016

Peel		
Plant used	**Metal ions removed**	**Reference no.**
Solanum tuberosum (Potato)	Cu (II)	Aman *et al*., 2008
Punica granatum (Pomegranate)	Pb (II), Cu (II)	El-ashtoukhy *et al*., 2008
Citrus poonensis (Ponkan)	Pb (II)	Pavan *et al*., 2008
Mangifera indica (Mango)	Ni (II), Zn (II), Cu (II)	Iqbal *et al*., 2013
Vitis vinifera (Grapes)	Zn (II), Ni (II)	Iqbal *et al*., 2009
Citrus sinensis (Orange)	Cu, Ni, Zn, Cd, Pb	Thirumavalavan *et al*., 2010
Musa pudica (Banana)	Cu, Ni, Zn, Cd, Pb	Thirumavalavan *et al*., 2010
Citrus limon (Lemon)	Cu, Ni, Zn, Cd, Pb	Thirumavalavan *et al*., 2010; Bhatnagar *et al*., 2010
Citrus	Cd (II)	Sud *et al*., 2008
Citrus limetta (Mosambi)	Ni (II)	Krishna *et al*., 2011
Citrus sinensis (Orange)	Cd (II), Cu (II), Pb (II)	Lasheen *et al*., 2012
Citrus	Cu	Pandhram *et al*., 2013
Cucumis sativus (Cucumber)	Cd (II)	Pandey *et al*., 2014
Persea americana (Avocando)	Ni (II), Pb (II)	Mallampati *et al*., 2015
Cucumis melo (Hamimelon)	Ni (II), Pb (II)	Mallampati *et al*., 2015
Hylocereus undatus (Dragon fruit)	Ni (II), Pb (II)	Mallampati *et al*., 2015
Musa pudica (Banana)	Cd (II)	Anwar *et al*., 2010; Castro *et al*., 2011
Trapa bispinora (Singhara)	Uranium	Naseem *et al*., 2016
Musa pudica (Banana)	Fluoride	Mondal *et al*., 2017
Stem		
Plant used	**Metal ions removed**	**References no.**
Helianthus annuus (Sunflower)	Cr (VI)	Jain *et al*., 2009
Vitex negundo (Chaste tree or Chinese five leaf)	Cd (II)	Kumar *et al*., 2017

Husk		
Plant used	**Metal ions removed**	**References no.**
Brassica nigra (Mustard)	Cd (II), Pb (II)	Meena *et al*., 2008
Coffea (Coffee)	Cr (VI), Cu (II)	Oliveira *et al*., 2008
Phaseolus (Green bean)	Sb	Iqbal *et al*., 2013
Oryza sativa (Rice)	Ni (II)	Patel *et al*., 2013
Cajanus cajan (pigeon pea)	Ni (II)	Patel *et al*., 2013
Oryza sativa (Rice hull)	Cd	Wang *et al*., 2010
Sesanum indicum (sesame)	Cu (II)	El-araby *et al*., 2017
Vigna mungo (Black gram)	Pb (II), Ni (II)	Wang *et al*., 2011

Seed		
Plant used	**Metal ions removed**	**References no.**
Moringa oleifera	Cd, Cr, Pb, Zn	Patel *et al*., 2013
Litchi chinensis (Litchi)	Ni (II)	Flores-garnic *et al*., 2013
Moringa oleifera	Cu, Pb, Cd, Cr	Ravikumar *et al*., 2013
Mangifera indica (Mango)	Cu	Ashtikar *et al*., 2014
Carica papaya (Papaya)	Mn (II), Pb (II)	Egilae *et al*., 2011
Shell		
Plant used	**Metal ions removed**	**References no.**
Juglans (Walnut)	Cr (VI)	Pehlivan *et al*., 2008
Prunus dulcis (Almond)	Cr (VI)	Pehlivan *et al*., 2008
Corylus (Hazelnut)	Cr (VI)	Pehlivan *et al*., 2008
Castanea (Chestnut)	Cd	Vazquez *et al*., 2010
Arachis hypogaea (Peanut)	Cu (II), Cr (III)	Witek-krowiak *et al*., 2011
Arachis hypogaea (Groundnut)	Cr (III)	Choudhury *et al*., 2012
Citrullus lanatus (Watermelon)	Cu	Banerjee *et al*., 2012
Actinidia deliciosa (Kiwi)	Pb, Ni, Cd	Galeshi *et al*., 2017
Anacardium occidentale (Cashew nut)	Zn (II), Ni (II), Cd (II), Cu (II)	Senthil *et al*., 2012
Annona squamosal (Sugar apple)	Pb, Cd	Isaaca *et al*., 2013
Roots		
Plant used	**Metal ions removed**	**References no.**
Eichhornia crassipes (Water hyacinth)	Cu	Zheng *et al*., 2009
Brassica campestris	As, Pb, Hg	Tangahu *et al*., 2011
Populus deltoides (Eastern cotton wood)	As, Pb, Hg	Tangahu *et al*., 2011

Pteris aberrans	As, Pb, Hg	Tangahu *et al*., 2011
Eichhornia crassipes (Water hyacinth)	Cr, Cd	Narain *et al*., 2011
Calatropis procera	Pb (II), Cd (II)	Ramalingam *et al*., 2013
Straw/Barn		
Plant used	**Metal ions removed**	**Reference no.**
Glycine max (Soyabean)	Cu	Zhu *et al*., 2008
Triticum (Wheat)	Cd (II), Cu (II)	Dang *et al*., 2009
Hordeum vulgare (Barley)	Cu (II), Pb (II)	Pehlivan *et al*., 2009
Triticum (Wheat bran)	Ni, Zn, Cr, Cd, Pb, Cu	Farooq *et al*., 2010
Oryza sativa (Rice)	Cu (II), Zn (II), Cd (II), Hg (II)	Goncalves E*et al*., 2009
Flower		
Plant used	**Metal ions removed**	**Reference no.**
Delonix regia (Flamboyant)	Co (II), Cu (II), Pb (II)	Jimoh *et al*., 2012
Gossypium (Cotton)	Cr (III)	Sharma *et al*., 2011
Pulp/ Cortex		
Plant used	**Metal ions removed**	**References no.**
Citrus sinensis (Orange)	Cu, Pb, Cd	Kelly-vargas *et al*., 2012
Citrus limon (Lemon)	Cu, Pb, Cd	Kelly-vargas *et al*., 2012
Musa pudica (Banana)	Cu, Pb, Cd	Kelly-vargas *et al*., 2012
Cucurbita (Pumpkin)	Pb, Cr	https://www.amnh.org/learn-teach/curriculum-collections/young-naturalist-awards/winning-essays/2012/pumpkin-purifier-removal-of-toxic-metals-from-water-using-curcurbita-agricultural-waste
Actinidia deliciosa (Kiwi)	Cr (III), Zn (II), Cd (II)	Al-Qahtani *et al*., 2016
Citrus tangerine (Tangerine)	Cr (III), Zn (II), Cd (II)	Al-Qahtani *et al*., 206
Musa pudica (Banana)	Cr (III), Zn (II), Cd (II)	Al-Qahtani *et al*., 206
Grass		
Plant used	**Metal ions removed**	**References no.**
Pennisetum purpureum (Elephant grass)	Pb (II)	Babarinde *et al*., 2010
Chrysopogon zizanioides (Vetiver grass)	Heavy metal ions	Gupta *et al*., 2012
Desmostachya bipinnata (Kush grass)	Cd (II)	Hassan *et al*., 2015
Others		
Plant used	**Metal ions removed**	**References no.**
Cocos nucifera (Coconut coir)	Cr (VI)	Gonzaleza *et al*., 2018
Prunus dulcis (Almond green hull)	Cr (VI)	Sahranavard *et al*., 2011
Cajanus cajan (Pigeon pea pod)	Ni (II)	Aravind *et al*., 2015
Saccharum officinarum (Sugarcane bagasse)	Pb (II), Cu (II), Cd (II)	Gurgel *et al*., 2009

Cocos nucifera (Coconut bottons)	Pb, Hg, Cu	Anirudhan *et al*., 2011
Spinacia oleracea (Spinach stalk)	Mn, Pb	Egila *et al*., 2011
Allium cepa & Allium sativum (Onion & garlic wastes)	Pb, Sn, Fe	Negi *et al*., 2012
Cork powder	Zn (II)	Kanawade *et al*., 2011
Eichhornia crassipes weeds (water hyacinth)	Cr, Cd, Pb, Zn	Dixit *et al*., 2015
Datura stramonium (Datura)	-	Donadkar *et al*., 2016
Amaranthus cruentus (African spinach)	Mn, Pb	Egila *et al*., 2011
Saw dust	Cu, Zn	Agouborde *et al*., 2009
Marine green macro algae	Cu (II), Zn (II)	Chebil *et al*., 2009

Table 3: Percentage of toxic metal ions removed from wastewater by using different plant parts/wastes

Leaves			
Plant used	**Metal ions removed**	**% of metal ions removed**	**References no.**
Neem	Cr (VI)	62.97mg/g	Babu *et al*., 2008
Saraca (Ashoka tree)	Pb (II)	95.37%	Goyal *et al*., 2008
Neem	Cu (II) Ni (II) Zn (II) Pb (II)	76.8% 67.5% 58.4% 41.45%	Oboh *et al*., 2009
Tobacco	Cr (VI)	113.2mg/g	Chen *et al*., 2009
Date tree	Pb (II)	94%	Boudrahem *et al*., 2011
Bamboo	Cd (II)	92.08%	Pandeya *et al*., 2015
Moringa	Cr, Cd, Pb, Ni	-	George *et al*., 2016
Ocimum (Tulsi)	Fe (II) Pb (II)	73.62% 95.63%	Sreelakshmi *et al*., 2017
Urtica dioica	Zn (II), Pb (II), Cu (II)	-	Tiwari *et al*., 2017
Papaya	Pb (II)	90.52%	Seetha *et al*., 2012
Bark			
Plant used	**Metal ions removed**	**% of metal ions removed**	**References no.**
Moringa	Ni (by bark) (by leaf)	53.8% 23%	George *et al*., 2016

Peel			
Plant used	**Metal ions removed**	**% of metal ions removed**	**Reference no.**
Potato	Cu (II)	99.8%	Aman *et al*., 2008
Citrus	Cd (II)	-	Sud *et al*., 2008
Pomegranate	Pb (II), Cu (II)	-	El-ashtoukhy *et al*., 2008
Ponkan	Pb (II)	-	Pavan *et al*., 2008
Grapes	Zn (II), Ni (II)	98%	Iqbal *et al*., 2009
Mango	Ni (II) Zn (II) Cu (II)	39.75% 28.21% 46.09%	Iqbal *et al*., 2013
Orange	Cu Ni Zn Cd Pb	70.92mg/g 80mg/g 27.86mg/g 54.64mg/g 37.87mg/g	Thirumavalavan *et al*., 2010
Banana	Cu, Ni, Zn, Cd, Pb	-	Thirumavalavan *et al*., 2010
Lemon	Co	22.0 mg/g	Bhatnagar *et al*., 2010
Banana	Cd (II)	-	Anwar *et al*., 2010; Castro *et al*., 2011
Mosambi	Ni (II)	73.82%	Krishna *et al*., 2011
Orange	Cd (II) Cu (II) Pb (II)	81.03% 89.57% 99.5%	Lasheen *et al*., 2012
Citrus	Cu	84.85%	Pandhram *et al*., 2013
Cucumber	Cd (II)	-	Pandey *et al*., 2014
Avocando	Ni (II), Pb (II)	9.45 mg/g 7.89 mg/g	Mallampati *et al*., 2015
Hamimelon	Ni (II) Pb (II)	-	Mallampati *et al*., 2015
Dragon fruit	Pb (II) Ni (II)	-	Mallampati *et al*., 2015
Trapa bispinora (Singhara)	Uranium	38.46 mg/g	Naseem *et al*., 2016
Banana	Fluoride		Mondal *et al*., 2017

Stem			
Plant used	**Metal ins removed**	**% of metal ions removed**	**References no.**
Sunflower	Cr (VI)	81.7%	Jain *et al*., 2009
Chinese five leaf (Vitex negundo)	Cd (II)	42.29%	Kumar *et al*., 2017

Husk			
Plant used	**Metal ions removed**	**% of metal removed**	**Reference no.**
Mustard	Cd (II) Pb (II)	42.85 mg/g 30.48 mg/g	Eena *et al*., 2008
Coffee	Cr (VI) Cu (II) Cd (II) Zn (II)	86% 90% 85% 79%	Oliveira *et al*., 2008
Rice hull	Cd	-	Wang *et al*., 2010
Black gram	Pb (II), Ni (II)	-	Anwar *et al*., 2010
Green bean	Sb (III)	97%	Iqbal *et al*., 2013
Pigeon pea	Zn (II) Cd (II)	55% 65%	Patel *et al*., 2013
Sesame	Cu (II)	95.13%	El-araby *et al*., 2017

Seed			
Plant used	**Metal ions removed**	**% of metal ions removed**	**Reference no.**
Papaya	Mn (II) Pb (II)	4.1 mg/g 3.63 mg/g	Egila *et al*., 2011
Litchi	Ni (II)	66.62 mg/g	Flores-garnic *et al*., 2013
Moringa	Cd (II) Zn (II)	65% 55%	Patel *et al*., 2013
Moringa	Cu Pb Cd Cr	95% 93% 76% 70%	Ravikumar *et al*., 2013
Mango	Cu	69%	Ashtikar *et al*., 2014

Shell			
Plant used	**Metal ions removed**	**% of metal ions removed**	**References no.**
Walnut	Cr (VI)	85.32%	Pehlivan *et al*., 2008
Almond	Cr (VI)	55%	Pehlivan *et al*., 2008

Hazelnut	Cr (VI)	88.46%	Pehlivan *et al.*, 2008
Chestnut	Cd	98.6%	Vazquez *et al.*, 2010
Peanut	Cu (II) Cr (III)	25.39 mg/g 27.86 mg/g	Witek-krowiak *et al.*, 2011
Groundnut	Cr (III)	87.5%	Choudhury *et al.*, 2012
Watermelon	Cu (II)	85%	Banerjee *et al.*, 2012
Kiwi	Pb, Ni, Cd	-	Galeshi *et al.*, 2017
Cashew nut	Zn (II), Ni (II), Cd (II) and Cu (II)	-	Senthil *et al.*, 2012
Annona squamosal	Pb, Cd	-	Isaaca *et al.*, 2013
Roots			
Plant used	**Metal ions removed**	**% of metal ions removed**	**References no.**
Water hyacinth	Cu	22.7 mg/g	Zheng *et al.*, 2009
Brassica	As, Pb, Hg	-	Tangahu *et al.*, 2011
Populus	As, Pb, Hg	-	Tangahu *et al.*, 2011
Pteris	As, Pb, Hg	-	Tangahu *et al.*, 2011
Water hyacinth	Cr Cd	80.26% 71.28%	Narain *et al.*, 2011
Calatropis	Pb (II) Cd (II)	97% 96%	Ramalingam *et al.*, 2013
Straw/Bran			
Plant used	**Metal ions removed**	**% of metal ions removed**	**Reference no.**
Soyabean	Cu	0.76 mmole/g	Zhu *et al.*, 2008
Wheat	Cd (II) Cu (II)	27% More than 27%	Dang *et al.*, 2009
Barley	Cu (II) Pb (II)	4.64 mg/g 23.20 mg/g	Pehlivan *et al.*, 2009
Wheat bran	Ni, Zn, Cr, Cd, Pb, Cu	-	Farooq *et al.*, 2010
Rice	Cu (II) Zn (II) Cd (II) Hg (II)	0.128 mmole/g 0.132 mmole/g 0.133 mmole/g 0.110 mmole/g	Goncalves *et al.*, 2009

Flower			
Plant used	**Metal ions removed**	**% of metal ions removed**	**References no.**
Flamboyant	Co (II), Cu (II), Pb (II)	-	Jimoh *et al*., 2012
Cotton	Cr (III)	76%	Sharma *et al*., 2011
Pulp/ Cortex			
Plant used	**Metal ions removed**	**% of metal ions removed**	**References no.**
Orange	Cu, Pb, Cd	-	Kelly-vargas *et al*., 2012
Lemon	Cu, Pb, Cd	-	Kelly-vargas *et al*., 2012
Banana	Cu, Pb, Cd	57%	Kelly-vargas *et al*., 2012
Pumpkin	Pb Cr	77.5% 28.7%	https://www.amnh.org/learn-teach/curriculum-collections/young-naturalist-awards/winning-essays/2012/pumpkin-purifier-removal-of-toxic-metals-from-water-using-curcurbita-agricultural-waste
Kiwi	Cr (III) Zn (II) Cd (II)	98% 52% 73%	Al-Qahtani *et al*., 2016
Tangerine	Cr (III) Zn (II) Cd (II)	98% 52% 73%	Al-Qahtani *et al*., 2016
Banana	Cr (III) Zn (II) Cd (II)	55% 32% 44%	Al-Qahtani *et al*., 2016
Grass			
Plant used	**Metal ions removed**	**% of metal ions removed**	**References no.**
Elephant grass	Pb (II)	-	Babarinde *et al*., 2010
Vetiver grass	Heavy metal ions	-	Gupta *et al*., 2012
Kush grass	Cd (II)	94.18%	Pandeya *et al*., 2015
Others			
Plant used	**Metal ions removed**	**% of metal ions removed**	**References no.**
Coconut coir	Cr (VI)	58%	Babarinde *et al*., 2010
Almond green hull	Cr (VI)	94.14%	Sahranavard *et al*., 2011
Pigeon pea pod	Ni (II)	96.54%	Aravind *et al*., 2015
Sugarcane bagasse	Pb (II) Cu (II) Cd (II)	86.2mg/g 59.5mg/g 69.4mg/g	Gurgel *et al*., 2009

Coconut buttons	Pb Hg Cu	92.72mg/g	Anirudhan *et al*., 2011
Spinach stalk	Mn Pb	4.1 mg/g 3.63 mg/g	Egila *et al*., 2011
Onion & garlic wastes	Pb, Sn, Fe	-	Negi *et al*., 2012
Cork powder	Zn (II)	98%	Kanawade *et al*., 2011
Eichhornia crassipes weeds	Cr Cd Pb Zn	70% 92% 84% 42%	Dixit *et al*., 2015
Datura	-	-	Donadkar *et al*., 2016
African spinach	Mn Pb	-	Egila *et al*., 2011
Saw dust	Cu (II) Zn (II)	4.69 mg/g 5.59 mg/g	Agouborde *et al*., 2009
Marine green macro algae	Cu (II) Zn (II)	1.46 mmole/g 1.97 mmole/g	Chebil *et al*., 2009

Table and figure titles and legends:
Table 1: sources and toxicities of heavy metal ions
Table 2: Various plant parts used to remove different toxic metal ions from wastewater
Table 3: Percentage of toxic metal ions removed from wastewater by using different plant parts/wastes.

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