

# Removal of Ni (II) Ions from Wastewater by Raw and Modified Plant Wastes as Adsorbents: A Review

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**ABSTRACT:** Adsorption may be used to process significant metal particles in contaminated wastewater by various methods. The authors looked at various adsorbents for the expulsion of Ni(II) particles from an aquatic environment by different researchers. This paper aims to gather scattered open knowledge on a large variety of potentially persuasive adsorbents for the removal of Ni(II) particles. The present work on the usage of nickel by various natural/modified adsorbents was studied profoundly, for example, natural/modified agricultural waste, agricultural activated carbon, algae, fungal and, aquatic plant biomasses. This performance was assessed for removal efficiency and the sorbent capacity of used natural/waste materials in the system processes. Isotherm and kinetic study results were obtained from pH solution equilibrium contact time, adsorbent dose, initial metal concentration, and temperature of various adsorbents toward the Ni(II) particles to be examined. A documented analysis of reputed published papers revealed that industrial solid waste products, natural materials, and biosorbents have extraordinary Ni(II) adsorption ability from wastewater.

**KEYWORDS:** Wastewater; Adsorption; Nickel; Sustainable Natural/Modified Biosorbents.

## INTRODUCTION

Today, water utilization increases due to population and urbanization. With the expansion of industrialization, the amount of water consumed increased incredibly. Though freshwater assets are tainted by industrial activities,

it is hard to discover new freshwater sources because of depleting groundwater levels every day. In this regard, the utilization of freshwater by industries and the discharge of the resulting wastewater into the environment without

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| Treatment Technologies     |                                  |                                     |                             |                      |                                |
|----------------------------|----------------------------------|-------------------------------------|-----------------------------|----------------------|--------------------------------|
| <b>Membrane Separation</b> | <b>Electrochemical Treatment</b> | <b>Coagulation and Flocculation</b> | <b>Flotation</b>            | <b>Adsorption</b>    | <b>Chemical Precipitation</b>  |
| <b>Ultra Filtration</b>    | <b>Electro-oxidation</b>         |                                     | <b>Air Flotation</b>        | <b>Ion Exchange</b>  | <b>Hydroxide Precipitation</b> |
| <b>Nano Filtration</b>     | <b>Electro-coagulation</b>       |                                     | <b>Electro Flotation</b>    | <b>Chemisorption</b> | <b>Sulfide Precipitation</b>   |
| <b>Reverse Osmosis</b>     | <b>Electro-dialysis</b>          |                                     | <b>Biological Flotation</b> | <b>Physisorption</b> |                                |

Fig. 1: Various Wastewater Treatment Methods [Adapted from [21]].

treatment is a major issue [1,2]. Besides, contamination of water, and raw materials used and converted to waste materials by e industries are significant issues as regards the environment and economy. Hence, a superior treatment procedure is needed. Contamination in small concentrations is harmful to humans and other living things [3-5].

The removal of toxic metals from aqueous solutions requires several treatment methods. These procedures can be arranged into three groups: physical, chemical, and biological. Among expulsion forms, chemical precipitation [6], ion exchange [7], adsorption [8], membrane filtration [9, 10], liquid membrane [11], coagulation and flocculation [12], flotation [13,14], and electrochemical treatment [15] were examined by numerous analysts. Some treatment strategies were additionally applied in real-life ns [16, 17]. Reduction and precipitation, ion exchange and adsorption processes became forces to be reckoned with as they were the most used method to expel heavy metals from wastewater [18,19]. The methods referenced above have their characteristics as also advantages and disadvantages. All approaches had advantages and disadvantages when methods to extract nickel from water and wastewater were investigated. The rise of new alternatives is unavoidable, due to conventional and advanced treatment methods having disadvantages. Fig. 1 shows the different treatment methods involved in the removal of Ni (II) ions from wastewater and Fig. 2 describes the graphical layout of pollutant removal in adsorption techniques for wastewater systems using clay minerals as adsorbents [20].

Adsorption is a quick and cost-efficient disposal method for wastewater. The bulk of adsorbents can be regenerated and reused. The adsorption method includes a solid (adsorbent) and two phase-liquid stages. Mechanisms of adsorption involve adsorbing in the internal and external spheres. Additionally, these approaches are classified as specific and non-specific. Ion exchange, chemisorption, and physisorption mechanisms are explained in Fig. 3 [21,22]. Simple design and lower control systems, easy operating conditions, being cost-effective, metal selection, regeneration, lack of toxic sludge generation, metal recovery, and effective, high metal binding capacities, wide pH range even when metal ions are present to a concentration of 1 mg/L are the advantages while the production of waste products and, low selectivity are the disadvantages of the adsorption method [23].

Heavy metal pollutants and contamination are significant natural issues as they are harmful to living life forms and are not biodegradable [12,24]. Industries like metal plating, leather, textile industries, pesticides and fertilizers, battery manufacture, paints and pigments, electrical appliances, and chemical industries produce wastewater with diverse heavy metals, in addition to releasing effluents into the environment. Raw materials run out because of these utilizations, and wastewater with these materials leads to basic ecological issues by upsetting the ecosystem. Heavy metals, for example, Pb, Hg, Cu, Cd, Ni, and Cr are the most toxic pollutants found in wastewater [25,26]. The removal and recovery of heavy metals are significant issues and are now focused on both ecology and economy [27].

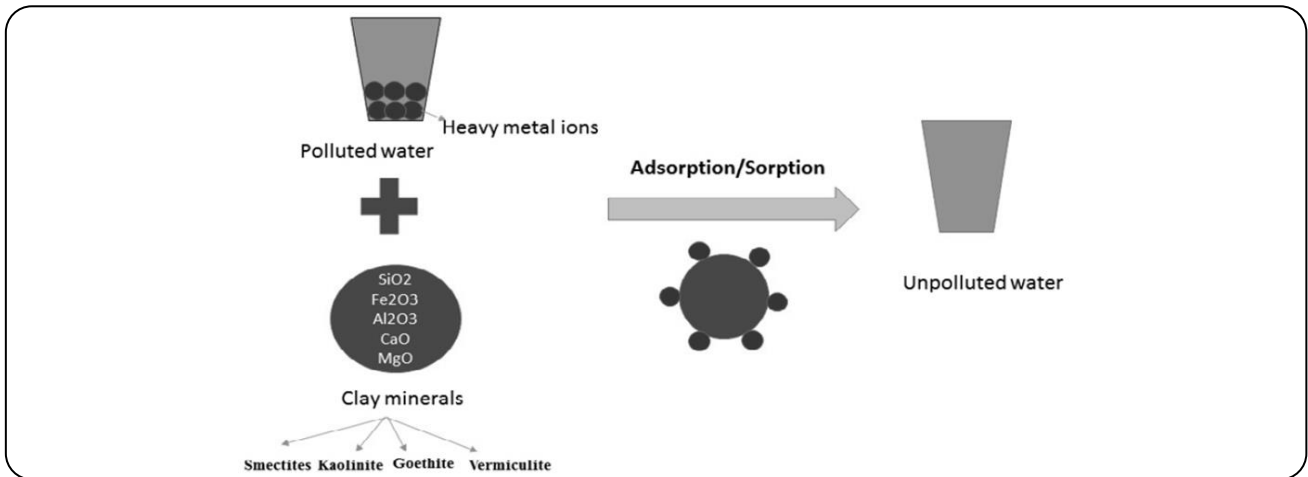


Fig. 2: Graphical layout of removal of pollutants using adsorption method [Adapted from [20]].

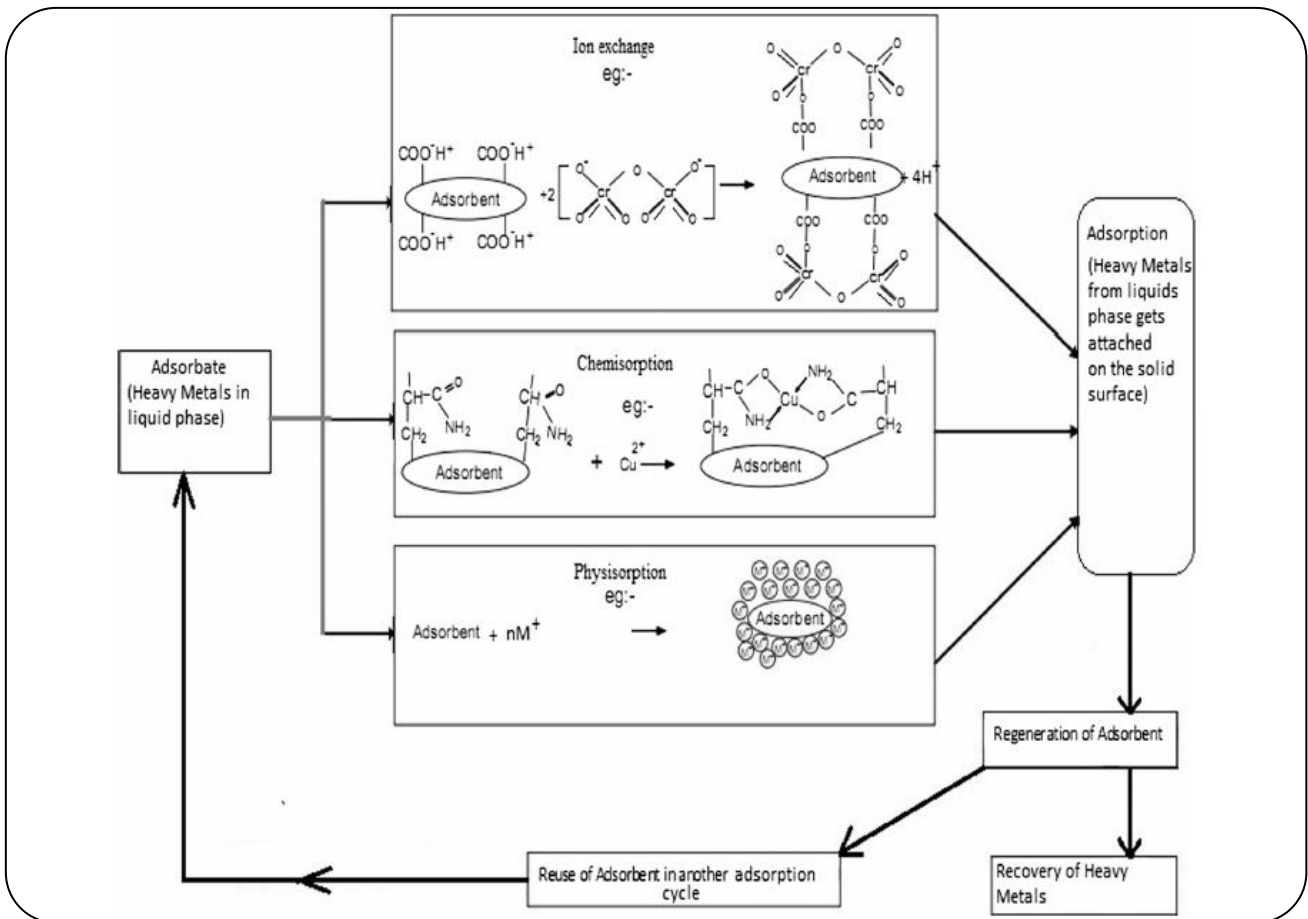


Fig. 3: Heavy metal adsorption mechanism on adsorbent's surface [Adapted from [21]].

Nickel is a silver-white shading metal among pollutants. It is strong, malleable and the richest component in the earth's crust. Ni(II) oxidation condition of nickel is significant in aqueous solutions. Nickel upgrades durability and protects against corrosion for

different metals in a wide temperature range when it is alloyed with them. This is a significant highlight of nickel. Nickel, its mixes, and composites are utilized in numerous modern and business applications [28,29]. Nickel is available normally in the water, soil, and the ocean salts

as sulfides, nitrates, and oxides. Its characteristic levels in water are in the range of 3 to 10 mg/L [30,31]. Nickel electroplating, leather tanning, battery production, paint formulation, painting, power plants, ceramic industries, enameling, and aircraft factories use nickel in their processes [32-34]. Exorbitant utilization of products with nickel leads to serious environmental issues. When people are exposed to high nickel-contaminated environmental media, various pathological issues affect humans. These include contact dermatitis, lung fibrosis, cancer, and cardiovascular, and kidney diseases [28]. Nickel fixation in water should be 0.02 mg/L for human utilization. Moreover, the most extreme nickel concentration in drinking water was determined as 0.5 mg/L by USEPA [35-37]. Recuperation and reuse of nickel are critical for recycling by which, ecological dangers can be minimized.

Various adsorbents are used to extract heavy metals from water and wastewater. Adsorbents should be selective for quick separation, favorable transport, and kinetic features, heat, chemical stability, and mechanical stabilization, resist fouling, have regenerating ability and low solubility to the liquid in contact, large surface area, and high efficiency, suitable pore size and volume, consistency, viable accessibility, easy regeneration, be cost-effective, environment friendly and have simple processing procedures. Adsorbents are classified as activated carbon, zeolite, biomaterials, nanomaterials, and polymer. The adsorbent surface can be modified chemically, physically, or by both [21]. In biosorption; fungus, bacteria, seaweed, higher plants, and others are used as dead biomass for different heavy metal expulsion effectively [38-41]. Regardless of whether the fundamental intention is to take up metal particles by utilizing biosorbents, biomasses ought to be safe enough to withstand outrageous working conditions. Different factors, for example, materials and treatment costs, availability, and permanent supply are significant for the selection of a biosorbent. A suitable sorbent must be compelling in wide pH and temperature ranges, should not deliver secondary pollutants and have solidness. Additionally, it must present a decent take-up limit about various ions, be economical, require no pretreatment, modifications, system design, removal of metal particles successively, and should fit for simple desorption and reuse. These necessities cannot be provided by biomasses found in nature. Subsequently, biosorbents can be custom-made to meet specialized technical requirements [42,43].

The point of this examination is to explore the removal of nickel ions from water and wastewater by adsorption which is a productive and practical treatment process. The outcomes from this research concerning adsorption were assessed to reveal insights for further adsorption. Biosorption component, impacts of pH, initial metal concentration, the mass of sorbent, equilibrium time, and temperature were additionally examined.

The number of metal ions sorbed by the adsorbent was calculated using Equations 1 and 2 from variations between the original quantity of metal ions added and the quantity remaining in the supernatant:

Adsorbent capacity

$$(Q) = \frac{V(C_o - C_f)}{M} \quad (1)$$

Adsorbent efficiency

$$(\%) = \frac{C_o - C_f}{C_o} \times 100 \quad (2)$$

Where  $Q$  is the uptake of metal ions (mg/g),  $C_o$  and  $C_f$  are the original and final concentrations of metal ions in the solution (mg/L),  $V$  is the volume of metal solution (L) respectively, and  $M$  is the weight of added sorbent (g).

### **Adsorption of Ni(II) by various natural/modified adsorbents**

Typical natural/modified sorbents can be derived from three sources as revealed in the literature (i) Natural/Chemically modified agricultural biomass, (ii) Agricultural activated carbon, and (iii) Algal/Fungal/ Aquatic plants biomass.

#### **Agricultural biomass**

##### *Natural agricultural biomass*

A global annual residue supply was estimated at 500 million tonnes, with most agriculture and forestry residue comprising crop waste or by-products such as sugar cane, corn, peanut, sorghum, and oil palm for food and bioenergy generation [44,45]. In this chapter, we discuss varieties of natural waste of agricultural biomass like orange peel [46], watermelon rinds [47], rice bran [48,49], black gram husk [50], hazelnut and almond shells [51], tea waste [52,53], moringa oleifera tree seeds [54], Quercus ilex plant powder [55], petiolar felt-sheath of palm [56],

and maple sawdust [57,58]. Their performance and characteristics are reported in Table 1.

Citrus *reticulata* (orange fruit) screened fruit peel was utilized to extract nickel ions from metal solutions. To remove dirt, the fruit peel was thoroughly dried, crushed, washed in deionized water, and dried in an oven for a day. The adsorbent was tested and used in 150 mesh sizes after drying. The capacity of the orange peel for adsorption was studied for the removal of Ni, Zn, Cu, Pb, and Cr from metal ion solutions. Adsorption was in Ni(II)>Cu(II)>Pb(II) >Zn(II)>Cr(II) order with approx. 97.5% Ni and at least 30% Cr. Depending on sorbent dose (0.5 g), Co, pH, and T, the degree of Ni(II) elimination were observed. First-order kinetics were followed by the adsorption process. This cycle demonstrated endothermic adsorption of the Ni(II) monolayer at an ionic strength of 50mg/L at a pH 6 at maximum adsorption of 96% and adsorption strength of a 158 mg/g at 50°C. Desorption with 0.05 M HCl was possible, and 95.83% was found in columns and 76% in batch processes. The adsorbent expended was regenerated and used in three cycles. The removal and recovery efficiencies were found to be 89% and 93.33% respectively [46].

Watermelon rinds (WR) from the local fruit market were obtained by washing with tap water and through double distillation water. WR was separated into smaller sections and dried for seven days under sunlight after thorough washing. To avoid any soluble matter dried WR was periodically washed with hot water (70°C) and dried for 48 hours in an oven at 85°C. Using a grinder, oven-dried WR was brushed into a 100 mesh sieve. The sieved WR material was used for sorption experiments and stored in airtight polyethylene tubes. The present research explains the usage of watermelon rind to extract Ni(II) and Co(II) ions from aqueous solutions. Batch tests were conducted with differing pH (2-7), adsorbent dosage (0.5-5 g/L), contact duration (30 min), and initial metal ion concentration (50 mg/L). Desorption and regeneration experiments were undertaken to determine the reusability of WR. Maximal sorption potential of WR was 35.3 and 23.3 mg/g for Ni(II) and Co(II) ions, respectively, at pH 5 and sorbent concentrations of 2-2.5 g/L. Ni(II) ions had a higher affinity and adsorption levels relative to Co(II) ions under laboratory conditions. The presence of other metals due to competition was much affected by the extraction of Ni(II) and Co(II) ions [47].

Rice Bran (RB) used as a biosorbent was collected from the local rice production micro-industry. The biomass was dried in an oven at 105°C for 24 hours and stored in closed glass bottles. Raw, dry, unground RB was used in both sets of experiments (mean particle diameter: 320  $\mu$ m and surface area (BET): 0.46 m<sup>2</sup>/g). The adsorption method from aqueous solution also explored RB's ability the absorption of chromium and nickel. Adsorption models of Langmuir and Freundlich, commonly used to describe sorption equilibrium for wastewater treatment applications, reflect the experimental and equilibrium results that fit well with the Freundlich isothermal model. The average output of Ni(II) was 40% equivalent to Cr(VI) at pH 5, RB 200 mg/20 mL of metal solution which stabilized at 60-min. The negative value of  $\Delta G^\circ$  for Ni(II) indicated the spontaneous nature of the sorption, but positive values for Cr(VI) and Cr(III) were been determined. Ni(II) was consumed as the active sites of the sorbent connect intensely. Nickel sorption kinetics was tested on RB by mass transfer and intraparticle diffusion to enhance understanding of the sorption process. The pseudo-second-order kinetic model was used to generate a very high correlation coefficient that suggested that the nickel-sorption process in RB particles seemed to obey second-order kinetics [49].

Black Gram Husk (BGH) was used in metal biosorption experiments. Black gram or common gram, also called Bengal gram, developed by the seed-splitting method is a waste of no value. The approximate density of the adsorbent, its lignocellulosic elements, and its BGH particle size description illustrate its general physicochemical nature. BGH was actively cleaned with tap water and with double-distillation water for over three hours and periodically changed till the water was free of coloring. The boiled and cleaned BGH was dried in an oven for 24 hours at 80 pumice and placed in a dryer for use. As seen from numerous experiments, the quantity of BGH biomass was significant. The present work provides for the suppression of heavy metals by milling agro-waste of *Cicer arietinum* (black gram) as a biosorbent when placed individually or in binary and ternary metal solutions. The biosorbent effectively removed Ni(II) ions from aqueous solutions at a dose of 10 g/L and particle size of 1.4-4 mm. As the metal content (10 mg/L) decreased, the biosorption of metal ions by Black Gram Husk (BGH) increased. The biosorption equilibrium

is defined by Langmuir and Freundlich's adsorption was established within 30 minutes. Ni(II) adsorbed at an equilibrium of 19.56 mg/g (90.5% removal) in a BGH yield. Biosorption potential was pH-dependent and maximum adsorption occurred at solution pH 5. Biosorbent efficiency in the removal of Ni(II) from binary and ternary systems with Cu(II) and Zn(II) was the same as when supplied alone. Desorption of Ni(II) (96.4%) and other metals in single and multimetal solutions with 0.1 M HCl was achieved. This report is said to be the first paper to deal with the degradation of the harmful Ni(II) in binary and ternary structures based on agro-waste biosorption. It suggests the potential to incorporate multi-metal approaches to handle products containing heavy metals [50].

Hazelnut (SH) and almond (SA) shells were used to prepare adsorbents. It was washed with purified water multiple times to eliminate impurities and dried at 373 K for 24 hours. The shells were ground and sheathed to improve surface area using a blender. Adsorption activity of Ni(II) from aqueous solutions of SH and SA shells was studied. Equilibrium time for maximal adsorption mg/g (3.83 for SH and 3.11 for SA) was determined as 120 min at a dose of 10 g/L and an ionic concentration of 100 mg/L. The shells adsorbed by Langmuir and Freundlich linear isotherms for adsorption were collected. The degree of equilibrium adsorption was determined based on time, concentration, and solution temperature. The negative free energy ( $\Delta G$ ) values demonstrated the random existence of the Ni(II) adsorption in SH and SA and the positive enthalpy transition ( $\Delta H$ ) values the adsorption process 'endothermic aspect. The highest correlation coefficients were observed for the pseudo-second-order kinetic model. Ion exchange is a key aspect where divalent metal ions may be bound to SH and SA surfaces [51].

Tea Waste (TW) is the residual waste from tea factories. To prepare for the tests tea waste was washed with pure water till all soluble debris and colored elements were eliminated before a colorless TW solution at room temperature was detected. Decolorized and washed tea were dried for a couple of days at room temperature. This article presents data on the adsorption impact of nickel (II) on tea waste, initial concentration, pH solution, agitated volume, and temperature. Experiments of batch adsorption were conducted. The Freundlich and Langmuir isotherm established nickel (II) adsorption equilibrium at various temperatures (25-60°C). Langmuir isotherm was calculated

as possible adsorption at 15.26 mg Ni(II)/g. (86 percent removal) at initial pH 4, sorbent dosage of 10 g/L, regulated period and temperature of 120 min, and 25°C. The findings of the thermodynamic studies indicated random ( $\Delta G^\circ < 0$ ), mildly endothermic ( $\Delta H^\circ > 0$ ), and irreversible ( $\Delta S^\circ > 0$ ) responses to adsorption [52].

Moringa Oleifera tree Seeds (MOS) were washed to remove the mud with double distilled water, dried at 65°C for 24 hours, smashed, and sieved with 8.66 microns copper strains with pore mesh (105 $\mu$ , 210 $\mu$ , and 420 $\mu$ ). The shelled seeds were divided by the husks covering each nut, and the kernel with a blender and ground to a fine powder. According to the adsorption study, no other chemical or physical treatment was used. Competitive Ni(II) biosorption of unmodified shelled MOS was contained in a single metal solution. Adsorption efficiency of ternary metal ions measured on unmodified MOS was small (10–20%) relative to single metal ions. MOS extracted the targeted Ni(II) ions at 61.21% in the first step, with an optimal pH level of 7.5, MOS dosage of 4 g/L, and a contact period of 40 minutes. Measuring adsorption effects, the sorption equilibrium demonstrated the efficiency of the system for biosorption. And for 4 cycles with 99.10 percent desorption capacity, recycling of used biomass was attempted to restore the sorbent to its original condition [54].

Bone, stem, and root sections of Quercus Ilex (QI) were dried at 55°C overnight. The dried material with the aid of liquid nitrogen was pounded to homogeneous powder using a mortar and pestle. In this analysis, QI's ability as Ni, Cr, Cu, Cd, and Pb, adsorbent from the surface, leaf, and root was studied. Root metal absorption ability for various metals was determined to be in the range of Ni>Cd>Pb>Cu>Cr; stem Ni>Pb>Cu>Cd>Cr; and leaf Ni>Cd>Cu>Pb>Cr. The maximum volume adsorbed was Ni (root>leaf>stem) at pH 6 and a contact time of 6 hours. Data from this lab revealed that Ni was mainly sequestered in roots at rates of up to 0.00043 mg/g dry wt. Once one-year-old seedlings were handled with Ni (2000 mg/L), the topsoil which contained Ni was in small quantities compared to 0.00007 mg/g dry wt. This indicated Ni's complicating the ability of the root biomass for QI. Desorption with 10 mM Na<sub>4</sub> EDTA was successful (55-90%) and hence there was a possibility to recycle QI. Recycled QI biosorption tests indicated that the chosen adsorbents were reusable. The benefits and potential of QI

Table 1: Sorption of Ni (II) by natural agricultural biomass.

| Adsorbent                                | Optimum conditions (pH, dose, Ni (II) concentration, equilibrium time, temp) | Sorbent capacity (mg/g) | Adsorption Efficiency (%) | Desorption Efficiency(%) | References |
|--|--|-------------------------|---------------------------|--------------------------|------------|
| Orange peel                              | pH 6, 0.5 g/L, 50mg/L at 50°C  | 158                     | 97.5                      | 95.8                     | [46]       |
| Watermelon rind                          | pH 5, 2-2.5 g/L, 50mg/L and 30 mins  | 35.3                    | NA                        | NA                       | [47]       |
| Raw rice bran                            | pH 5, 10 g/L, 10mg/L and 60-90 mins  | NA                      | 40-50                     | NA                       | [49]       |
| Agrowaste of black gram husk             | pH 5, 10 g/L, 10mg/L and 30 mins   | 19.56                   | 90.5                      | 96.4                     | [50]       |
| Shells of hazelnut and almond            | 10 g/L, 100 mg/L, and 120 mins   | 3.83 & 3.11             | NA                        | NA                       | [51]       |
| Tea waste                                | pH 4, 10 g/L and 120 mins at 25°C  | 15.26                   | 86                        | NA                       | [52]       |
| Moringo oleifera seeds                   | pH 7.5, 4 g/L and 40 mins  | NA                      | 61.21                     | 97.10                    | [54]       |
| Quercus ilex                             | pH 6, 5 g/L, 10mg/L and 6 hrs at 25°C  | 0.00043                 | NA                        | 55-90                    | [55]       |
| Palm tree trunk peelings                 | NA   | 1.59                    | 76.3                      | NA                       | [56]       |
| Maple sawdust                            | NA   | NA                      | 75                        | NA                       | [58]       |
| Walnut shell                             | pH 6.5, 3 g/L, 150 mg/L and 120 mins at 15-30°C and 520°C                    | 13.92                   | 96                        | 88-100                   | [59]       |
| Quercus crassipes                        | pH 8, 1 g/L, 358 mg/L and 120 hrs at 20°C                                    | 104.17                  | 95                        | NA                       | [60]       |
| Carissa Carandas and Syzygium aromaticum | pH 6, 20 g/L, 100 mg/L and 180 mins at 30°C                                  | 3.76 and 2.96           | 85 and 74                 | NA                       | [61]       |
| Peat                                     | pH 5, 5 g/L, 100 mg/L and 60 mins at 30°C                                    | 61.27                   | 92.5                      | 98.5                     | [62]       |
| Barbadensis Miller leaves                | pH 7, 1 g/L, 100 mg/L and 180 mins at 30°C                                   | 10                      | 60.2                      | NA                       | [63]       |

as a biofilter of toxic trace metals, its variety, and the need to increase QI's efficacy as an adsorbent of metals, are discussed [55].

The reticulate Fiber network of Palm Felt (PFP) was obtained to get peelings from the palm trunk of *Liuirtona Schinnerer*, in filtered deionized water, and felt sheaths were cleaned to remove contaminants or other particulate matter. The washed sheaths were dried at 70°C for 24 h and sliced into individual films of a liter or less particle size. They were oven-dried at 90°C at a constant weight. PFP biosorption from wastewater was observed in heavy metals such as Ni(II) and Cr(III). Two toxic metal ions in the selectivity order of Ni(II)>Cr(III) were found to efficiently eliminate PFP (76.3>56.9 percent). With more than 70% in 5 minutes, Ni(II) uptake was quick. After multiple adsorption cycles, the bundled metal ions were efficiently dissolved with the PFP fibrous biomass being effective [56]. Similar to PFP, maple also had a successful removal performance adsorbing more than 75% [58].

#### Chemically modified agricultural biomass

In most cases, adsorbents' efficiency was not as high as required due to their low to medium adsorption

capacities. In recent years, the emphasis has been on adsorbent surface modification by various techniques to increase adsorbent adsorption capacity. Many surface modification techniques, including chemical and physical, have been widely used by researchers over the last few decades. Chemical changes entail acid/base treatment of adsorbent. Treatment of the acid leads to protonation, which improves the positive surface density of the adsorbent surface. The acid treatment induces a heavy electrostatic interaction between negatively charged ions and protonated adsorbent surfaces. Base treatment of adsorbent decreases the negative charge on the adsorbent's surface resulting in enhanced electrostatic interaction with the positively charged particles [21,64].

Modifying plant waste facilitates the isolation and production of soluble organic compounds. A variety of color removal study groups chemically modified agents like acids (sulphuric acid, nitric acid, hydrochloric acid, Tartarean acid, oxalic acid), base (sodium hydroxide, calcium hydroxide, sodium carbonate), oxidation agents (hydrogen peroxide), and, organic compounds (formaldehyde) [65,66]. Throughout this segment, we addressed varieties of Teakwood sawdust and groundnut shells [67], Green

coconut shells [68], Pigeon peas hulls [69], Rice bran, soybean, and cottonseed hulls [70], Coir pith [71,72], Jute fiber [73], Maize cob [74], Bagasse and fly ash [75,76], Tea leaves [77], Tobacco dust [78], Oak sawdust [79,80], Meranti sawdust [81], Dalbergia sissoo sawdust [82] and, Nigerian bamboo [83], with more adsorbents removing Ni (II) ions from real-time/synthetic wastewater, details of which are reported in Table 2.

Local adsorbent biomaterials (Teakwood Sawdust (TS) and Groundnut Shaws (GS)) were used for two different cellulose-containing and inexpensive agricultural goods. For uniform consistency, sawdust and broken groundnut shells of 40 and 20 mesh sizes were used. They were boiled in a 1 g/L soap solution and thoroughly washed with water spray for 15 minutes to remove impurities. The purified biomaterials were then packed with soluble coloration. For Cu(II), Ni(II), and Zn(II) adsorption from aqueous solutions, the potential of cheap cellulose-containing naturals like GS and TS was calculated. Both demonstrated strong adsorption capacities, but the rates based on the mix of adsorbing content and metal ion varied. Using a different dye, C.I. reactive orange 13 increased adsorption ability. The average metal ion absorption of the dye-loaded groundnut shells, for Ni(II), was 7.49 mg/g, compared to the equivalent level of 3.83 mg/g attained when raw groundnut shells were used as adsorbents. Similarly, dye-filled sawdust had an adsorption value of 9.87 mg/g, which was greater than the equivalent value of 8.05 mg/g obtained by unloaded sawdust as an adsorbent. All adsorbing materials displayed reduced adsorption ability after the pH of the metal ion solution was reduced. Both adsorbing materials displayed lowered adsorption capability when the pH of the metal ion solution was reduced. When the pH of the metal cation solution fell below the lowest 1.5, then adsorption achieved limited values under all situations. Also under low pH, metal ions adsorption was slightly higher on dye-charged adsorbents. Isothermal adsorption models were established to ensure the best possible fit of the Langmuir model. Three consecutive (above 95 percent) and adsorption-adsorbent intervals were tested for recovery and reusability of the adsorbents [67].

**Green coconut shells** (GS) were treated for three hours with NaOH 0.1 mol/l, cleaned with a buffer solution (pH 5.0), and dried at 50°C with deionized water. It was cooled and shifted to achieve the required particle dimensions

(0.246-0.074 mm) at room temperature. This thesis used GS as an adsorbent for the elimination of harmful metal ions from aqueous effluents through batch adsorption. The findings indicated that ion concentration was feasible at an optimal pH dose of 5.100 mg/L.e. The discovery curves for multiple elements provided the following order of adsorption capacity: Ni(II)>Zn(II) (2.98>0.753 mg/g) for a single ion system and Zn(II)>Ni(II) (4.16>1.68 mg/g) for a multi-ion system. Samples from the electroplating industry can be processed efficiently and Ni(II) ions can be collected [68].

Pigeon Pea Hull (PPH), collected from nearby farms was washed with filtered water to remove soil and dried in sunlight and after processing, the hulls were, broken into small pieces. To extract lignin-based colored materials supplemented with 0.1 N H<sub>2</sub>SO<sub>4</sub> the dry hulls were submerged in 0.1 N NaOH. Lastly, PPH was washed with filtered water several times, dried in an oven for 12 hours at 80°C, and cooled to room temperature. The oven-dried hulls were ground to a fine powder and screened in 20-30 fractions mesh and adsorbed to Pb(II) and Ni(II) without any pre-treatment. PPH content was used as an adsorbent to remove Pb(II) and Ni(II) ions from aquatic water, a low-cost agricultural by-product. Adsorption characteristics were investigated using well-established and efficient criteria, including pH effect, contact duration, adsorbent dose, initial concentration of metal ions, and temperature. Optimum adsorption of Pb(II) and Ni(II) at pH 4.0 was observed. Kinetic experiments revealed that the adsorption results matched a pseudo-second-order model with a strong correlation coefficient. The Langmuir model provided a stronger match compared to the Freundlich and Dubinin-Radushkevich versions. Thermodynamic properties, i.e.  $\Delta G$ ,  $\Delta H$ , and  $\Delta S$  showed that adsorption of Pb(II) and Ni(II) to PPH was endothermic, spontaneous, and feasible at temperatures of 293-313 K. Adsorbed PPH capacity was 23.64 and 23.63 mg/g for Ni(II) and Pb(II) at pH 4, 0.4 g/L, 50 mg/L, and 40 mins equilibrium time at 40°C. PPH powder can be used as an efficient, low-cost, and environment-friendly green adsorbent to remove selected metal ions from aqueous solutions [69].

Samples of full-bodied and defatted, stable rice bran were defatted with hexane and dried. Full-fat bran is a co-product of rice oil. It was stabilized with an expander to generate collets under proprietary temperature, time, and speed. Collets underwent hexane extraction in the



Crown extractor. After extraction, hexane was extracted and the defatted collets were dried and ground to powder. These activities were carried out at Riceland Foods. Wastewater was manufactured by a metal plating firm. Their sorption and resistance to abrasion were checked for defatted rice bran (RB), soybean (SH), and cottonseed (CH) shells because of their possible usage as industrial metal adsorbents. Such by-products were evaluated for the likelihood of Zn(II), Cu(II), and Ni(II) adsorption by utilizing aqueous solutions as well as metal plating wastewater. Plant-prepared bran was more robust in extrusion and had higher adsorption efficiency than commercially available bran. Mechanical abrasion resistance in batch applications was low in both rice brans. NaOH- and HCl-washed cotton and soy hulls typically had low adsorption levels but were more or less adsorptive than the water-washed shells, respectively. Adsorption properties of hot seed cotton and soy hulls were lower than water-washed hulls. Unlike rice bran, mechanical abrasion tolerance of soybeans and cottonseed hulls in batch applications was demonstrated. Hulls were reused after one adsorption/desorption process and adsorption capability was significantly decreased classifying d Hulls as single-use adsorbents when decorated with HCl. Optimized conditions and adsorption capacities are given in Table 2 [70].

The local coir industry acquired Coir Pith (CP). Coir pit carbon was dried in sunlight for five hours and then activated with zinc chloride. Coir pith was immersed in water at a weight ratio of 2:1 in zinc chloride. The filtered contents were carbonized under stable conditions at a temperature of 700°C during washing. After refrigeration, HCl dilute was added to excess zinc chloride in the carbonated material. The carbon washed off ZnCl<sub>2</sub> excess and was dried. The carbonized substance was sieved to 250-500µm particle size and used in adsorption experiments. Abundant lignocellulose industrial waste, coir pith, was used to produce activated carbon ZnCl<sub>2</sub> to extract radioactive anions, heavy metals, and organic compounds which are dyes, from water. Sorption of metals such as nickel(II) was observed. The intake was also tested for the potential application of the adsorbent to handle toxic surface water in acidic teats, such as acid blue, acid violet, basic dyes like methylene blue, rhodamine B, direct dyes like transparent red12B, and, congo red and reactive dyes, such as procion red and orange. The preferred

conditions for maximum removal of Ni(II) were 58% in raw CP and 41% in Zn-CP at an adsorbate concentration of 20 mg/L, pH 5, 12 g/L, and equilibrium at 180 min at 35°C. The results showed that ZnCl<sub>2</sub> activated coir pith carbon was effective in removing toxic pollutants from water [72].

Jute Fiber (JF) waste was obtained from local industries and washed, processed, cut to a standard length of 1 cm, and chemically prepared. 100 g of JF was immersed in 4 liters of diluted fluid comprising 50 mL stock dye fluid at 40°C with the temperature being gradually raised to 85°C. After 10 min, 65 g/L of sodium sulfate decahydrate was applied to the substance in two batches of 10 min to increase dye exhaustion. After another 20 min, 15 g/L of sodium carbonate was applied to the same bath for covalent fixation of the dye on the substance and the process proceeded at 85°C for another 30 min. In the end, the substance was purified and cleaned vigorously with hot water. The colored content was then dried in an oven at 50°C overnight and used as an adsorbent. The volume of hydrogen peroxide used for oxidation of JF was greater than the level usually used for oxidative bleaching of JF to achieve the required whiteness. The goal was to oxidize the hydroxyl groups of cellulose in JF to carboxyl groups, thereby producing a poor cationic ion-exchanger. The same treatment of dye-filled with JF was performed at this point. The ability to remove heavy metal ions, such as Ni(II) from their water solutions was calculated by the lignocellulosic filament jute. The fiber was also used as an adsorbent after chemically modifying the dye with a particular structure (C.I) through two separate techniques. Oxidizing of hydrogen peroxide and volatile Orange 13 increased the adsorption of ions from carbon and changed jute fibers. Thus, for Ni(II) metal ion absorption of dye-loaded jute was 5.26 mg/g while for the oxidized fibers the corresponding values were 5.57 mg/g in contrast to unmodified jute fiber 3.37 mg/g. Isothermal adsorption models demonstrated that they fit modified jute fiber Langmuir applications. Adsorption lessened with fewer pH. Three straight adsorption-desorption years were tested for the desorption, regenerative, and reuse ability of the adsorbent compounds. Adsorbent strength was retained while caustic soda regeneration was undertaken during desorption as an intermediate step [73]. A possible mechanism is provided in Table 2.

**Maize Cob (MC)** was obtained from shops and cleaned with double distilled water. The samples were then washed for 12 hours in a 1N diluted solution of sulphuric acid. After 12 hours, fresh water was used to purify the dried samples until the soluble and colored components were separated and dried in sunlight for many hours. The samples were then soaked for 12 hours in 1N NaOH till the deionized water was washed away. Maize Cob was dried 24 hours a day at 100°C in hot air to separate the particles according to their proportions, which were then compressed and inserted into a mechanical sieve. Nickel(II) adsorption on MC was tested using nuclear absorption spectroscopy for metal estimation. Parameters including heavy metal content, adsorbent dosage, touch duration, and irritation intensity were tested. Langmuir and Freundlich's isotherms were used to explain the adsorption equilibrium. The full volume of Ni(II) adsorbed was measured by a Freundlich isotherm. The research concluded that MC, a waste substance, could extract hazardous heavy metals such as Ni(II) from industrial wastewater by approximately 95% at pH 4, 1.25 g/l, 10 mg/L, and 90 min. respectively [74].

Two low-cost adsorbent products including untreated bagasse (BA) and fly ash (FA) were used in the study. Powdered activated carbon was collected from a chemical manufacturer. FA, the waste material of BA furnace, was the waste material from a sugar factory. FA was cleaned vigorously with double purified water to absorb soil and other foreign matter and was dried in sunlight for 6–7 h. BA was then washed vigorously with purified water to absorb the dust particles and dried at 40°C for 4–5 h. Dry BA was then soaked in a NaOH 0.1N solution to extract lignin content throughout the day and washed with dual-distilled water as well. BA was immersed in 0.1N CH<sub>3</sub>COOH, for 2–3 h to eliminate signs of NaOH. Then till the wash water became colorless, the sun cooled, and sorbent content was put separately in a vacuum desiccator before use. BA was intensely washed with double filtered water. These inexpensive adsorbents were used for the extraction of chromium and nickel from a water solution. The physical and chemical properties of the adsorbent, adsorbent, and experimental compositions were the products of adsorption kinetics and the amount of adsorption in equilibrium. Batch studies investigated the impact of chromium and nickel intakes on hydrogen ion concentration, length of interaction, sorbent dosage,

original concentrations of adsorbed, and particle size. Evidence on sorption was associated with models of adsorption in Langmuir, Freundlich. The efficacy of adsorbent materials for removal of Cr(VI) and Ni(II) was between 56.2, 96.2, 83.6, and 100% respectively at pH 8, 14 g/L doses, 100 mg/L concentration, and 60 min contact time. The findings were obtained under controlled pH conditions, contact duration, sorbent dosage, sorbate concentration of 100 mg/L, and adsorbent particle size ranging between 0.075 and 4.75 mm. The order of selectivity was powder-activated carbon>fly ash>bagasse for Ni(II) elimination [76].

Tea leave Wastes (TW) from homemade tea were used for adsorption. The materials gathered were sprayed multiple times with filtered water to remove all soil particles. It was then heated with distilled water at a temperature of 80°C for 1 hour to remove caffeine, tannins, and colors. At room temperature, the color of the solution was spectrometrically calculated. Tea was dried in an oven at 105°C for 10 hours. Then the compact, sieved (100µm) dry materials were placed in a container. 2 grams of magnetic particles were dissolved in 80 ml of double purified water in an extreme stirrer while 2.1 g of FeSO<sub>4</sub>•7H<sub>2</sub>O and 3.1 g of FeCl<sub>3</sub>•6H<sub>2</sub>O were dissolved in double-distilled water. As the water was heated to 80°C, an ammonium hydroxide solution of 10 mL (25 percent) was added. The extraction of Ni(II), prepared and impregnated with tea waste (Fe<sub>3</sub>O<sub>4</sub>-TW), from aqueous solutions by magnetic nanoparticles from agricultural biomass was investigated. Chemical precipitation of Fe<sup>2+</sup> and Fe<sup>3+</sup> aqueous salts by ammonia solution was used to form magnetic nanoparticles (Fe<sub>3</sub>O<sub>4</sub>). The results of different variables like contact duration, pH, concentration, adsorption dose, and temperature were studied. Followed by kinetics, the value of the first order was 1.90x10<sup>-2</sup> min<sup>-1</sup> at 100 mg/L and 303 K. Inside a solution of 50 to 100 mg/L, removal performance fell from 99 percent to 87 percent. The temperature was increased by Ni(II) adsorption from 303 to 323 K and the cycle was endothermic. It was estimated to be 38.3 mg/g for the Langmuir and Freundlich calculations as adsorption isothermal data and Langmuir adsorption strength. Studies revealed that tea waste entered biomass nanoparticles and hence was an alternative for metal recovery. The optimal parameters are listed in Table 2 [77].

**Tobacco Dust (TD)**, was washed with deionized water and altered with 0.1 M HCl at 1:5 (w/v) for 1 h before suspension pH reached 4.5–5.0 at 105°C. Tobacco dust is produced from: 30% lignin; 94.2% solids; 72.0% volatile; 28.0% charcoal; 43.0% sulphur; 2.37% nitrogen; 1.70% potassium; 4.2% calcium; and 0.70% magnesium. The dust was formed from the following mass compositions: This also included B, Cu, Fe, Zn, and Na 26, 57, 0.57, 761, and 288 mg/kg. Typical agricultural lignocellulosic particles, including tobacco and mud, were examined for the binding capacity of heavy metals. TD demonstrated good potential for heavy metals, such as Ni(II), with a resulting balance load of 24.5 mg of the metal per g of the sorbent at pH 6.34, 1 g/L of TD injection, 100 mg/L of Ni(II) ion concentration, and 90 minutes of equilibrium time at 25°C. In comparison, heavy metals added to the biosorbent could safely be extracted with a dilute HCl solution. Testing on zeta potential and surface acidity showed a strong degree of acidity and the efficacy of OH adsorption tobacco powder over a broad pH spectrum (pH>2). Changes in tobacco surface morphology as seen by atomic force microscopy revealed that the sorption of heavy metal ions on tobacco may be related to improvements in the surface properties of salt particles. This alteration could be due to the failure of the acid-metal ion solution of some surface structures in the particles. However, there were no significant improvements in tobacco dust chemical composition under biosorption by Fourier Transformed InfraRed (FT-IR) spectroscopy. Metal-H ion exchange or metal-ion surface adsorption or both may be defined as Heavy Metals consuming tobacco dust [78].

This research was conducted using HCl-treated acid-modified Oak Sawdust (OS) (*Quercus coccifera*). During modification, the volume of lignin increased and both cellulosic and hemicellulosic substances and extracts decreased. This was positive because previous research showed that lignin rather than cellulose and hemicellulose were adsorbed by heavy metals. This paper discusses the adsorption of heavy metal ions from aqueous fluids by OS changed by an HCl application. Our analysis checked the elimination of three heavy metals, Ni and Cr. An estimate was made of optimum shaking rate, adsorbent capacity, contact period, and pH and adsorption insulation using metal ion amounts of 0.1 to 100 mg/L. Adsorption showed pseudo-second-order kinetic reaction as well as isotherms

for the adsorption of Langmuir and D–R. Also, this research article addressed thermodynamic adsorptive parameters (free energy, entropy, and Gibbs enthalpy). Our review reveals that, under normal circumstances, adsorption was spontaneous and endothermic. The full removal efficiency was 84% for Ni(II) at pH 8, 30 g/L, 97 mg/L and 8 hours at 30°C, and 82% for Cr(VI) at pH 3 [79].

Meranti sawdust was gathered and cleaned with purified water and dried in a dryer at 70°C to remove all moisture. Through a still press, the aggregate was processed to a fine powder. The resultant substance was sieved to 100-150 µm particle size. The ground powder was washed with 0.5 M HCl at room temperature for 4 h to extract color and water-soluble substances. Then, the sawdust was drained and, cleaned with purified water multiple times to ensure no chloride emission, and dried in a dryer at 70°C. The present study proposed the use of meranti sawdust in synthesis solutions to remove Cu(II), Cr(III), Ni(II), and Pb(II). Sample adsorption experiments demonstrated meranti sawdust's potential for ion adsorption in concentration ranges of 1–200 mg/L from aquatic solutions: Cu(II), Cr(III), Ni(II), and Pb(II). Maximum adsorption was at pH 6, while pH 1 with all-metal ions were the beginning of adsorption. Effects established the length of interaction, initial metal ion concentration, adsorbent dose, and temperature. To more comprehensively grasp the process of isothermal adsorption, the operation of Langmuir, Freundlich, and Dubin–Radushkevich isotherms were checked. When checked for adsorption with pseudo-first-order and pseudo-second-order models, large  $R^2$  values were recorded from 0.850 to 0.932, and between 0.991 and 0.999. Meranti sawdust was found to be cost-effective and to have good efficiency with (Ni(II) being 35.97 higher than Pb(II) 34.35 and Cu(II) 32.05 mg/g at pH 6, 5 g/L, 100 mg/L, and 120 min at 30°C in removing toxic metal ions from aqueous solutions [81].

Dalbergia Sissoo (DS) sawdust was obtained from a nearby sawmill. To boost its adsorption properties sawdust was treated with a sodium hydroxide solution. Metal-binding of biomass was responsible for carboxylate ligands. It made sure that the volume of carboxylate ligands in biomass could strengthen metal bonding. The principal components in most plant tissues are cellulose, hemicellulose, and lignin which are methyl esters that

do not bind metallic ions tightly. However, by treating biomass with a base, such as sodium hydroxide, methyl esters can be transformed into carboxylate ligands, thereby increasing their metal-binding ability. A beaker with a cap was used to hold 100 grams of scab and 500 cm<sup>3</sup> 0.5 M of NaOH solution. The resulting mixture was blended with a magnetic agitator for an hour. The material in the beaker was cleansed thoroughly and washed through the Howman filter tube with double distilled water. It was dried for 5 hours at 373 K and cooled for 24 hours in a desiccator. Sawdust particles of almost 200µm size were separated by sieving and stored in a closed Pyrex glass bottle. DS sawdust a by-product of sawmills was found to be a promising adsorbent for the removal of nickel ions from aqueous solutions. The sorption of nickel ions in DS sawdust was studied using the batch technique. Kinetics studies showed that nickel ion sorption obeyed the law of the first-order rate. Data applicability of the Langmuir and Freundlich models was tested. Both models accurately defined the experimental biosorption results for nickel ions as 10.47 mg/g at pH 6, 1 g/L DS dose, 100 mg/L Ni(II) concentration, and equilibrium time at 20 min at 25°C. Thermodynamic parameter  $\Delta H=4.80$  kJ/mol indicated that nickel ion sorption in sawdust was an endothermic operation. Another researcher recorded that walnut sawdust displayed stronger adsorption efficiency of 6.43 within 60 minutes of contact time, respectively [82].

Unit adsorption of different heavy metals (Zinc, Nickel, and Chromium) in industrial wastewater utilizing Nigerian-based activated carbon bamboo (NBAC) was reported. This was carbonized from 300 to 450°C and processed at 800°C with HNO<sub>3</sub>. Compared to industrial carbons, bulk length, the volume of iodine, adsorption of benzene, methylene, and the activated carbon powder all performed well. Multi-adsorption of these metals in the same solution using NBAC revealed that adsorption potential was in the form of Ni=Cr (15-20 mg/g) at pH 7, 10g/L, and 4 hours of equilibrium, suggesting that these metal ions could be specifically adsorbed by NBAC. This work demonstrates, that NBAC can be a valuable source of activated carbon with several metal ions with the potential to act as a safer replacement for industrial activated carbon. Nonetheless, the quest for less expensive adsorbents and their ability to extract Zn(II) ions from industrial wastewater [83] should continue.

pH<sub>PZC</sub> is an essential feature of a biosorbent as it reveals its acidity-basicity and the net surface charge of the carob seed biosorbent in Ni (II) solution. pH<sub>PZC</sub> is 5.9 and 6.9, for raw seeds and NaOH seeds respectively. It is seen that raw seeds have an acidic base. But, after NaOH, there was an increase in the pH<sub>PZC</sub>. Weak pH<sub>PZC</sub> was associated with the predominance of surface acid groups. The results show that the surfaces of raw seeds and NaOH seeds are positively charged with pH below 5.9 and 6.9. Biosorption of the observed metals was hindered in this pH due to electronic repulsion between the metal ions and positively charged functional groups. Conversely, for a pH higher than 5.9 and 6.9, the number of negatively charged sites on the surface of raw seeds and NaOH seeds increased and metal biosorption became important for pH<sub>PZC</sub>. Optimal parameters are listed in Table 2 [84,85]. Different values of the proton exchange ratio for Ni(II) adsorption on different mineral surfaces suggest that the sorption of Ni(II) reactions for different substrates was significantly different. This difference may be due to the difference in the crystal structure, specific surface area, and the pH<sub>PZC</sub> of each mineral [43].

#### ***Agricultural activated carbon***

Adsorbents for Activated Carbon (AC) are commonly utilized for heavy metal pollutant treatment. AC are large surface area materials created from different amorphous carbon compounds. In general, the processing of activated carbon can be split into two categories: physical and chemical activation. Physical activation requires carbonization of the intermediate at ambient temperatures (500-900°C) in an inert environment, accompanied by activation of the resultant carbon at high temperatures (800-1000°C) in the presence of a CO<sub>2</sub> or steam environment. In the chemical activation method, the raw material is filled with an activating reagent which is heated in an inert atmosphere. The carbonization and activation steps occur simultaneously in the chemical activation method [87]. The resulting surface area is primarily attributed to a large number of micropores and mesopores. To remove heavy metals, many researchers investigated the usage of AC [89,90]. Increased demand currently stems from the insufficient availability of commercial coal-dependent AC. An option may be the possible advances in the adsorption of heavy metals to AC at no risk to the pollutants, pathogens, and AC composites.

Table 2: Sorption of Ni(II) by modified agricultural biomass

| Adsorbent                                | Modifying Agent                         | Optimum conditions (pH, dose, Ni (II) concentration, equilibrium time, activated temp) | Sorbent capacity (mg/g) | Adsorption Efficiency (%) | Desorption Efficiency (%) | References |
|--|---|--|-------------------------|---------------------------|---------------------------|------------|
| Teakwood sawdust and groundnut shells    | Raw                                     | pH 6, 20g/L, 83.9 mg/L and 120 mins at 25°C  | 8.05 and 3.83           | 51.40 (both)              | NA                        | [67]       |
|  | Base coloring agent                     |  | 9.87 and 7.49           | 87.93 and 81.34           | NA                        |            |
| Green coconut shells                     | NaOH                                    | pH 5, 100 mg/L at Room temperature   | 2.98                    | NA                        | NA                        | [68]       |
| Pigeon peas hulls                        | H <sub>2</sub> SO <sub>4</sub>          | pH 4, 0.4 g/L, 50 mg/L and 40 mins at 40°C   | 23.64                   | 98.5                      | 90                        | [69]       |
| Rice bran, soybean, and cottonseed hulls | HCl, NaOH, and Heat                     | pH 4-5, 40 g/L, 0-2000 mg/L and 120 mins at 25°C                                       | 38.3, 69.8 and 72.8     | NA                        | NA                        | [70]       |
| Coir pith                                | Zinc chloride and HCl                   | pH 5, 12 g/L, 20 mg/L and 180 mins at 35°C and 700°C                                   | NA                      | 58                        | 80-90                     | [72]       |
| Jute fiber                               | Unmodified and Hydrogen peroxide        | pH 6.58, 10 g/L, 82.3 mg/L and 180 mins at 25°C  | 3.37 and 5.57           | 34.92 and 53.70           | 72.3                      | [73]       |
| Maize cob                                | H <sub>2</sub> SO <sub>4</sub> and NaOH | pH 4, 1.25 g/L, 10 mg/L and 90 mins at Room temperature                                | NA                      | above 95                  | NA                        | [74]       |
| Bagasse and fly ash                      | CH <sub>3</sub> COOH and NaOH           | pH 8, 14 g/L, 100 mg/L and 60 mins   | 83.6                    | 100                       | NA                        | [76]       |
| Tea leaves                               | Nano Fe <sub>3</sub> O <sub>4</sub>     | pH 4, 6 g/L, 100 mg/L and 120 mins at 40°C   | 38.3                    | 99                        | 95                        | [77]       |
| Tobacco dust                             | HCl                                     | pH 6.34, 1 g/L, 100 mg/L and 90 mins at 25°C   | 24.5                    | 60-70                     | 70-80                     | [78]       |
| Oak sawdust                              | HCl                                     | pH 8, 30 g/L, 97 mg/L and 8 hrs at 30°C  | 3.37                    | 84                        | 71                        | [79]       |
| Meranti sawdust                          | HCl                                     | pH 6, 5 g/L, 100 mg/L and 120 mins at 30°C   | 35.97                   | 94                        | 85                        | [81]       |
| Dalbergia sissoo sawdust                 | NaOH                                    | pH 6, 1 g/L, 100 mg/L and 20 mins at 25°C  | 10.47                   | NA                        | NA                        | [82]       |
| Nigerian-based bamboo                    | HNO <sub>3</sub>                        | pH 7, 10 g/L, 166 and 500 mg/L and 4 hrs at 25°C                                       | 15-20                   | NA                        | NA                        | [83]       |
| Carob Seeds                              | NaOH                                    | pH 6, 1 g/L, 50 mg/L and 90 mins at 25°C   | 85.73                   | 76                        | NA                        | [86]       |

Effective heavy metal adsorbents can be alginate [91], tannic acid [92,93], magnesium [94], surfactant [95], and AC compounds. Characterization of activated carbon includes the calculation of physical properties such as bulk mass, pore length, percentage of pyrolysis content, moisture quality, ash quality, particle size, benzene adsorption, heating temperature, iodine number, and chemical properties such as pH, minerals and chemical composition, H-C bonding strength and adsorption capacity [96,97]. Due to its tough texture and low ash content, farm waste is a rich source of activated carbon generation [98]. In this chapter, we discuss varieties of activated carbons such as peanut shell [99], hazelnut shell [100], rice straw, soya hull, sugar cane bagasse, peanut shell, pecan and walnut shell [101,102], coir pith [103], coconut tree sawdust, silk cotton hull, industrial sago waste, banana pith and maize cob [104]. Their performance is listed in Table 4.

Peanut shell (PSAC) was milled to U.S. sieve particle thickness of 10 x 20 mesh (2.00-0.85 mm) size. Molasses were used to combine milled peanut shells at a 1.5:1 weight. The briquettes were placed and weighed onto a ceramic evaporating tray. They were then placed in a Lindberg oven. Although nitrogen gas could fill the sealed retort, the briquettes were heated for two hours at 800°C. Agricultural by-products, such as peanut shells, add significant amounts of lignocellulosic materials to the atmosphere during the growing season. The goal of this research was to turn peanut shells into changed carbons for the absorption of selected metal ions, namely Ni(II), Cd(II), and Zn(II). Milled PSAC was pyrolyzed at 800°C in an inert N<sub>2</sub> environment and then triggered with HCl in a particle size <1 mm. The prepared carbons were measured for either adsorption capacity or adsorption strength, with these parameters being compared with those obtained from standard commercial carbon materials. PSAC-based

carbonaceous materials had a Ni ion adsorption capacity (0.546 mmol/g) lower than that of Zn (0.479 mmol/g) and Cd (0.232 mmol/g) at 4.8 pH and 4 hours of contact time. This research demonstrates that PSAC can function as a source for activated carbon with metal ion reduction ability and also as a replacement for coal-based natural fuels in various applications [99].

The total stock of activated carbon for Hazelnut shell (HSAC) was roughly  $3 \times 10^5$  tons annually in Turkey. Air washed, compressed and purified carbon was impregnated with concentrated  $H_2SO_4$  to create 5 fractions, with their dimensions ranging between 0.5 and 2 mm of 100 g HSAC. This was activated for 24 hours in a hot air furnace at  $150^\circ C$ . Sterile water was poured on the carbonized material, which absorbed free acid and submerged the activated carbon into a 1%  $NaHCO_3$  solution to absorb the residual acid. It was treated with filtered water until the pH of activated carbon reached 6.25,  $105^\circ C$ , and 0.9-1.60 mm. HSAC was used as an adsorbent to extract Ni(II) from an aqueous solution. Batch mode adsorption experiments were performed with different initial concentrations of metal ions, agitation intensity, temperature, and particle size. A contact period of 180 min was required to maintain harmony. Balance data were analyzed using the Langmuir, Freundlich, and Temkin isotherms. Characteristic criteria for each isotherm were defined. The Langmuir isotherm provided the strongest connection for Ni(II) to activated carbon. Thermodynamic parameters showed that Ni(II) adsorption was exothermic [100].

By-products included soft lignocelluloses such as rice straw, soya bean hull, sugar cane bagasse, peanut shell, and strong materials like pecan and walnut shells for the disposal of heated metal in wastewater. Granular activated carbon (GAC) was allowed by its manufacturers to adsorb chemical and/or metal(s). Binders, coal tar, and cocoon shell GACs were not used in the manufacture of coal or turbot industrial GACs. Surplus by-products of low-value crop crops could be converted into GACs used for remediation of environmental pollution. This research identified and analyzed GACs generated as effective organic matter removers from soils and feedstock. The stronger fabrics were mixed with binders, and molasses, for the manufacture of briquettes and pellets. The precursors were CO or steam-activated and subsequent therapies involved oxidation to enhance metal adsorption. Neither CO nor steam activation was especially beneficial

in the development of metal adsorption. Oxidation using O gas improved metal adsorption while the NH solution did not. Oxidize GACs produced from soya bean hull, sugar cane bagasse, peanut shell, and rice straw adsorbed from a mixture of higher concentrations of Ni(II) than other industrial GACs. GACs produced from industrial by-products had significant absorption ability for organic and metals of environmental significance. Equilibrium conditions and adsorption capacities are listed in Table 4 [102].

Coir pith was obtained from the coir manufacturing sector and dried in sunlight. Cu(II), Ni(II), and Pb(II) containing wastewater were obtained from the radiator and plating industries using normal methods (APHA, 1980). Wastewater was filtered to the correct quantity and used for pH and carbon quantity tests. Activated carbon was extracted from the coir pith using a chemical activation process that has been described. Toxic heavy metals, Ni(II), and Cu(II) adsorption with synthetic solutions was studied. The present work has explored the adsorption of harmful heavy metals through coir pith carbon in industrial wastewater. Percent adsorption rose from 2 to 6 with a rise in pH staying stable up to 10. Ni(II) was adsorbed below 92% and Cu(II) at 73% at 3.5 pH. When coir pith was drained from coir waste, the resulting carbon could be a cheap solution to remove hazardous heavy metals from industrial wastewater [103].

Activated carbon extracted as adsorbent (the major agricultural waste in this field) from industrial solid waste and adsorbates were collected. Coconut tree sawdust, silk cotton shell, and sago mill waste were extracted from the agriculture manufacturing industry. The other two sorbents were collected from Banana Pith and maize cob. These products were used with concentrated sulphuric acid to handle activated carbons. Carbon production was from solid agricultural waste and the cocoon-cotton wrapper, coconut tree sawdust, sago waste, maize-cob, and banana pith. Adsorption of both dyes and metal ions required a very short period and culminated in a quantitative removal at pH 4-5, 25 mg/L, 2.5 g/L, and a balance of  $29-33^\circ C$  within 60 minutes. Experimental findings indicated that both carbons were successful in eliminating toxins from water. As agricultural solid waste used in this investigation was easily, readily, and locally accessible, the resultant carbons were considered to be commercially viable for wastewater treatment. Removal of efficiencies and equilibrium conditions are seen in Table 4 [104].

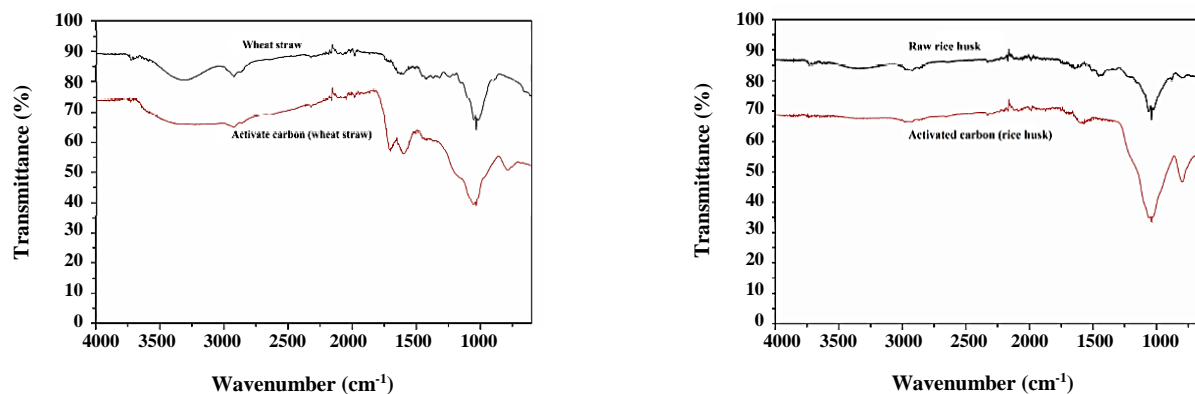


Fig. 4: FTIR Spectra of raw and activated carbons of rice husk, wheat straw and corncob [Adapted from [105]].

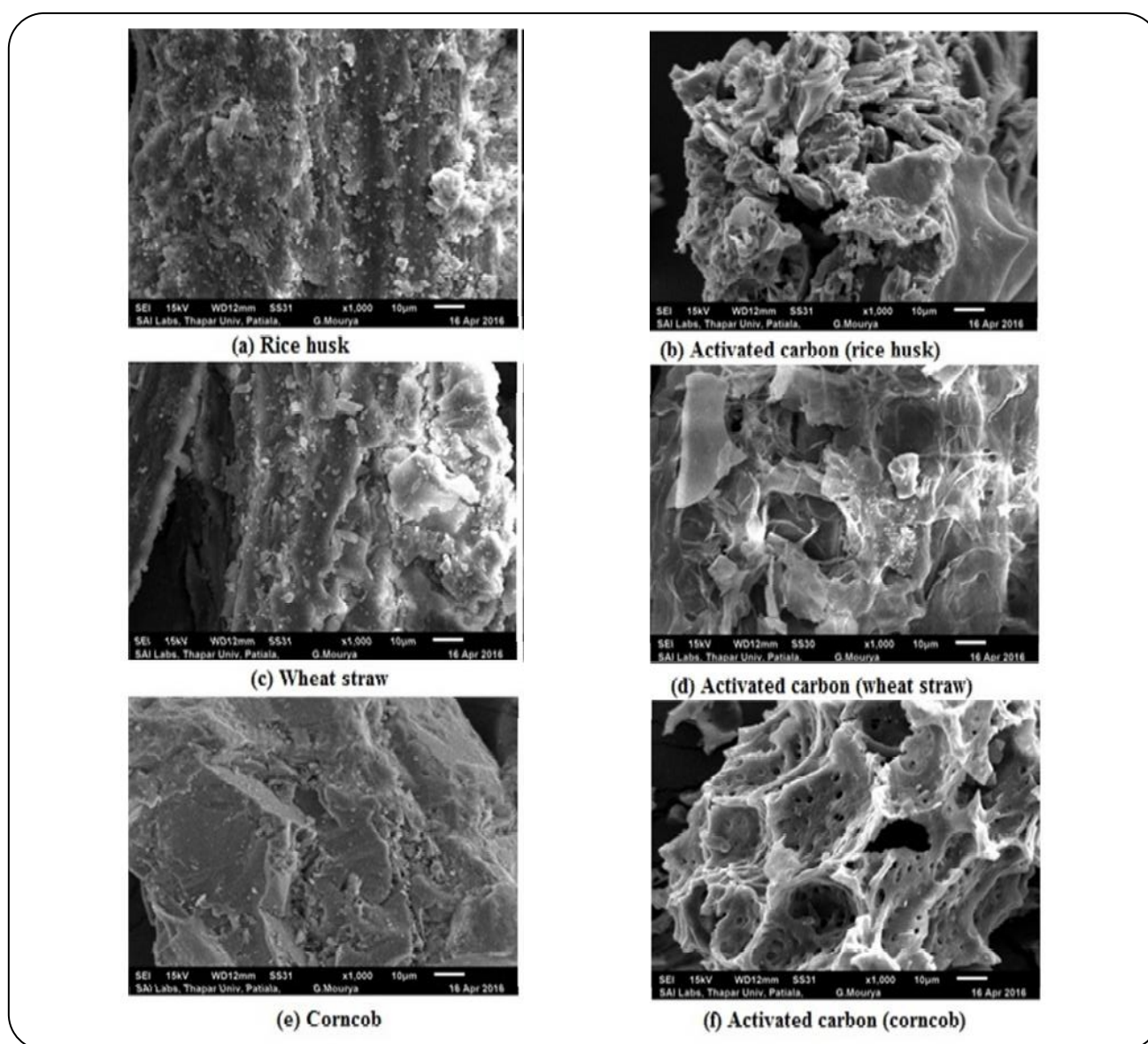


Fig. 5: SEM images of raw and activated carbons of rice husk, wheat straw, and corncob [Adapted from [105]].

Rice Husk (RH), corncob (CC), and Wheat Straw (WS) were used as precursors for an activated carbon process. A basic process involving chemical activation using NaCl was studied to produce activated carbon. FT-IR spectra of activated carbons were reported to evaluate the structural groups present on the surface. Fig. 4 indicates a significant difference in the surface chemistry of the processed activated carbons and the respective raw materials. This discrepancy could be due to the absence of several e-functional groups during the carbonization and activation cycles. Thermal oxidation during carbonization contributed to the dissolution and creation of some functional groups. The FT-IR spectra (Fig.4) of active rice husk carbon revealed the existence of the following functional groups: O-H level ( $600-800\text{ cm}^{-1}$ ); ester ( $1750-1800\text{ cm}^{-1}$ ); C-O and C-O-C ( $1060-1115\text{ cm}^{-1}$ ); alkyl halide C-Cl ( $1620-1680\text{ cm}^{-1}$ ). Fig. 4 is the FT-IR spectrum of raw and activated carbon (wheat straw). Peak height at  $3399\text{ cm}^{-1}$  correlates with the O-H stretch bond. Peaks about  $2950-2900\text{ cm}^{-1}$  are attributed to C-H stretching. The hydrophilic tendency ( $-\text{OH}$  groups) of raw and activated carbon (wheat straw) was expressed in the area of  $3700-3100\text{ cm}^{-1}$ . The highest at  $1652\text{ cm}^{-1}$  were the carboxylate groups. Peaks at  $1373\text{ cm}^{-1}$  reflected the asymmetrical deformation of C-H. Peaks in a range of  $1200-1059\text{ cm}^{-1}$  were both C-O stretch lines. FTIR spectra of activated carbon (corncob) also displayed identical effects. Fig. 5 (a), (b), and (c) are the SEM photos of rice husk, wheat straw, corncob, and their respective activated carbons. Figs. 5 (d), (e) indicate that the surfaces of the rice husk, wheat straw, and corn cob were smooth without pores for activation. Surfaces of related activated carbons, though, are rough which could be due to modification and treatment of NaCl. Porosity is often evident on surfaces of the activated carbon produced and could be due to successful activation and carbonization. Activated carbon (corncob) displayed a more brittle structure (Fig. 5 (f)) relative to other activated carbons. Porosity was outstanding adsorbent material as it offered a wide surface area for the adsorption cycle. An Energy Dispersive X-ray (EDX) study of the raw materials and the collected activated carbons was conducted to approximate the composition of the different components found in the adsorbents. This is seen from the fact that the carbon weight percentage increased in all three active carbons as a result of activation and carbonization as seen in Table 3.

The atmosphere is made of a high proportion of carbon and oxygen. The EDX study indicated the concentration of sodium and chlorine on activated carbons. As sodium chloride is a heavy dehydrating agent, it collects water from the ambient environment, increasing the raw material's porosity [105,106]. Other properties like the removal of efficiencies and equilibrium conditions are listed in Table 4.

#### *Algal/Fungal/Aquatic plants biomass*

The use of microbial biomass of the living, dead, and their components proved highly successful in detoxifying all metal forms, whether insoluble phase or particulate matter. Due to the presence of different functional classes, the cell surface of the microorganism was a negative phase, and carboxylic, hydroxyl, amines, and phenols provide a microorganism the ability to bind other cationic metals [106,107].

#### *Algal biomass*

Algae, sustainable natural biomass found proliferating all over the planet and abundantly in coastal areas, has drawn the attention of researchers as being a species to be tested and used as new metal ion adsorbents. Wide range, low cost, high metal sorption ability, and relatively good efficiency are the advantages of applying algae as biosorbents [108]. Algae is readily available in all lakes, and marine and ocean environments were used for the removal of heavy metals as biosorbent content. Red, green, and brown algae were used in adsorption analysis, although the focus was on brown algae due to its enhanced sorption capacity [21,109]. Throughout this segment, we addressed varieties of algal biomass such as the *Dunaliella* algae species [110], *Codium vermilara*, *Spirogyra insignis*, *Asparagopsis armata*, *Chondrus Crispus*, *Fucus spiralis*, and *Ascophyllum nodosum* [111]. Their efficiency and characteristics are described in Table 5.

The purest form of *Dunaliella* sp. (DS) an alga was centrifuged (5000 rpm for 20 min) and deposited in a liquid medium for 7 d at  $20^{\circ}\text{C}$  under a light. Toxicity and metabolic accumulation by a single-green flagellum sp of heavy metals were prosecuted. DS can organically remove heavy metals at a concentration of about 85 mg/L from wastewater. *Dunaliella* cells were first soaked in freshwater obtained from various sources for seven days and their growth levels were calculated at 560 nm wavelength.



**Table 3: Chemical composition of raw and activated carbons of rick husk, wheat straw and corncob using EDX [Adapted from [105]].**

| Elements | Chemical composition (%) |       |      |       |      |       |
|----------|--------------------------|-------|------|-------|------|-------|
|          | RH                       | RH-AC | WS   | WS-AC | CC   | CC-AC |
| C        | 30.1                     | 46.1  | 60   | 68    | 39.4 | 46.7  |
| O        | 58.4                     | 36.5  | 34.8 | 29.5  | 59.1 | 52.6  |
| Na       | 0.2                      | 2.3   | 1.6  | 0.9   | 0.2  | 0.1   |
| Mg       | 0.4                      | 0     | 0    | 0     | 0.3  | 0.2   |
| Si       | 9.7                      | 11.3  | 2    | 1     | 0.2  | 0.1   |
| Cl       | 0.1                      | 3.7   | 1.6  | 0.6   | 0.2  | 0.1   |
| Ca       | 0.7                      | 0.1   | 0    | 0     | 0.3  | 0.1   |
| Other    | 0.4                      | 0     | 0    | 0     | 0.3  | 0.1   |

**Table 4: Sorption of Ni (II) by agricultural activated carbon.**

| Adsorbent  | Modifying Agent                | Optimum conditions (pH, dose, Ni (II) concentration, equilibrium time, activated temp) | Sorbent capacity (mg/g) | Adsorption Efficiency(%) | Desorption Efficiency (%) | References |
|--|--------------------------------|--|-------------------------|--------------------------|---------------------------|------------|
| Peanut shell   | HCl                            | pH 4.8, 4 hrs, 800°C   | 0.546                   | Upto 75                  | 60                        | [99]       |
| Hazelnut shell   | H <sub>2</sub> SO <sub>4</sub> | pH 7, 180 mins at 50°C and 150°C   | 11.64                   | 80-90                    | NA                        | [100]      |
| rice straw, sugarcane bagasse, peanut shell, soybean hull                      | H <sub>2</sub> SO <sub>4</sub> | pH 5, 0.1g/L, 120 mins at 23°C and 800°C   | 0.5, 1.7, 2.2 and 3.4   | 90-95                    | NA                        | [102]      |
| Corepith   | H <sub>2</sub> SO <sub>4</sub> | pH 5 and 800°C   | NA                      | 92                       | 85                        | [103]      |
| Coconut tree sawdust, silk cotton hull, sago waste, banana pith, and maize cob | H <sub>2</sub> SO <sub>4</sub> | pH 4-5, 2.5 g/L, 25 mg/L and 60 mins at 29-33°C and 650°C                              | NA                      | 81, 58, 100, 100, 90.8   | NA                        | [104]      |
| Rice husk, wheat straw, and corncob  | NaCl                           | pH 12, 0.05 g/L, 50 mg/L and 240 mins at 25°C and 600°C                                | 72.4, 90.9 and 72.5     | 99.5, 99.2 and 88.7      | 70-90                     | [105]      |

It was found that the adsorption rate was so fast initially (0-24 hours) that 95% of the metal was biologically adsorbed. The average biosorption potential of DS was calculated as 0.79 mg for Ni(II) per 75 algae cells. Certain components were adsorbed at much lower concentrations. Toxicity and biosorption were significant in the DS production to treat heavy metal wastewater. DS algae may be used as phytomediators to reduce the exposure of heavy metals from polluted contaminants to humans [110].

Six algae from the three major groups (Green-Codium vermilara, Spirogyra insignis) (Brown-Asparagopsis armata, Chondrus crispus) (Red-Fucus spiralis, Ascophyllum nodosum) were chosen for the experiments. The analysis was prepared with much cleaning with washed water and a simple visual washing of impurities. The over-flow generated in any wash created tiny, much

harder biomass fragments that were centrifuged for 10–15 minutes at 5000 rpm. The pellet was mixed with previously washed biomass to avoid serious harm until the clear solvent was removed and the whole unit dried to a suitable weight of 60 °C in an oven. The samples were ground for biosorption to correct particle size (< 0.5 mm) when dry. The approximate biomass region (0.48 m<sup>2</sup>/g) was measured using an automated micrometer with N<sub>2</sub> adsorption at liquid nitrogen temperature. To extract nickel from aqueous solutions the sorption potential of six different algae (green, red, and brown) was checked. Optimal sorption conditions for each monometallic device were established. The optimal pH was 6 for Ni recovery. The strongest findings were achieved for the lowest concentration of biomass used (0.5 g/L). The experimental results matched the Langmuir model. Brown algae reached

the lowest concentration of metal in solution; better tests were obtained with *Ascophyllum nodosum* (50 mg/g). Eventually, a digital computer system was used to model the method by matching the theoretical with experimental findings and demonstrating small variations between the two data forms [111].

*Kappaphycus Alvarezii* (KA) samples were obtained and washed with deionized water (DI) for 2 days in sunlight. The maximum particle size was 0.75 mm for the dry algae biomass. This project investigated KA red algae's capacity to extract Ni(II). The biosorption process was characterized by FT-IR and SEM as interactions between positively loaded metal ions and negatively loaded functional groups on the surface of KA. Hence, the pH solution greatly impaired the biosorption potential of red seaweed. Isothermal biosorption obtained at pH 4.5 indicated that Ni was absorbed more by KA (9.24 mg/g). It was linked to its atomic weight, ion distance, and electric reactivity which clarified the sorbent's dynamic attraction to a single metal ion. The Toth model better estimated the experimental isothermal outcomes with good association and low error values across different isothermal models (Langmuir, Freundlich, Toth, and Sips). Kinetic testing showed that KA's levels of metal removal were high, and 90 percent of the process was completed in 2 g/L and 10 mg/L within 45 minutes. Maximal desorption of all-metal loaded ions was discovered in desorption tests utilizing different elutant (0.01 M NaOH, 0.1 M NaOH, 0.01 M HCl, and 0.1 M HCl). 0.01 M HCl reached a high eluant for KA [112].

New biomass of the plant's *Sargassum*, *Turbinaria*, and *Ulva* were gathered and washed thoroughly with deionized water and sun-dried to a particle size of 0.5–1 mm. This thesis investigated the possible usage of several sorbents for the combined elimination of eight sorbates (metals) from aqueous solutions. The tests were performed in both batch and continuous modes of service. Among the sorbents used in these batch studies, *turbinaria* was successful with a sorption strength of 280 mg/g at pH 4.5, 2 g/L, and 3 hours at 22°C, while it was 225 and *Ulva* 173 mg/g for other algae and *sargassum*. This research revealed many 1 functional problems relevant to the biosorption cycle, like leaching of excess light metal ions, weak anion compatibility, and the scent of effluent. The study also highlighted s other biosorption deficiencies and proposed technical approaches to overcome them [113].

*Sargassum* sp., *Turbinaria conoides* (brown algae), and *Ulva* sp. (green algae) were obtained at the site and sun-dried initially. Throughout the test, all marine weeds were deliberately cleaned and freed from sand and other impurities with deionized water. Samples of seaweed were n ground in a blender to achieve a mean particle size of 0.75 mm for use in tests after overnight over-drying. This work tested sorbent's potential to absorb heavy-metal ions from specific lab waste, thereby simulating an extremely complex laboratory effluent. In the laboratory effluent configuration, the overall concentration of heavy metals was 0.016 M. The most widely used heavy metal is Cd, Co, Cu, Cr, Mn, Ni, Pb, and Zn at 0.002 M each. In the emulation of laboratory effluents, nitrate salt with heavy metal ions was used. Each heavy metal reagent was prepared with a solution of 0.1 m and combined with 20 mL. By adding deionized water, the mixture was reduced to 1 L. Biosorption is a well-known heavy metal ion remediation technique but its functional use is little understood. Owing to the nature of their lives effluents produced in testing labs pose significant problems.s. This article uses specific biosorption techniques. For remediation of wastewater, eight different Ni(II) heavy metal ions were formed at a collective concentration of 0.016 M for the three seaweeds, *Sargassum*, *Ulva*, and *Turbinaria*. Between the seaweeds, the batch, and continuous operating mode *Turbinaria* worked well with a combined absorption capacity of 0.2 mmol/g, while the other algae were 0.05–0.2 mmol/g respectively. This paper also discusses the biosorption cycle of algae, together with practical problems in specific applications concerning the biosorption method, including plant design, cost, biosorbent supply, modus operativity, and final consistency of the effluent and final disposal [114].

Before using sand particles and salt extraction, *Gracilaria* (GS) species were collected and washed many times with tap water. For six days, it was dried in sunlight. The dry biomass was cut, milled, and used in adsorption studies (0.5–1 mm fraction size). Ni<sup>2+</sup> batch processing of Marine Dried (MD) red algae GS and it's Activated Carbon (AC) wastewater solution was documented. Adsorption of Ni<sup>2+</sup> used to form two AC and MD biomass was used for the experiments. Both methods used these amounts of pH, biomass, and original Ni<sup>2+</sup>. Adsorption models and clinical trials were eventually performed. The average Ni<sup>2+</sup> output for MD and AC respectively was 83.55 and 99.04%.

Experimental adsorption findings in the Langmuir adsorption model were updated. In the pseudo-second-order model nickel(II) adsorption of biosorbents was more accurately established. Kinetic studies revealed that AC was readily adsorbed by heavy metals relative to MD. AC developed using MD biomass demonstrated improved biosorption performance. The pH of the solvent is the adsorption potential; pH 5.0 is ideal for nickel. Ni<sup>2+</sup> removal was the highlight of the AC cycle. The pH ability of the component is connected; pH 5.0 is optimal for a nickel. Data for controlling adsorption was compatible with the Langmuir isotherm method. For kinetic second-order versions, adsorption kinetic data may be shown. Table 5 demonstrates optimum conditions and adsorption performance.[115].

Samples of brown aquatic algae were obtained and washed with tap water for 48 hours to extract sand and other impurities, including *Cystoseira Indica* (CI), *Sargassum Glaucescens* (SG), *Nizimuddinina Zanardini* (NZ), and *Padina Australis* (PA). Double Distilled Water (DDW) washed the bio-mass, which was then capped, and cleaned in a furnace at 80°C for 24 h, to a scale of 0.5–1.0 mm. Such a resource is referred to as preserved biomass. The ground alteration was done with formaldehyde (FA), glutaraldehyde (GA), polyethyleneimine (PEI), calcium chloride (CaCl<sub>2</sub>), and hydrochloric acid (HCl). The present research focuses on the determination of biosorption degradation of Ni(II) ions by both intact and pre-treated brown marine algae. The pH impacts, contact period, biomass concentration, and original metal content in the removal cycle were studied by batch shaking adsorption studies. For every heavy metal, optimum sorption conditions were appropriate. Single-way ANOVA and a subset of experiments were conducted to test the biosorption capacity which was statistically relevant after 5 cycles of sorption and desorption. Full adsorption potential of all algae under FA alteration (6.6, 4.06, 8.1, and 10.06 mg/g for NZ, PA, SG, and CI, respectively) at pH 6, was 2 g/L dose and 120 min contact time. Experimental equilibrium results were evaluated using common isotherms. The Freundlich model was more balanced by results between the model with two parameters and that 1 with three parameters of the isotherm Ni(II) of the Toth, Khan, and Radke-Prausnitz models. The kinetic state was designed for the first-order and second-order pseudo models. The second-pseudo-kinetic model

gave a stronger reason for nickel-ion biosorption from the collected data [116].

#### *Fungal biomass*

The fungus has a wide range of extra cells, amino acids, and other metabolites. Fungi can be suited to any environment and ecosystem [118-120]. The major functional groups involved in fungal biosorption are amines, amides, carboxyls, and phosphates [121]. Biosorption of metal ions results in Ionic interactions and a complex arrangement of heavy metal ions and feature classes on fungal cell surfaces [122]. Fermentation industries use fungal organisms to manufacture compounds such as pesticides, toxins, enzymes, additives, fragrances, flavorings, and microbial insecticides. Filamentous fungi are used as biosorption agents. Bioremediation is applied to many species because of its capacity to absorb toxic heavy metal ions from liquid substrates. A variety of fungal species such as *T.auroviride*, *T.Harzianum*, *T.Virens*, and *Aspergillus niger*, which are used in the cleaning phase in contaminated areas [123-129] were identified. Compared to other biosorption agents, fungi biomass had a strong proportion in cell wall products, with excellent metal-binding properties where significant amounts of heavy metals are consumed and there is no physiological activity [81]. Fungi (*Aspergillus* spp., *Mucor* spp., *Rhizopus* spp., and *Penicillium* spp.) have been commonly used as adsorbents for the elimination of harmful heavy metals from polluted wastewater. In this segment, we addressed a variety of fungal biomass such as *T.harzianum*, *T.Aureoviride*, and *T.Virens* [130], polyporous *Versicolor* [131], *aspergillusniger* [132,133], and *mucor rouxii* [134]. Their efficiency and characteristics are seen in Table 6.

Following seven days of incubation, flasks containing filamentous fungi (*T. Harzianum*, *T. Aureoviride*, and *T. Virens*) were extracted and purified using Whatman No. 1 filtering paper in various heavy metal concentrations. Samples of biomass were rinsed with dry water on many occasions and placed in an oven at 50°C until a constant weight was achieved. This research was performed to evaluate susceptibility levels to various amounts of heavy metals using three fungi. Based on the results, the strain of *T. virens* had the highest tolerance for Ni(II) at a concentration of 1200 mg/L. Accumulation and uptake ability was calculated by the full removal of Ni by

Table 5: Sorption of Ni (II) by algal biomass.

| Adsorbent  | Optimum conditions (pH, dose, Ni (II) concentration, equilibrium time, temp) | Sorbent capacity (mg/g)             | Adsorption Efficiency (%) | Desorption Efficiency (%) | References |
|--|--|-------------------------------------|---------------------------|---------------------------|------------|
| Dunaliella sp.   | 85 mg/L and 0-24 hrs at 25°C   | NA                                  | 95                        | NA                        | [110]      |
| Codium vermilara, Spirogyra insignis, Asparagopsis Armata, Chondrus crispus, Fucus spiralis, Ascophyllum nodosum | pH 6, 0.5 g/L, 50 mg/L and 60 mins at Room temperature                       | 13.2, 17.5, 17.1, 37.2, 43.3 and 50 | NA                        | NA                        | [111]      |
| Kappaphycus alvarezii  | pH 4.5, 2 g/L, 10 mg/L and 45 mins at 32°C                                   | 9.24                                | 90                        | 98.7                      | [112]      |
| Sargassum, turbinaria and ulva   | pH 4.5, 2 g/L and 180 mins at 22°C   | 225, 280 and 173                    | 10-15                     | NA                        | [113]      |
| Sargassum, turbinaria and ulva   | pH 5, 2 g/L, 10 mg/L and 180 mins at 22°C                                    | 2.43-4.86, 4.86 and 1.22-2.43       | 15-20                     | 41.2                      | [114]      |
| Gracilaria species   | pH 5, 4 g/L, 10 mg/L and 15 mins at 25°C                                     | NA                                  | 99.04                     | NA                        | [115]      |
| Cystoseira indica, Sargassum glaucescens, Nizimuddinina zanardini and Padina australis                           | pH 6, 2 g/L, 10 mg/L and 120 mins at 25°C                                    | 10.06, 8.10, 6.6 and 7.01           | 90                        | NA                        | [116]      |
| Enteromorpha prolifera   | pH 4.3, 1.2 g/L, 100 mg/L and 120 mins at 30°C                               | 36.8                                | 63.2                      | NA                        | [117]      |

T. harzianum in a liquid medium similar to other fungi. Ni(II) elimination at a concentration of 100 mg/L was 835 mg/g for T.harzianum, 512 mg/g for T.Aureoviride and 53 mg/g for T.virens [130].

**Polyporus Versicolor** (PV) was treated with sterile water. A 3.5 ml spore-containing fluid was inoculated into a 500 ml flask comprising a pH 5.5 200 ml PV growth medium. After inoculation, cultures were grown at 30°C on an orbital shaker (180 rpm). The use of white-red PV fungus as a bio sorbent for the removal of Ni(II) was examined. The effects of pH, time, temperature, and concentration were assessed in kinetic and isothermal sorption tests. A time-level variation of Ni(II) uptake and initial Ni(II) uptake at specific temperatures (20, 25, and 35°C) indicated that both the initial uptake rate and Ni(II) uptake capacity I increased with an increase in temperature. Biosorption of Ni(II), calculated in the Freundlicher and Langmuir models, has been sufficiently defined. PV adsorptive potential of Ni(II) showed an increase as the temperature increased from 20°C to 25°C, which was evident. The increase in initial concentration revealed a greater increase in metal absorption at 25°C and 35°C than at 20°C. At 35°C, the maximum adsorption

potential was achieved with pH 5 for 57 mg/g, appropriate PV dosage, ionic strength of 50 mg/L, 60 minutes, and optimal temperature [131].

The fungus used for the processing of citric acid and aconitic hydrase was *Aspergillus niger* (AN) was developed in a liquid medium using a shake flask. Biomass harvesting was carried out by filtering the cultured medium in the shake flask through a 150 µm sieve. After harvesting, the biomass was washed with deionized water. Ample biomass was used in carbon absorption tests. Technology to extract harmful heavy metal ions present in wastewater needs to be established. Micro-organisms are believed to absorb heavy metal ions from the soil. The ability of AN fungus to extract Ni, Cd, and Cu ions were assessed in this analysis. In minimizing nickel (1.75 mg/g), raw A.N biomass was more efficient than Cd and Cu (1.31 and 0.75 mg/g). Metal ion biosorption decreased at pH 3 and significantly improved when the pH of the solution was increased to 4. Adsorption equilibrium exceeded 5, 6, and 8 h respectively for Cd, Cu, and Ni. Equilibrium was attained in 5 h. For the 0.05N HNO<sub>3</sub> solution, 99.3% desorption was achieved in five cycles for biosorbed metal ions. As it elutinated, the accumulation of metal ions

was regenerated and then hit by the solution being washed with deionized water. This research found that fungal biosorption was capable of utilizing Ni (II) metal ions in drainage wastewater [132]. The same AN biomass used in another study by another author reported that metal adsorption capacity was better between pH 4 to 6 [133].

A laboratory strain of *Mucor Rouxii* (MR) was cultivated in the filamentous form under aerobic conditions for 3 days using liquid media in a shake flask. Various crop media were used to analyze their impact on biomass development and metal removal. Biomass was extracted by filtering the culture mixture into a 150 mm sieve. The biomass gathered was completely washed with large quantities of distilled-deionized water to eliminate the remaining growth medium. The washed biomass (live biomass) was subsequently used. Biosorption of Ni, Cd, and Zn by live *Mucor rouxii* biomass treated with NaOH was observed across a pH spectrum. The biosorption process contributed to the interaction of ions between monovalent metals when ions were extracted from water as they were counter ions e found in biomass macrophytes and heavy metal ions. The use of multi-metal or individual metal approaches revealed no significant differences in metal exchange. In the presence of additional metal ions, biosorption ability of individual metal ions was reduced for bi- or multi-metal ion adsorption, but total biosorption efficiency improved, demonstrating MR biomass potential for adsorption of multi-metal ions. MR biomass created with different media exhibited the same degree of capacity to fasten metal ions after the elucidated MR was washed using DI water before interacting with different adsorbates in various concentrations. While pure water demonstrated marginal metal elucidation, biomass-adsorbed metal ions with HNO<sub>3</sub> could be efficiently elucidated. Regeneration of NaOH biomass was not feasible until three adsorption–elution–regeneration cycles at approximately 8 mg/g restored or enhanced biosorption capacity [134].

#### *Aquatic plants biomass*

Aquatic plants ensure a perfect in-situ method with simple maintenance. Mechanisms for aquatic macrophyte metallurgical removal involve surface adsorption and/or absorption and penetration into or deposition of attached tissues [21,137]. In this portion, we discuss varieties of aquatic plants such as *lemna minor* [138], *spirodela polyrhiza* [139], *spirodela intermedia*, *lemna minor*, and

*pistia stratiotes* [140,141] and, *Ceratophyllum demersum* [142]. Their output and characteristics are described in Table 7.

Samples of *Lemna minor* (LM) (an aquatic plant) were collected before the experiment. n the LM sample(15x15x90cm), in 3 polyethylene panels was designed to maximize the surface of the water/airfield. Around 1 g of duckweed weights (around 50 leaf buds) were withdrawn from large tanks to start each test. Wet weight-associated well with dry weight, and hence the calculation of wet weight did not affect plants like measuring dry weight. About 88-94% of water was observed to be in LM samples after they were put in a drying oven at 105°C for two days. Heavy metal pollutants from surface water may be removed from marine plants. This work examined the potential of LM under different conditions in the laboratory to remove soluble lead and nickel. LM was tested for potential rivalries between adsorption metals in the Pb and Ni batch cycles. Original Pb and Ni levels were 0, 5, and 10 mg/L, and 0, 2.5, and 5 mg/L. LM extracted a minimum of 76% of lead and 82% of nickel. In multiple metal removal studies, no synergistic/antagonistic effect was identified [138]. Compared to LM, *Spirodela polyrhiza* (aquatic plant) revealed a maximum adsorption rate of 44.9 mg/g i n the Ni(II) metal solution [139].

Macrophytes (*Spirodela intermedia*, *Lemna minor*, and *Pistia stratiotes*) were washed with Mill Q water to clear evidence of extract pollutants, dried at 60°C and n grained in a Moulinex mill and sieved via a 2 mm sieve. In recent years there has been a rise in the use of dead dried aquatic plants as a basic biosorbent to extract metals obtained from manufacturing activities. The process was investigated in 3 biomass macrophytes for the simultaneous removal of Ni(II), Pb(II), and Cd(II). L. Minor biomass had the highest mean removal percentage and P. stratiotes the lowest for all metals tested. Average extraction capacity for 3 macrophytes at pH 6 was 0.44-1.14 mg/g in Ni=Cd at 0.26-0.31 mg/g at a dose 0.2g/L and 90 minutes contact period in metals of 10 mg/L. The findings were tested according to Langmuir and Freundlich isotherms simultaneously. Tests fitted the Langmuir with Ni and Cd only and, with Freundlich isotherm for all metals, while 97 percent was estimated to be taken out of Ni(II) (0.057-0.082 and 0.033-0.037 mg/g). First-order kinetics followed the adsorption process

**Table 6: Sorption of Ni (II) by fungal biomass.**

| Adsorbent   | Optimum conditions (pH, dose, Ni (II) concentration, equilibrium time, temp) | Sorbent capacity (mg/g) | Adsorption Efficiency (%) | Desorption Efficiency (%) | References |
|---|--|-------------------------|---------------------------|---------------------------|------------|
| Trichoderma harzianum, T. aureoviride and T. virens | pH 5, 100 mg/L at 26-30°C  | 835, 512 and 53         | 95-100                    | NA                        | [130]      |
| Polyporous versicolor                               | pH 5, 50 mg/L and 60 mins at 35°C  | 57                      | NA                        | NA                        | [131]      |
| Aspergillus niger                                   | pH 7, 0.1 g/L, 5 mg/L and 8 hrs at 20-24°C                                   | 1.75                    | 90-100                    | 99.3                      | [132]      |
| Mucor rouxii  | pH 5, 0.05 g/L, 5 mg/L and 60 mins at 20-24°C                                | 11.09                   | 90                        | 72                        | [134]      |
| Penicillium sp.                                     | pH 5.5, 7.5 g/L, 5 mg/L and 140 mins at 20-24°C                              | 63.6                    | 74.6                      | NA                        | [135]      |
| Aspergillus niger                                   | pH 6.25, 2.98 g/L, 30 mg/L and 120 mins at 30°C                              | 4.82                    | 70.3                      | NA                        | [136]      |

**Table 7: Sorption of Ni (II) by aquatic plants**

| Adsorbent  | Optimum conditions (pH, dose, Ni (II) concentration, equilibrium time, temp) | Sorbent capacity (mg/g) | Adsorption Efficiency (%) | Desorption Efficiency (%) | References |
|--|--|-------------------------|---------------------------|---------------------------|------------|
| Lemna minor  | 1 g/L, 10 mg/L   | NA                      | 82                        | NA                        | [138]      |
| Spirodela polyrhiza                                  | NA   | 44.9                    | NA                        | NA                        | [139]      |
| Spirodela intermedia, Lemna minor, Pistia stratiotes | pH 6, 0.2 g/L, 10 mg/L and 90 mins   | 0.44-1.14               | 97                        | NA                        | [140]      |
| Ceratophyllum demersum                               | pH 7, 6 mg/L   | 338.65                  | 50                        | NA                        | [142]      |
| Ensis siliqua  | pH 4, 1.6 g/L, 200 mg/L and 30 mins  | 0.79                    | 5-40                      | NA                        | [143]      |

for the three species were studied. The biosorption process contributed to the interaction of ions between monovalent metals when ions were extracted from water as they were counter ions found in biomass macrophytes and heavy metal ions. The use of multi-metal or individual metal approaches revealed no major differences in the metal exchange [140].

Ceratophyllum Demersum (CD) is a widely accessible water macrophyte. CD cultures were developed in nurseries in 30L plastic containers packed with half-strong Hoagland nutrient solution. Under these conditions, the plants were cultivated for 4 weeks before the start of the experiments. A pH 7 nutrient solution was substituted after 3 days. Preliminary pH experiments were conducted to establish the correct pH spectrum for plant research growth and metal accumulation. Phytoremediation with aquatic plants is a modern, reliable, and affordable approach to enhancing the quality of water and wastewater. In this analysis, the removal of nickel from the aquatic plant CD

was studied in four separate nickel concentrations 1 (0, 1, 2, 4, and 6 mg/L) after optimally increasing pH within 4 days of cultivation in a polluted Hoagland nutrient solution. A study of nickel concentration in the cultivation solvent and the original and final nickel concentration in plants assessed the ability for phytoextraction of nickel and the biological effects of nickel on coontail increasing with biomass production. Full removal output was 50 percent determined from a metal concentration of 6 mg/L. The average bioconcentration factor and the average metal absorption level of 6 mg/L were 338.6. Average (3.6 g/day) and minimum (1.27 g/day) biomass output was 0 mg/L and 6 mg/L of pollutant concentrations. Nickel phytoremediation by CD was correctly carried out based on the experiments [142].

The Review briefly explains the properties and removal characters of all reviewed adsorbents in this paper with the comparative results being shown in Table 8 and Figs. 6 & 7.

Table 8: A comparative review of Ni(II) sorption by the various adsorbent.

| Adsorbent                | Modifying Agent                         | Sorbent capacity (mg/g) | Adsorption Efficiency (%) | References |
|--------------------------|---|-------------------------|---------------------------|------------|
| Raw rice bran            | -                                       | NA                      | 40 to 50                  | [49]       |
| Moringo oleifera seeds   | -                                       | NA                      | 61.21                     | [54]       |
| Maple sawdust            | -                                       | NA                      | 75.00                     | [58]       |
| Coir pith                | ZnCl <sub>2</sub> and HCl               | NA                      | 58.00                     | [72]       |
| Maize cob                | H <sub>2</sub> SO <sub>4</sub> and NaOH | NA                      | above 95                  | [74]       |
| Corepith                 | H <sub>2</sub> SO <sub>4</sub>          | NA                      | 92.00                     | [103]      |
| Coconut tree sawdust     | H <sub>2</sub> SO <sub>4</sub>          | NA                      | 81.00                     | [104]      |
| Silk cotton hull         | H <sub>2</sub> SO <sub>4</sub>          | NA                      | 58.00                     | [104]      |
| Sago waste               | H <sub>2</sub> SO <sub>4</sub>          | NA                      | 100.00                    | [104]      |
| Banana pith              | H <sub>2</sub> SO <sub>4</sub>          | NA                      | 100.00                    | [104]      |
| Maize cob                | H <sub>2</sub> SO <sub>4</sub>          | NA                      | 90.80                     | [104]      |
| Dunaliella sp.           | -                                       | NA                      | 95.00                     | [110]      |
| Gracilaria species       | -                                       | NA                      | 99.04                     | [115]      |
| Lemna minor              | -                                       | NA                      | 82.00                     | [138]      |
| Quercus ilex             | -                                       | 0.01                    | NA                        | [55]       |
| Pistia stratiotes        | -                                       | 0.38                    | 97.00                     | [140]      |
| Rice straw               | H <sub>2</sub> SO <sub>4</sub>          | 0.50                    | 90 to 95                  | [102]      |
| Peanut shell             | HCl                                     | 0.55                    | Upto 75                   | [99]       |
| Lemna minor              | -                                       | 0.76                    | 97.00                     | [140]      |
| Ensis siliqua            | -                                       | 0.79                    | 5 to 40                   | [143]      |
| Spirodela intermedia     | -                                       | 1.14                    | 97.00                     | [140]      |
| Palm tree trunk peelings | -                                       | 1.59                    | 76.30                     | [56]       |
| Sugarcane bagasse        | H <sub>2</sub> SO <sub>4</sub>          | 1.70                    | 90 to 95                  | [102]      |
| Aspergillus niger        |   | 1.75                    | 90 to 100                 | [122]      |
| Peanut shell             | H <sub>2</sub> SO <sub>4</sub>          | 2.20                    | 90 to 95                  | [102]      |
| Ulva algae               | -                                       | 2.43                    | 15 to 20                  | [114]      |
| Syzygium aromaticum      | -                                       | 2.96                    | 74.00                     | [61]       |
| Green coconut shells     | NaOH                                    | 2.98                    | NA                        | [68]       |
| Shells of almond         | -                                       | 3.11                    | NA                        | [51]       |
| Jute fiber               | -                                       | 3.37                    | 34.92                     | [73]       |
| Oak sawdust              | HCl                                     | 3.37                    | 84.00                     | [79]       |
| Soybean hull             | H <sub>2</sub> SO <sub>4</sub>          | 3.40                    | 90 to 95                  | [102]      |
| Carissa Carandas         | -                                       | 3.76                    | 85.00                     | [61]       |
| Shells of hazelnut       | -                                       | 3.83                    | NA                        | [51]       |

Table 8: A comparative review of Ni(II) sorption by the various adsorbent.

| Adsorbent                    | Modifying Agent                     | Sorbent capacity (mg/g) | Adsorption Efficiency (%) | References |
|------------------------------|-------------------------------------|-------------------------|---------------------------|------------|
| Groundnut shells             | -                                   | 3.83                    | 51.40                     | [67]       |
| Aspergillus niger            | -                                   | 4.82                    | 70.30                     | [136]      |
| Sargassum algae              | -                                   | 4.86                    | 15 to 20                  | [114]      |
| Turbinaria algae             | -                                   | 4.86                    | 15 to 20                  | [114]      |
| Jute fiber                   | H <sub>2</sub> O <sub>2</sub>       | 5.57                    | 53.70                     | [73]       |
| Nizimuddinia zanardini       | -                                   | 6.60                    | 90.00                     | [116]      |
| Padina australis             | -                                   | 7.01                    | 90.00                     | [116]      |
| Groundnut shells             | Colouring agent                     | 7.49                    | 81.34                     | [67]       |
| Teakwood sawdust             | -                                   | 8.05                    | 51.40                     | [67]       |
| Sargassum glaucescens        | -                                   | 8.10                    | 90.00                     | [116]      |
| Kappaphycus alvarezii        | -                                   | 9.24                    | 90.00                     | [112]      |
| Teakwood sawdust             | Colouring agent                     | 9.87                    | 87.93                     | [67]       |
| Barbadensis Miller leaves    | -                                   | 10.00                   | 60.20                     | [63]       |
| Cystoseira indica            | -                                   | 10.06                   | 90.00                     | [116]      |
| Dalbergia sissoo sawdust     | NaOH                                | 10.47                   | NA                        | [82]       |
| Mucor rouxii                 | -                                   | 11.09                   | 90.00                     | [134]      |
| Hazelnut shell               | H <sub>2</sub> SO <sub>4</sub>      | 11.64                   | 80 to 90                  | [100]      |
| Codium vermilara             | -                                   | 13.20                   | NA                        | [111]      |
| Walnut shell                 | -                                   | 13.92                   | 96.00                     | [59]       |
| Tea waste                    | -                                   | 15.26                   | 86.00                     | [52]       |
| Asparagopsis Armata          | -                                   | 17.10                   | NA                        | [111]      |
| Spirogyra insignis           | -                                   | 17.50                   | NA                        | [111]      |
| Agrowaste of black gram husk | -                                   | 19.56                   | 90.50                     | [50]       |
| Nigerian-based bamboo        | HNO <sub>3</sub>                    | 20.00                   | NA                        | [83]       |
| Pigeon peas hulls            | H <sub>2</sub> SO <sub>4</sub>      | 23.64                   | 98.50                     | [69]       |
| Tobacco dust                 | HCl                                 | 24.50                   | 60 to 70                  | [78]       |
| Watermelon rind              | -                                   | 35.30                   | NA                        | [47]       |
| Meranti sawdust              | HCl                                 | 35.97                   | 94.00                     | [81]       |
| Enteromorpha prolifera       | -                                   | 36.80                   | 63.20                     | [117]      |
| Chondrus crispus             | -                                   | 37.20                   | NA                        | [111]      |
| Rice bran                    | HCl, NaOH, and Heat                 | 38.30                   | NA                        | [70]       |
| Tea leaves                   | Nano Fe <sub>3</sub> O <sub>4</sub> | 38.30                   | 99.00                     | [77]       |
| Fucus spiralis               | -                                   | 43.30                   | NA                        | [111]      |
| Spirodela polyrhiza          | -                                   | 44.90                   | NA                        | [139]      |



Table 8: A comparative review of Ni(II) sorption by the various adsorbent.

| Adsorbent              | Modifying Agent               | Sorbent capacity (mg/g) | Adsorption Efficiency (%) | References |
|------------------------|-------------------------------|-------------------------|---------------------------|------------|
| Ascomyllum nodosum     | -                             | 50.00                   | NA                        | [111]      |
| T. virens              | -                             | 53.00                   | 95 to 100                 | [130]      |
| Polyporous Versicolor  | -                             | 57.00                   | NA                        | [131]      |
| Peat                   | -                             | 61.27                   | 92.50                     | [62]       |
| Penicillium sp.        | -                             | 63.60                   | 74.60                     | [135]      |
| Soybean                | HCl, NaOH, and Heat           | 69.80                   | NA                        | [70]       |
| Rice husk              | NaCl                          | 72.40                   | 99.50                     | [105]      |
| Corncob                | NaCl                          | 72.50                   | 88.70                     | [105]      |
| Cottonseed hulls       | HCl, NaOH, and Heat           | 72.80                   | NA                        | [70]       |
| Bagasse and fly ash    | CH <sub>3</sub> COOH and NaOH | 83.60                   | 100.00                    | [76]       |
| Carob Seeds            | NaOH                          | 85.73                   | 76.00                     | [86]       |
| Wheat Straw            | NaCl                          | 90.90                   | 99.20                     | [105]      |
| Quercuscassipes        | -                             | 104.17                  | 95.00                     | [60]       |
| Orange peel            | -                             | 158.00                  | 97.50                     | [46]       |
| Ulva algae             | -                             | 173.00                  | 10 to 15                  | [113]      |
| Sargassum algae        | -                             | 225.00                  | 10 to 15                  | [113]      |
| Turbinaria algae       | -                             | 280.00                  | 10 to 15                  | [113]      |
| Ceratophyllum demersum | -                             | 338.65                  | 50.00                     | [142]      |
| T. aureoviride         | -                             | 512.00                  | 95 to 100                 | [130]      |
| Trichoderma harzianum  | -                             | 835.00                  | 95 to 100                 | [130]      |

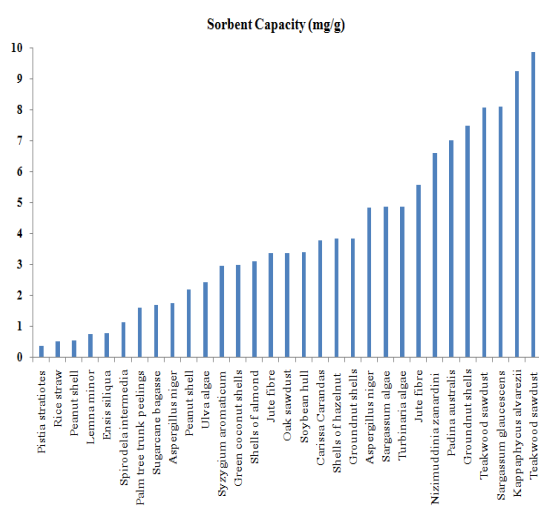


Fig. 6: A comparative review of Ni(II) sorption by various adsorbents (sorbent capacity &lt; 10 mg/g).

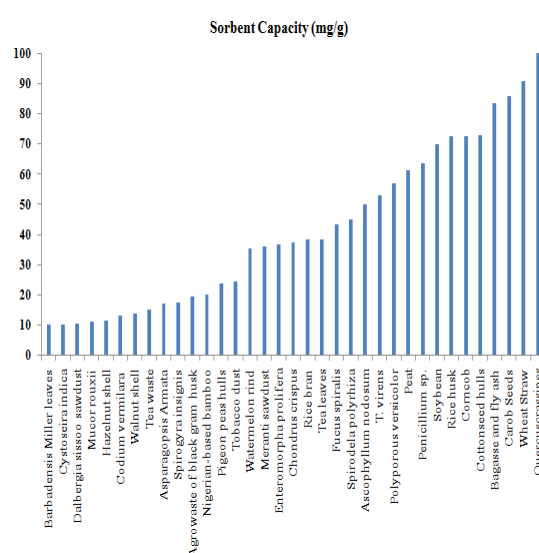


Fig. 7: A comparative review of Ni(II) sorption by various adsorbents (sorbent capacity 10 to 100 mg/g).

### **Disposal of used adsorbent after treatment**

To conform to environmental quality requirements, the spent biosorbent from experimental studies had to be detoxified and stabilized before its ultimate discharge or use. Conventional disposal methods are landfills, road surfacing, incineration, forestry, land reclamation, compression into building blocks, sea dumping, and carbonization. Another approach to add value to solid waste is to incinerate it, producing a high-energy output thereby reducing the volume for final disposal considerably. Nevertheless, the production of dioxins and poisonous by-products of combustion is a significant drawback of this method [144,145]. Chemical activation of sludge-based spent adsorbents was shown to be successful in the creation of surface areas and the improvement of adsorbent efficiency. However, the usage of chemical agents and acid washing of adsorbents was reported for the processing of waste solvents containing organic and inorganic impurities. The processing of such solvents is a major issue. More work is required on the use of eco-friendly and economic technologies to enhance the efficiency of spent adsorbent sludge to ensure safe disposal. Desorption of such adsorbents may add to the cost is yet another concern [146,147]. Reuse and disposal of used adsorbents is a significant concern not yet thoroughly considered, and which can be carried out in future research on metal removal. Thus the safe disposal of used adsorbent after proper stabilization is a better alternative in its management.

### **Future research on Ni (II) removal**

While a large number of research papers on Ni(II) adsorption reported on mineral surfaces at an incredible pace, there are still multiple gaps that require further research. Conducting more efficient nickel adsorption tests in the presence of another metal ion, anion, and dye on various adsorbents in multi-complex pollutant systems can be tried out. Many of the papers mentioned here included nickel adsorption by batch and column modes, and only a few operated on a pilot or industrial scale. Further advanced experimental techniques and instrumentation are required to clarify the real Ni(II) adsorption process at the solid-water interface. Highly effective, renewable, and eco-friendly materials with actual industrial effluents should be produced, and also the adsorption method should be viable, and cost-effective

under all environmental conditions. Reuse and disposal of used adsorbents is a concern not considered thoroughly. There exists a great ability to grow toxin-free and aggregation-free nano adsorbents composites to reduce Ni(II) ions from wastewater. Not much research is currently being undertaken in the usage of industrial byproducts such as pulp and paper waste, fabrics, feedstock, sludge, rubber, plastic, and medicinal waste and green waste such as leaves, barks, seeds, straws, and grass and use of animal skeletons, bones, flowers, hair, feathers as reduction adsorbents to remove Ni(II) ions.

### **CONCLUSIONS**

The current review has tried to address the position of natural/modified biomass as a significant treatment medium for the sequestration of Ni (II) from wastewater. It is evident from this research that the processing of nickel with different natural/modified biomass can be accomplished. A variety of scientific studies undertaken by scientists around the world have demonstrated strong absorption and removal efficiencies for biosorbents. A large spectrum of biomass provided very strong outcomes for nickel treatment in the literature. There is also tremendous scope for large-scale industrial projects in the future. This work shows that the recovery of nickel from natural/modified biomass is of great importance both economically and environmentally. The identification and development of new biomass for nickel removal are critical for potential research. Further, if suitable adsorbents and technologies that are highly successful in the elimination of heavy metals and a safe environment are tried out, they will also lead to a healthy world that safeguards human safety, thereby leading ultimately to more promising approaches for a secure and clean future.

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