

# Original Research Article

## POTENTIALITY OF WEED PLANTS FOR PHYTOREMEDIATION OF HEAVY METAL POLLUTED SOIL

### ABSTRACT

Soil remediation through plants is the return of soil to a condition of ecological stability together with the establishment of plant communities it supports to conditions prior to disturbance. Phytoremediation offers to metal-contaminated sites an innovative and cost-effective option to address recalcitrant environmental contaminants. Processes include using plants that tolerate and accumulate metals at high levels and using plants that can grow under conditions that are toxic to other plants while preventing. This article addresses key research, potential benefits and the potential future needs for phytoremediation. Total concentrations of heavy metals have been estimated in soil and weed plant samples growing in an industrial area of Rajkot region. Results indicated that uptake patterns of metals by weed plant tissues were more or less related with nature of metals and species specifications. All the studies suggested that each weed plant could be used as a modern tool as a biomonitor.

**Keywords:** Biomonitors, Environmental contaminants, Heavy metals, Plant communities, Phytoremediation

### 1 INTRODUCTION

Phytoremediation is combined multidisciplinary approach to the cleanup of contaminated soils, which combines the disciplines of plant physiology, soil chemistry, and soil microbiology. Phytoremediation has

**Comment [IH1]:** This should be removed from the Abstract. Include more details about the experimental program, the

25 been applied to a number of contaminants in small scale field and laboratory studies. These contaminants  
26 include heavy metals, radionuclides, chlorinated solvents, petroleum hydrocarbons, PCBs, PAHs,  
27 organophosphate insecticides, explosives, and surfactants [1]. Certain species of higher plants can  
28 accumulate very high concentrations of metals in their tissues without showing toxicity [2]. Such plants  
29 can be used successfully to clean up heavy metal polluted soils if their biomass and metal content are  
30 large enough to complete remediation within a reasonable period.

31  
32 Phytoremediation has secured popularity with government agencies and industry in the past ten years.  
33 This popularity is based in part on the relatively low cost of phytoremediation, combined with the limited  
34 funds available for environmental cleanup. The costs associated with environmental remediation are  
35 staggering. Currently, \$6-8 billion per year is spent for environmental cleanup in the United States, and  
36 \$25-50 billion per year worldwide [3]. Because biological methods are eventually solar-driven,  
37 phytoremediation is on average tenfold low-cost than engineering-based remediation methods. The way  
38 that phytoremediation is normally completed in situ adds to its expense adequacy and may decrease  
39 openness of the contaminated substrate to people, natural life, and the climate. ~~So that, government~~  
40 ~~agencies like to include phytoremediation in their cleanup strategies to stretch available funds,~~  
41 ~~corporations (e.g., electric power, oil, chemical industry) like to advertise their involvement with this~~  
42 ~~environment friendly technology, and environmental consultancy companies increasingly include~~  
43 ~~phytoremediation in their package of offered technologies.~~

**Comment [IH2]:** Rewrite this part, do not use "So" or "like" in academic writing. Use scientific words.

44  
45 In general, either in situ or ex situ, remediation technologies accomplish one of two things: They either  
46 remove the contaminants from the substratum (site decontamination or clean-up techniques) or lessen  
47 the risk of exposure (site stabilization techniques) to the contaminants. One "gentle" plant-based site  
48 stabilization approach, suitable for heavily contaminated sites, is phytostabilization aimed to decrease soil  
49 metal bioavailability using a combination of plants and soil amendments [4]. Another approach directed  
50 towards real decontamination is trace element phytoextraction, representing use of plants for trace  
51 element removal from the soil by concentrating them in the harvestable parts [5]. An opinion exists that

52 trace element phytoextraction will be more economically feasible if, in addition to metal removal, plants  
53 produce biomass with an added economical value [2].

54  
55 Recently, many plants have been reported to accumulate high level of the toxic metals in their sinks in the  
56 aquatic and terrestrial ecosystems. Such plants can remove the pollutant metals from soil and water [6,  
57 7]. This potential approach to clean the environment, termed phytoremediation, draws on our centuries of  
58 experience in cultivating crops and is emerging as a low cost treatment technology for the contaminated  
59 environment.

60  
61 Indian Mustard (*Brassica juncea* L), Italian serpentine plant (*Alyssum bertolonii*) and *Thlaspi caerulescens*  
62 are some of the most potential terrestrial plant species which have recently been used to extract heavy  
63 metals from soil and sediments and translocate these metals to the roots, harvestable stalks and leaves  
64 etc. of the plants [8]. Many other plants eg. spinach, cauliflower, cabbage, radish, onions, potato, wheat  
65 and *Eichhornia* etc. collected from Ni and Cr contaminated fields in the industrial vicinity of Sonapat  
66 (Haryana) have been reported to possess high sink for the metal accumulation [9]. Therefore, it appears  
67 that selecting a more appropriate plant species for the phytoextraction (phytoremediation), i.e. removal of  
68 heavy metals from the contaminated soils, sludges and sediments in the vicinity of the industrial towns  
69 having specific metal contaminants using a potential plant species/cultivar is yet a task ahead. For such  
70 an application, the contaminated sites with rich vegetation can provide naturally evolved  
71 hyperaccumulator and the metal tolerant species and cultivars which can be used commercially for the  
72 cleaning of the contaminated sites in a systematically cultivated manner.

73  
74 The selection of many potential phytoremediators need an areawise/metalwise screening keeping the  
75 Indian cultivars acclimatised for the specific agroclimatic conditions in mind. An attention to find out a  
76 local cultivar of commercially potential phytoremediator plants targeting to the cleaning of the specific  
77 sites of cities, towns and metropolitans suffering from the heavy metal contamination.

**Comment [IH3]:** In this paragraph, present the differences between your work and the previous work, the importance of your work, the novelty of your work (if any), and the new information that will be gained from this study.

**Comment [IH4]:** In the last paragraph of the introduction, you need to talk about your experiences.

## 79 2 MATERIALS AND METHODS

80 **2.1 Field survey**

81 Rajkot is most developing city of Gujarat and epicenter of the Saurashtra region. As per industrialization,  
82 there are more than 500 foundry units in Rajkot region. Most of foundry units in Rajkot produce grey iron  
83 castings for domestic market and also export to worldwide. Industrial products include bearings, diesel  
84 engines, kitchen knives, watch part, automotive parts etc. there are so many forging industries, casting  
85 industries and machine tools production units.

Comment [IH5]: What country?

86  
87 The industrial effluents are pulled on in a well through the number of channels and then disposed off in  
88 drain No.8, a canal in which sewage effluents also get mixed at certain points. Water of the drain No. 8  
89 containing industrial effluents along with the sewage waste water is lifted with the help of diesel pumps  
90 etc. to irrigate the crop field situated near by.

Comment [IH6]: Provide a figure showing that

91  
92 **2.2 Collection of soil samples**

93 Soil samples were collected from industrial fields. After removing grasses and other vegetation from the  
94 surface, samples were taken from 0-15 cm depth from 5 to 8 different points in the same location using  
95 Auger. All the samples were mixed together and almost 5 kg taken out of it. Half of the soil samples were  
96 dried in shade and then stored in clean polythene bag. These samples were then carried to the  
97 laboratory. There is no difference in soil profile for all the samples. At each site 2-3 composite samples  
98 were taken from different horizons viz., 0-15 cm, 15-30 cm and 30-45 cm segments. Dried Soil samples  
99 were crushed in to small pieces, mixed well together and spread it to make it air dry and passed through  
100 a sieve with round holes of 2 mm diameter. One kg of soil sample was taken as representative of the  
101 original material [10]. The samples were placed in clean polythene bag with tag, which had details of  
102 location, depth of soils etc.

Comment [IH7]: How many fields?

Comment [IH8]: Was the bag autoclaved, sterile or not?

Comment [IH9]: What do you mean There is no difference in soil profile for all the samples?

Comment [IH10]: How did you dry the soil?

Comment [IH11]: How did you crush the soil?

Comment [IH12]: How come ? Dried soil samples .....to make air dry?

Comment [IH13]: Provide a Table showing the samples and the information?

103  
104 **2.3 Analysis of Soil**

105 At the outset, a comprehensive survey was conducted in order to evaluate soil from different locations of  
106 industrial areas located in Rajkot for assessment of heavy metals contamination (Cu, Cr, Mn, Pb and Cd).

107

108 **2.3.1 Physico-chemical properties**

109 **Table 1. Methods for Physico-chemical properties**

| Properties              | Methods   |
|-------------------------|---|
| Soil texture            | Hydrometric method [11].                                    |
| Ph                      | Digital pH meter [12].                                      |
| Electrical conductivity | Digital EC meter [12].                                      |
| Bulk Density            | By lab method for disturbed soil. [13]                      |
| Soil Organic Carbon     | Walkley and Black method [14]                               |
| Soil Organic Matter     | Van Bemmelen,[15]   |
| Heavy Metals            | Atomic Absorption Spectrophotometer (AAS), DTPA method [16] |

**Comment [IH14]:** Provide information about the data in Table 1

110

111 **2.3.2 Contamination factor (CF)**

112 The CF is the ratio obtained from heavy metal concentrations in polluted and background sites [17].

113

114  $CF = C_{mSample} / C_{mBackground}$

115

116 Where  $C_m$  represents the concentrations of metals in contaminated and background sites.

117

118 **2.3.3 Pollution load index (PLI)**

119 PLI was calculated by the following formula adopted from Muhammad et al. [18].

120  $PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \dots \dots \dots CF_n}$

121 Where n is the number of metals and CF is the contamination factor value.

122

123 **2.4 Collection of weed plants**

124 **2.4.1 Survey the flora of contaminated sites**

125 An ecological survey was done from March 2009 to March 2010. Community analysis was carried out  
126 during rainy season when majority of the plants were at the peak of their growth. In every study sites, 30  
127 quadrats of 10 m X 10 m (100 sq m) size were randomly laid to study plant species. The herbaceous  
128 species was studied by laying 50 quadrats of 1m X 1m (1sq m) size randomly in each study site.

**Comment [IH15]:** Provide a Table showing the samples and the information?

129

130

#### 131 **2.4.1.1 Quantitative analysis**

132 The important quantitative analysis such as density and frequency of tree species, shrubs and herbs  
133 species were determined as per Curtis and McIntosh [19].

##### 134 **(a) Density**

135 Density is an expression of the numerical strength of a species where the total number of individuals of  
136 each species in all the quadrats is divided by the total number of quadrats studied.

137

138 Density is calculated by the equation:

$$139 \text{ Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$140 \text{ Total number of quadrats studied}$$

141

##### 142 **(b) Frequency (%)**

143 This term refers to the degree of dispersion of individual species in an area and usually expressed in  
144 terms of percentage occurrence. It was studied by sampling the study area at several places at random  
145 and recorded the name of the species that occurred in each sampling units.

146

147 It is calculated by the equation:

$$148 \text{ Frequency (\%)} = \frac{\text{Number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}} \times 100$$

$$149 \text{ Total number of quadrats studied}$$

150 Due to the heterogeneity of the characteristics of the soil, observed in the first sampling, each subplot  
151 was divided equally, establishing 20 different vegetation sampling sites. Surveys were conducted in

152 October-November 2021. For each survey, a 30 X 30 cm quadrat was used [20]. The quadrat was  
153 randomly placed three times within each sampling site. Plant species were listed and vegetation cover  
154 estimated. Plant species were determined and named following the keys and nomenclature proposed by  
155 Valde's et al. [21]. Than the most frequent species were collected for metal analysis.

## 156 **2.5 Analysis of Weed plants**

### 157 **2.5.1 Metal analysis of plants of contaminated sites.**

158 Plant samples were collected from the same sites as the soil samples. Plant identification was confirmed  
159 by the Forest Research of India, Dehradun. At least three to five individuals of all plant species were  
160 randomly collected within the sampling areas. Fresh plant materials were washed thoroughly with the tap  
161 water, washed for at least 15 seconds with a 0.1 N HCl solution and cleaned with distilled water and then  
162 separated into leaf, root and shoot. All plant parts were oven dried at 72°C for 72 h and then ground and  
163 passed through a 500-mm stainless-steel sieve to powders. For total metal concentrations in the plant  
164 components 0.5 g of plant samples were digested. Heavy metal concentrations in plants were also  
165 determined by the method as outlined by Gupta [22]. The total metal concentrations were measured by  
166 an atomic absorption spectrophotometry (AAS A-700, Perkin-Elmer) [16]. To assess the analytical  
167 precision, three analytical replicates of each sample, an appropriate standard reference material (from  
168 Sigma-Aldrich Company) and a reagent blank were performed in each analytical batch.

169

### 170 **2.5.2 Bio-accumulation factor (BAF)**

171 Bio-accumulation factor is used to explain the transport of trace elements (heavy metals) from  
172 complex soil mixture to plants. The bioaccumulation factor of a metal can be calculated as the  
173 ratio between the amount of metal in the plant (dry weight) to same in the corresponding soil  
174 [23, 24]. The BAF for different heavy metals was calculated as follows:

175

$$176 \quad \text{BAF} = C_{\text{Plant}} / C_{\text{Soil}}$$

177

**Comment [IH16]:** Add the details of the methods here, the procedure and then use the reference.

178 *C Plant* is concentration of heavy metal in plant (dry weight) and *C Soil* is concentration of heavy metal in  
179 corresponding soil under plant. BAF =1 means plant only absorbed the heavy metal but no accumulation  
180 while BAF > 1 denotes absorption and accumulation of heavy metal by plant [25].

## 181 2.6 Data analysis

182 Statistical analysis was done by an analysis of variance (ANOVA). Data were considered to be significant  
183 at p % 0.05 and highly significant at p % 0.005, level of significance.

184

## 185 3 RESULTS AND DISCUSSION

### 186 3.1 Analysis of Soil

#### 187 3.1.1 Physico-chemical properties of Soil

188 Texture of contaminated soil was the class sandy clay loamy which was in accord with the report of Carter  
189 and Gregorich [26]. Texture reflects the particle size distribution of the soil and thus the content of fine  
190 particles like oxides and clay. These compounds are important adsorption media for heavy metals in  
191 soils. Results showed that Shapar soil samples had sand particle between 68 to 70 % where Agricultural  
192 samples had almost 67%. Sand particles in Metoda samples were between Agricultural samples and  
193 Shapar samples. Silt particles were minimum in Agricultural samples like as 8 to 10 %. Silt particles were  
194 maximum in Metoda samples near about 12%. Silt particles in Shapar samples had also near about 10%.  
195 Clay particles were maximum (24%) in Agricultural soil samples where minimum (19%) in metoda A  
196 samples. The results obtained indicate that the dumpsite soils were highly permeable which are not  
197 suitable for waste disposal due to its high leaching capability contaminating groundwater resource in and  
198 around the waste dumpsite.

199

**Table 2. Soil Texture**

| Textural composition (%) | Different soil profiles (0-15)cm soil depth |            |            |            |
|--------------------------|---|------------|------------|------------|
|                          | Metoda A                                    | Metoda B   | Shapar A   | Shapar B   |
| Sand (0.05– 2.0 mm)      | 68.75±0.85                                  | 67.84±0.85 | 69.27±0.85 | 68.9±0.85  |
| Silt (0.002– 0.05 mm)    | 11.99±0.45                                  | 12.03±0.43 | 10.15±0.45 | 10.06±0.45 |

**Comment [IH17]:** Provide the details here. What have you done?

**Comment [IH18]:** What type of test did you use?

**Comment [IH19]:** How did you determine the percentage of silt in the soil sample?

**Comment [IH20]:** Table 2 is not explained in the text?

|                  |            |            |            |            |
|------------------|------------|------------|------------|------------|
| Clay (<0.002 mm) | 19.26±0.51 | 20.13±0.55 | 20.58±0.52 | 21.04±0.53 |
|------------------|------------|------------|------------|------------|

Mean values ± Standard deviation of means of three replicates

200  
201  
202  
203  
204  
205  
206  
207  
208

pH is one of the most significant parameter which influences the availability of most of the elements in the soil to both plants and microbes. The soil when continuously amended with industrial waste alters the pH to a certain extent and thus one crucial aspect in pollution studies of soils [27]. The physico – chemical analysis of the dumpsite soil samples investigated in the present study revealed pH value was varied from 6.8 to 7.2 in summer and 6.9 to 7.3 in winter (Grapg.4.1) with a mean pH of 6.98 in summer and 7.12 in winter [28] which were in accord with the ranges reported by [29] in their earlier studies.

Comment [IH21]: Explain that?

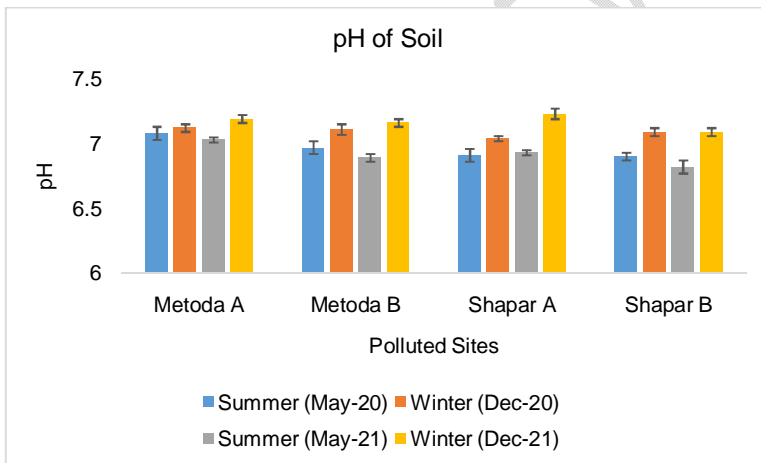


Figure 1. pH of Soil samples

Mean values ± Standard deviation of means of three replicates

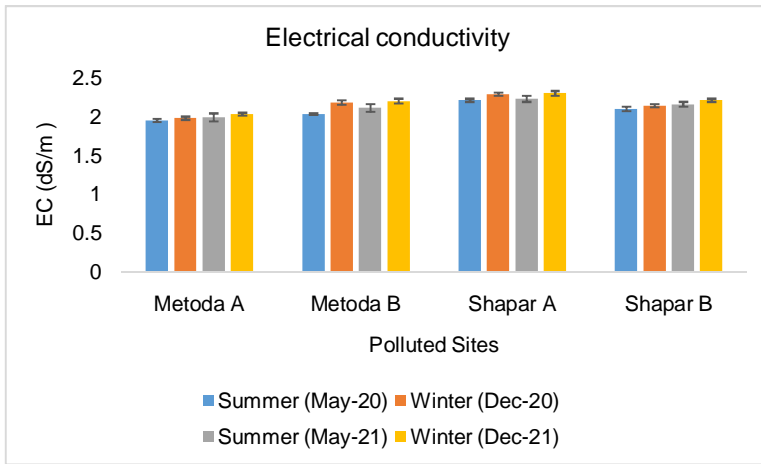
209  
210  
211  
212  
213  
214  
215  
216

The electrical conductivity recorded for the soil samples in the polluted sites ranged from 1.95 dS/m to 2.23 dS/m in summer and 1.98 dS/m to 2.3 dS/m in winter (Fig. 2) with a mean EC of 2.09 dS/m in summer and 2.18 dS/m in winter. The results were similar to those reported by Uba *et al.*, [30]. The mean EC recorded for the control soil samples was 0.38 dS/m in summer and 0.4 dS/m in winter. The EC

Comment [IH22]: What is Metoda A Metoda B...

Comment [IH23]:

217 recorded for the polluted site soils were slightly above the prescribed ranges for agricultural soils which  
 218 might hinder the uptake of water by the plants from the soils [31].  
 219



220  
 221 **Figure 2. EC of Soil samples**

222 *Mean values ± Standard deviation of means of three replicates*

223  
 224 Bulk density is an indicator of soil suitability for plant growth. The bulk density recorded for the soil  
 225 samples in the polluted sites were ranged from 1.29 mg/m<sup>3</sup> to 1.32 mg/m<sup>3</sup> in summer and 1.25 mg/m<sup>3</sup> to  
 226 1.3 mg/m<sup>3</sup> in winter with a mean bulk density of 1.31 mg/m<sup>3</sup> in summer and 1.28 mg/m<sup>3</sup> in winter. The  
 227 mean bulk density recorded for the control soil samples was 1.38 mg/m<sup>3</sup> in summer and 1.37 mg/m<sup>3</sup> in  
 228 winter. ). Mathur [32] observed that bulk density of soil treated with organic manure decreased from 1.46  
 229 to 1.40 mg/m<sup>3</sup> which confirms the present findings. Similar results were also reported by Chaudhury [33]  
 230 in a 31 years long-term field experiment for assessing soil quality under rice-based cropping system in  
 231 Indo-Gangetic alluvial soils of India.

Comment [IH24]: How did you determine the bulk density of the soil? You need to show that in the methods.

232  
 233 **Table 3. Bulk Density of Soil**

| Bulk Density (mg/m <sup>3</sup> ) |
|-----------------------------------|
|                                   |

Comment [IH25]: Why is the bulk density high in the summer and low in the winter?

| Site               | Metoda A  | Metoda B  | Shapar A  | Shapar B  |
|--------------------|-----------|-----------|-----------|-----------|
| Summer<br>(May-20) | 1.31±0.03 | 1.3±0.02  | 1.29±0.01 | 1.29±0.01 |
| Winter<br>(Dec-20) | 1.29±0.02 | 1.28±0.02 | 1.26±0.01 | 1.25±0.02 |
| Summer<br>(May-21) | 1.32±0.01 | 1.32±0.01 | 1.31±0.02 | 1.3±0.01  |
| Winter<br>(Dec-21) | 1.29±0.02 | 1.3±0.01  | 1.3±0.02  | 1.29±0.02 |

Mean values ± Standard deviation of means of three replicates

234  
235  
236  
237  
238  
239  
240  
241  
242

The soil organic carbon in the polluted site soils ranged from 0.78% to 1.02% in summer and 0.8% to 0.96% in winter with a mean of 0.9% in summer and 0.88% in winter. The mean soil organic carbon recorded for the control soil samples analyzed was 0.57% in summer and 0.58% in winter. The high soil organic carbon of the dumpsite soils is due to the high organic and compostable matter degradation [34] and also silt content in the soils which might have contributed to the excessive accumulation of SOC [35].

**Comment [IH26]:** What is the control soil samples? You have talked about it in the method?

**Table 4. Organic Carbon of Soil**

| Organic Carbon %   |           |           |           |           |
|--------------------|-----------|-----------|-----------|-----------|
| Site               | Metoda A  | Metoda B  | Shapar A  | Shapar B  |
| Summer<br>(May-20) | 0.9±0.02  | 0.96±0.02 | 0.78±0.02 | 0.81±0.02 |
| Winter<br>(Dec-20) | 0.89±0.03 | 0.92±0.02 | 0.81±0.02 | 0.8±0.03  |
| Summer<br>(May-21) | 0.98±0.02 | 1.02±0.03 | 0.87±0.02 | 0.9±0.02  |
| Winter<br>(Dec-21) | 0.91±0.03 | 0.96±0.03 | 0.81±0.03 | 0.86±0.02 |

**Comment [IH27]:** Explain the results and the data.

243 *Mean values ± Standard deviation of means of three replicates*

244 The SOM (Soil Organic Matter) of soil samples in the polluted site soil samples were ranged from 1.34%  
245 to 1.76% in summer and 1.38% to 1.66% in post - monsoon with a mean of 1.55% in summer and 1.52%  
246 in winter. The mean soil organic matter recorded for the control soil samples analyzed was 0.96% in  
247 summer and 1.00% in winter. However among all the soil samples analyzed control (Agricultural) soil  
248 samples recorded lower SOM percentages compared to the polluted site soils which was in accord with  
249 the previous studies of [36]. Soil organic matter is thus one crucial characteristics impacting soil physical  
250 properties.

251 **Table 5. Soil Organic Carbon**

| <b>Soil Organic Matter %</b> |                 |                 |                 |                 |
|------------------------------|-----------------|-----------------|-----------------|-----------------|
|                              | <b>Metoda A</b> | <b>Metoda B</b> | <b>Shapar A</b> | <b>Shapar B</b> |
| Summer<br>(May-20)           | 1.55±0.05       | 1.66±0.06       | 1.34±0.07       | 1.40±0.06       |
| Winter<br>(Dec-20)           | 1.53±0.05       | 1.59±0.06       | 1.40±0.07       | 1.38±0.05       |
| Summer<br>(May-21)           | 1.69±0.06       | 1.76±0.05       | 1.50±0.07       | 1.56±0.07       |
| Winter<br>(Dec-21)           | 1.57±0.05       | 1.66±0.04       | 1.40±0.06       | 1.48±0.06       |

252 *Mean values ± Standard deviation of means of three replicates*

253  
254 Copper content in the soils of the polluted site soil samples were ranged from 3.9 mg/kg to 6.83 mg/kg in  
255 summer and 6.38 mg/kg to 9.01 mg/kg in winter with a mean of 5.37 mg/kg in summer and 7.7 mg/kg in  
256 winter. The results recorded for polluted site soils might be due to the introduction of the industrial wastes  
257 which might increase the soil copper levels [37]. The mean copper content of the control soil samples  
258 recorded was 1.46 mg/kg in summer and 1.98 mg/kg in winter. Among all the samples analyzed polluted  
259 site soils recorded lower copper levels beyond the International Standards for Agricultural soils.

260

261 The amount of manganese varies greatly and is generally present in the form of manganese associated  
262 with organic matter, exchangeable manganese or manganese oxides. The mean Mn content in the soils  
263 of the polluted site ranged from 23.5 mg/kg to 25.6 mg/kg in summer and 24.4 mg/kg to 29.41 mg/kg in  
264 winter with a mean of 24.55 mg/kg in summer and 28.71 mg/kg in winter. The results recorded for the  
265 polluted site soil samples were lower than the ranges reported in a similar study by Udemé [38]. The  
266 mean Mn content of the control soil samples recorded 13.51 mg/kg in summer and 16.33 mg/kg in winter.  
267 Among all the soil samples analyzed polluted site soils recorded higher Mn content than the control soil  
268 samples due to the solubilizing effect of organic matter on Mn. The high Mn levels in polluted site may be  
269 due to the discarded battery materials and other metallic discards [39].

270 The mean Cr content in the soils of the polluted site samples were ranged from 0.21 mg/kg to 0.4 mg/kg  
271 in summer and 0.21 mg/kg to 1.02 mg/kg in winter with a mean of 0.31 mg/kg in summer and 0.62 mg/kg  
272 in winter. Similar study by Nwajei [40] also reported lower levels of Cr in the surface soils of a waste  
273 polluted site. The mean Cr content in the control sample recorded was 0.24 mg/kg in summer and 0.22  
274 mg/kg in winter.

275 The mean Pb content in the soil samples from the polluted site ranged from 2.68 mg/kg to 19.21 mg/kg in  
276 summer and 24.6 mg/kg to 41.02 mg/kg in winter with a mean of 10.95mg/kg in summer and 32.81 mg/kg  
277 in winter presented. The mean Pb content in control soil sample analyzed was recorded 0.2 mg/kg in  
278 summer and 0.21 mg/ kg in winter. Among all the soil samples analyzed polluted site soils recorded  
279 higher Pb content than the control soil samples which was similar to the previous findings of Ogunyemi  
280 [41]. The high Pb levels in polluted site soils may be due to the discarded plastics, glasses, paints,  
281 ceramics, batteries etc; The overall mean Pb levels recorded for the dumpsite soils samples in both the  
282 seasons were beyond the WHO standards for soil and below the International Standards for Agricultural  
283 soils.

284 The mean Cd content in the soils of the polluted site samples were ranged between 0.18 mg/kg to 0.25  
285 mg/kg in summer and 0.23 mg/kg to 0.38 mg/kg in winter with a mean of 0.22 mg/kg in summer and 0.31  
286 mg/kg in winter. The mean Cd content in control soil samples was recorded 0.02 mg/kg in summer and  
287 0.03 mg/kg in winter. Among all the samples analyzed polluted site soils recorded higher Cd levels than

288 the control soil samples. The overall mean Cd levels in polluted site soils were within the permissible  
 289 ranges of the International Standards for Agricultural soils and WHO. The results obtained were contrary  
 290 to a similar study of Awokunmi [42] who reported very high levels of Cd levels in the surface soils of the  
 291 polluted site. Many industrial processes required cadmium content raw materials and many industrial  
 292 operations required cadmium as a catalyst; hence these applications are responsible for increase the  
 293 lead content [43].

294

295 **Table 6. Heavy metals of Soil (in mg/kg)**

|                     | Elements        | Cadmium   | Lead       | Chromium  | Manganese  | Copper    |
|---------------------|-----------------|-----------|------------|-----------|------------|-----------|
| <b>Metoda<br/>A</b> | Summer (May-20) | 0.2±0.01  | 2.68±0.08  | 0.4±0.01  | 25.5±0.62  | 6.68±0.32 |
|                     | Winter (Dec-20) | 0.23±0.06 | 30.01±0.42 | 0.41±0.05 | 26.01±0.63 | 6.92±0.52 |
|                     | Summer (May-21) | 0.2±0.01  | 18.4±0.51  | 0.4±0.01  | 25.6±0.52  | 6.83±0.41 |
|                     | Winter (Dec-21) | 0.31±0.01 | 36.31±1.02 | 1.02±0.04 | 29.41±0.87 | 8.34±0.69 |
| <b>Metoda<br/>B</b> | Summer (May-20) | 0.21±0.01 | 2.69±0.12  | 0.31±0.02 | 25.00±0.28 | 6.05±0.5  |
|                     | Winter (Dec-20) | 0.27±0.01 | 24.6±0.78  | 0.38±0.04 | 25.87±0.81 | 6.38±0.25 |
|                     | Summer (May-21) | 0.2±0.05  | 14.51±0.58 | 0.35±0.03 | 25.21±0.42 | 6.12±0.21 |
|                     | Winter (Dec-21) | 0.32±0.01 | 28.06±1.25 | 0.98±0.01 | 28.06±0.85 | 7.59±0.22 |
| <b>Shapar<br/>A</b> | Summer (May-20) | 0.18±0.01 | 2.68±0.05  | 0.32±0.01 | 24.00±0.96 | 3.9±0.05  |
|                     | Winter (Dec-20) | 0.32±0.02 | 32.78±1.04 | 0.21±0.01 | 24.4±0.84  | 6.57±0.52 |
|                     | Summer (May-21) | 0.25±0.02 | 19.21±1.02 | 0.21±0.02 | 23.9±0.74  | 5.28±0.5  |
|                     | Winter (Dec-21) | 0.37±0.02 | 41.02±0.21 | 0.29±0.02 | 26.54±1.05 | 7.91±0.5  |
| <b>Shapar<br/>B</b> | Summer (May-20) | 0.21±0.01 | 2.68±0.05  | 0.40±0.01 | 23.5±0.88  | 4.09±0.05 |
|                     | Winter (Dec-20) | 0.38±0.02 | 30.14±0.85 | 0.32±0.01 | 25.93±1.04 | 7.82±0.14 |
|                     | Summer (May-21) | 0.23±0.02 | 15.67±0.52 | 0.30±0.01 | 23.53±0.99 | 5.42±0.5  |
|                     | Winter (Dec-21) | 0.3±0.01  | 39.10±0.75 | 0.40±0.01 | 26.88±1.05 | 9.01±0.6  |

296 *Mean values ± Standard deviation of means of three replicates*

297

298 **3.1.2 Contamination factor and Pollution load index**

299 Heavy metal concentrations in soil of Rajkot industrial zones are mentioned in table 1 & 2. With the help  
300 of background value (agricultural soil) of the heavy metals the contamination factor and pollution load  
301 index (PLI) was calculated which reflects the pollution of metals in soil. Contamination factor of metals in  
302 Metoda soil sample was Cu (1.98), Mn (1.58), Cr (1.58), Cd (7.67) and Pb (166.72). The PLI for this site  
303 was 397.51. Contamination factor of Shapar soil sample was Cu (2.24), Mn (1.58), Cr (1.23), Cd (12.67)  
304 and Pb (167.44). The PLI value for this site was 480.49. The Shapar site was highly contaminated when  
305 compared to the Metoda sites. These high values of PLI in the study area could be due to open dumping  
306 of industrial waste that may cause a potential health risk to the local community as well to grazing  
307 animals. In this study, the PLI values were greater than those reported by Muhammad et al. [18].

308  
309 Accumulation of lead in soil was significantly high compare to other metals found in their respective  
310 presence in soil during the study period. The intensity of adverse effects of several heavy metals depends  
311 upon the form and percentage distribution in soil. The soil parameters such as soil texture, organic matter  
312 content, pH, redox potential will affect the mobility of metal and its translocation [44]. Most of the trace  
313 metals are found in crystalline state and are immobile. Oxides of iron and manganese are generally  
314 coated on organic matted present in soil and fine particles of clay along with other colloidal material which  
315 are generally active provide mobility platform to trace metal. Several human interventions in environment  
316 geochemical cycle of trace metals, resulting in soil and water contamination which finally enters in food  
317 chain [44].

318  
319 The CF values at the Metoda site were observed to be in the order of  $Pb > Cd > Cu > Mn \geq Cr$ . According to  
320 the Muller classification, Pb and Cd were present at very highly polluted levels; others were highly  
321 polluted. The CF values at the Shapar site were observed to be in the order of  $Pb > Cd > Cu > Mn > Cr$ . The  
322 concentrations of Pb, Cd and Cu were present at very highly polluted levels; others were highly polluted  
323 level, as suggested by Muller. These results revealed that the Metoda and Shapar sites showed higher  
324 CF values for Pb, Cd, Cr, Mn, and Cu. The Shapar site showed higher CF values for Cd and Cu.

325

### 326 **3.2 Survey the flora of contaminated sites**

327 In the surveys of the polluted sites, more than 20 vascular plant species, representing 16 genera and 11  
 328 families were found. Most of these plants were annual or biannual and perennials were less represented.  
 329 Table shows the species that were present in more than 55% frequency and density of the sampling  
 330 sites. Moreover, under a Mediterranean condition, greatest development of annuals occurs in spring,  
 331 coinciding with the March and June surveys. In general, species richness, vegetation cover and biomass  
 332 production were significantly higher in the industrial zones in each survey. This pointed to a positive effect  
 333 of the metal concentration in enhancing plant colonization and plant development in spite of the chemical  
 334 heterogeneity revealed by soil analyses. The results obtained from these areas clearly indicate the  
 335 adverse conditions (very high metal contamination) of the polluted soil. The positive effects of the  
 336 pollution might be related to an increase in some species density. There were strong positive correlations  
 337 between soil metal concentration and the number of species, vegetation cover and biomass production.  
 338 The second thing was the increase in soil pH reduced trace element solubility and thus potential toxicity  
 339 to plants and microorganisms. Therefore the increase in soil pH seems to be the most important heavy  
 340 metals effect in reducing trace element solubility. Moreover, the nutrients added through the pollution  
 341 could also contribute to improving soil fertility in this soil.

342

343

**Table 7. Dominant plant species of polluted sites**

| NO | Plant Name                             | Family          |
|----|--|-----------------|
| 1  | <i>Alternanthera caracasana</i> Kunth. | Amaranthaceae   |
| 2  | <i>Amaranthus spinosus</i> L.          | Amaranthaceae   |
| 3  | <i>Calotropis gigantea</i> L.          | Apocynaceae     |
| 4  | <i>Cyperus haspan</i> L.               | Cyperaceae      |
| 5  | <i>Datura stramonium</i> L.            | Solanaceae      |
| 6  | <i>Ipomoea aquatica</i> Forssk.        | Convolvullaceae |
| 7  | <i>Phyllanthus nirudi</i> L.           | Phyllanthaceae  |
| 8  | <i>Withania somnifera</i> L. (Dunal)   | Solanaceae      |

344

345 **3.3 Metal analysis of plants of contaminated sites.**

346 In general, plants growing in the contaminated soils had higher concentrations of micronutrients and trace  
347 elements than control plants.

348

#### 349 **Cadmium**

350 The highest Cd concentration was measured 2.60 mg/kg in *C. gigantea* at shapar which is higher than the  
351 permissible limit set by WHO [45]. The result of Cd concentration of the plants species from both polluted  
352 sites were grouped together with Cd concentration of the Soil from both sites and correlated to find the  
353 correlation coefficient between them.

354

#### 355 **Lead**

356 The highest Pb concentration was measured 36.34 mg/kg in *A. spinosus* at shapar which is higher than  
357 the permissible limit set by WHO [45] and the lowest of 0.0 mg/kg in *I. aquatica* at shapar as shown in  
358 table. The result of Pb concentration of the plants species from both polluted sites were grouped together  
359 with Pb concentration of the Soil from both sites and correlated to find the correlation coefficient between  
360 them.

361

#### 362 **Chromium**

363 The highest Cr concentration was measured 64.30 mg/kg in *A. spinosus* at shapar which is higher than  
364 the permissible limit set by WHO [45]. The result of Cr concentration of the plants species from both  
365 polluted sites were grouped together with Cr concentration of the Soil from both sites and correlated to  
366 find the correlation coefficient between them.

367

#### 368 **Manganese**

369 The highest Mn concentration was measured 28.08 mg/kg in *W. somnifera* at metoda which is higher  
370 than the permissible limit set by WHO [45]. The result of Mn concentration of the plants species from both  
371 polluted sites were grouped together with Mn concentration of the Soil from both sites and correlated to  
372 find the correlation coefficient between them.

373

374 **Copper**

375 The highest Cu concentration was measured 43.68 mg/kg in *I. aquatica* at metoda which is higher than  
376 the permissible limit set by WHO [45]. The result of Cu concentration of the plants species from both  
377 polluted sites were grouped together with Cu concentration of the Soil from both sites and correlated to  
378 find the correlation coefficient between them.

379 **Table 8. Metal analysis of weed plants of Metoda site (in mg/kg)**

| Plant Name                             | Cd        | Pb         | Cr         | Mn         | Cu         |
|--|-----------|------------|------------|------------|------------|
| <i>Alternanthera caracasana</i> Kunth. | 1.48±0.05 | 11.23±0.5  | 4.09±0.04  | 18.04±0.05 | 2.03±0.05  |
| <i>Amaranthus spinosus</i> L.          | 0.59±0.02 | 21.32±0.11 | 36.40±0.13 | 12.03±0.8  | 3.09±0.04  |
| <i>Calotropis gigantea</i> L.          | 1.87±0.06 | 3.22±0.12  | 2.35±0.12  | 8.90±0.11  | 9.19±0.12  |
| <i>Cyprus haspan</i> L.                | 0.98±0.01 | 1.79±0.01  | 4.36±0.11  | 9.65±0.11  | 11.64±0.11 |
| <i>Datura stramonium</i> L.            | 0.12±0.01 | 0.43±0.01  | 2.70±0.05  | 5.96±0.05  | 1.22±0.04  |
| <i>Ipomoea aquatic</i> Forssk.         | 0.26±0.01 | 0.07±0.01  | 6.09±0.05  | 18.93±0.22 | 43.68±0.37 |
| <i>Phyllanthus nirudi</i> L.           | 0.12±0.02 | 1.09±0.05  | 3.06±0.05  | 12.37±0.05 | 11.71±0.12 |
| <i>Withania somnifera</i> L. (Dunal)   | 2.08±0.05 | 4.75±0.07  | 4.09±0.05  | 28.08±0.43 | 12.44±0.17 |

380 Mean values ± Standard deviation of means of three replicates

381 **Table 9. Metal analysis of weed plant of Shapar site (in mg/kg)**

| Plant Name                             | Cd        | Pb         | Cr         | Mn         | Cu         |
|--|-----------|------------|------------|------------|------------|
| <i>Alternanthera caracasana</i> Kunth. | 1.02±0.05 | 17.38±0.25 | 5.78±0.15  | 12.21±0.14 | 0.10±0.04  |
| <i>Amaranthus spinosus</i> L.          | 0.45±0.05 | 36.34±0.2  | 64.30±0.50 | 3.06±0.12  | 2.01±0.05  |
| <i>Calotropis gigantea</i> L.          | 2.60±0.05 | 10.50±0.12 | 4.30±0.10  | 7.74±0.11  | 18.20±0.24 |
| <i>Cyprus haspan</i> L.                | 1.09±0.1  | 2.38±0.11  | 3.09±0.10  | 5.97±0.21  | 22.36±0.51 |
| <i>Datura stramonium</i> L.            | 0.05±0.01 | 0.18±0.01  | 0.30±0.01  | 1.10±0.05  | 0.70±0.01  |
| <i>Ipomoea aquatica</i> Forssk.        | 0.10±0.01 | 0.00±0.00  | 4.55±0.09  | 16.74±0.24 | 32.41±0.65 |
| <i>Phyllanthus nirudi</i> L.           | 0.09±0.01 | 0.93±0.08  | 2.13±0.05  | 7.27±0.21  | 9.91±0.20  |
| <i>Withania somnifera</i> L. (Dunal)   | 1.69±0.08 | 5.34±0.11  | 3.69±0.10  | 25.66±0.50 | 16.03±0.50 |

382 Mean values  $\pm$  Standard deviation of means of three replicates

### 383 3.4 Bioaccumulation factor (BAF)

384 Ability of a plant to accumulate metals from contaminated soils was evaluated by the BAF,  
385 according to studies of Fayiga [46] and Yoon [47]. This study assumed that plants with BAF  
386 values  $> 1$  are accumulators, while plants with BAF values  $< 1$  are excluders [48]. Metoda and  
387 Shapar both polluted sites results showed that most of weed plant species had BAF values  $> 1$   
388 which indicating that they had the potential for use as accumulators of heavy metals. The  
389 success of the phytoremediation process depends on heavy metal removal by the plants [49].  
390 Conversely, the accumulation of heavy metals from soil to plant parts were an extremely  
391 multifaceted process which affected by several factors, which exert different influences on the  
392 process by means of various mechanisms. There were so many influencing factors include the  
393 chemical forms of the heavy metals, pH of the soil, conductivity of the soil, organic carbon,  
394 organicmatter content, plant species, climatic conditions, and irrigation with polluted water [50].

395

396 Table 10. BAF value in weed plants of Metoda site

| Plant name                             | Metoda soil sample (BAF value) |      |       |      |      |
|--|--------------------------------|------|-------|------|------|
|  | Cd                             | Pb   | Cr    | Mn   | Cu   |
| <i>Alternanthera caracasana</i> Kunth. | 7.40                           | 4.19 | 10.23 | 0.71 | 0.30 |
| <i>Amaranthus spinosus</i> L.          | 2.96                           | 7.96 | 91.00 | 0.47 | 0.46 |
| <i>Calotropis gigantea</i> L.          | 9.35                           | 1.20 | 5.88  | 0.35 | 1.38 |
| <i>Cyprus haspan</i> L.                | 4.90                           | 0.67 | 10.90 | 0.38 | 1.74 |
| <i>Datura stramonium</i> L.            | 0.60                           | 0.16 | 6.75  | 0.23 | 0.18 |
| <i>Ipomoea aquatica</i> Forssk.        | 1.30                           | 0.03 | 15.23 | 0.74 | 6.54 |
| <i>Phyllanthus nirudi</i> L.           | 0.62                           | 0.41 | 7.65  | 0.49 | 1.75 |
| <i>Withania somnifera</i> L. (Dunal)   | 10.40                          | 1.77 | 10.23 | 1.10 | 1.86 |

397

Table 11. BAF value in weed plants of Shapar site

| Plant name                             | Shapar soil sample |       |        |      |      |
|--|--------------------|-------|--------|------|------|
|  | Cd                 | Pb    | Cr     | Mn   | Cu   |
| <i>Alternanthera caracasana</i> Kunth. | 4.87               | 6.49  | 14.45  | 0.52 | 0.02 |
| <i>Amaranthus spinosus</i> L.          | 2.12               | 13.56 | 160.75 | 0.13 | 0.49 |
| <i>Calotropis gigantea</i> L.          | 12.38              | 3.92  | 10.75  | 0.33 | 4.45 |
| <i>Cyperus haspan</i> L.               | 5.19               | 0.89  | 7.73   | 0.25 | 5.47 |
| <i>Datura stramonium</i> L.            | 0.24               | 0.07  | 0.75   | 0.05 | 0.17 |
| <i>Ipomoea aquatica</i> Forssk.        | 0.47               | 0.00  | 11.38  | 0.71 | 7.92 |
| <i>Phyllanthus nirudi</i> L.           | 0.44               | 0.35  | 5.33   | 0.31 | 2.42 |
| <i>Withania somnifera</i> L. (Dunal)   | 8.05               | 1.99  | 9.23   | 1.09 | 3.92 |

399

#### 400 4 CONCLUSION

401 Phytoremediation is most suitable for removal of heavy metals from the polluted sites. But the potential of  
 402 phytoremediation steps, using hyper accumulators, has raised some concerns related to invasiveness  
 403 and disruption of indigenous ecosystems, as the introduction of alien plants may alter ecosystem function.  
 404 Therefore, the best option is to find native hyper accumulator plants from nearby regions to use them for  
 405 soil remediation. The results showed that concentrations of Cd, Pb, Cr, Mn, and Cu metal in the studied  
 406 native plant species were higher than the normal plant, and thereby indicating that soil was polluted and  
 407 required phytoremediation.

408

#### 409 6 REFERENCES

410

411 [1] Rahman, M. A., & Hasegawa, H. Aquatic arsenic: phytoremediation using floating  
 412 macrophytes. *Chemosphere*, (2011). 83(5), 633-646.

Comment [IH28]: Rewrite the conclusion, including numbers from the results.

- 413 [2] Wei, G., Fan, L., Zhu, W., Fu, Y., Yu, J., & Tang, M. Isolation and characterization of the heavy metal  
414 resistant bacteria CCNWR33-2 isolated from root nodule of *Lespedeza cuneata* in gold mine tailings in  
415 China. *Journal of hazardous materials*, (2009). 162(1), 50-56.
- 416 [3] Pilon-Smits, E. A., Quinn, C. F., Tapken, W., Malagoli, M., & Schiavon, M. Physiological functions of  
417 beneficial elements. *Current opinion in plant biology*, (2009). 12(3), 267-274.
- 418 [4] Vangronsveld, J., Herzig, R., Weyens, N., Boulet, J., Adriaensen, K., Ruttens, A., & Mench, M.  
419 Phytoremediation of contaminated soils and groundwater: lessons from the field. *Environmental Science  
420 and Pollution Research*, (2009). 16, 765-794.
- 421 [5] Xu, J., Grumbine, R. E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y. U. N., & Wilkes, A. The  
422 melting Himalayas: cascading effects of climate change on water, biodiversity, and  
423 livelihoods. *Conservation Biology*, (2009). 23(3), 520-530.
- 424 [6] Ensley, B. D., Raskin, I., & Salt, D. E. Phytoremediation applications for removing heavy metal  
425 contamination from soil and water. *Biotechnology in the sustainable environment*, (1997). 59-64.
- 426 [7] Cunningham, S. D., & Lee, C. R. Phytoremediation: Plant-based remediation of contaminated soils  
427 and sediments. *Bioremediation: Science and applications*, (1995). 43, 145-156.
- 428 [8] Schickler H, Caspi H. Response of antioxidative enzymes to nickel and cadmium stress in  
429 hyperaccumulator plants of the genus *Alyssum*. *Physiologia plantarum*. 1999;105(1):39-44.
- 430 [9] Prasad, M. N. V., Hagemeyer, J., Dietz, K. J., Baier, M., & Krämer, U. Free radicals and reactive  
431 oxygen species as mediators of heavy metal toxicity in plants. *Heavy metal stress in plants: from  
432 molecules to ecosystems*, (1999): 73-97.
- 433 [10] Campos-M, M., & Campos-C, R. Applications of quartering method in soils and foods. *International  
434 Journal of Engineering Research and Application*, (2017): 7(1), 35-39.
- 435 [11] Black, C.A. *Methods of Soil Analysis, Part II, Chemical and microbiological properties*. American  
436 Society of Agronomy, Madison, Wisconsin, USA, (1965): 771-72.
- 437 [12] Jackson, M.L. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi (1973).

- 438 [13] Cresswell, H. P. and G. J. Hamilton. Bulk Density and Pore Space Relations. In: Soil Physical  
439 Measurement and Interpretation For Land Evaluation. CSIRO Publishing: Collingwood, Victoria. (2002):  
440 35 – 58.
- 441 [14] Walkley, A., & Black, I. A. An examination of the Degtjareff method for determining soil organic  
442 matter, and a proposed modification of the chromic acid titration method. *Soil science*, (1934): 37(1), 29-  
443 38.
- 444 [15] Van Bemmelen JM. Ueber die Bestimmungen des Wassers, des Humus, des Schwefels, der in den  
445 Colloidalen Silikaten gebunden Kieselsaeuren, des mangans, u.s.w. im Ackerboden. *Landwirtschaftliche*  
446 *Versuch Station*, (1891): 37:279-290.
- 447 [16] Kumar, V., Sharma, A., Kaur, P., Sidhu, G. P. S., Bali, A. S., Bhardwaj, R. & Cerda, A. Pollution  
448 assessment of heavy metals in soils of India and ecological risk assessment: A state-of-the-art.  
449 *Chemosphere*, (2019): 216, 449-462.
- 450 [17] Riaz, A., Khan, S., Muhammad, S., Liu, C., Shah, M. T., & Tariq, M. Mercury contamination in  
451 selected foodstuffs and potential health risk assessment along the artisanal gold mining, Gilgit-Baltistan,  
452 Pakistan. *Environmental geochemistry and health*, (2018): 40, 625-635.
- 453 [18] Muhammad, S., Shah, M. T., & Khan, S. (2011). Heavy metal concentrations in soil and wild plants  
454 growing around Pb–Zn sulfide terrain in the Kohistan region, northern Pakistan. *Microchemical*  
455 *Journal*, (2011): 99(1), 67-75.
- 456 [19] Curtis, J. T., & McIntosh, R. P. The interrelations of certain analytic and synthetic phytosociological  
457 characters. *Ecology*, (1950): 31(3), 434-455.
- 458 [20] Cox, G. Population and community structure: Quadrat sampling techniques. *Laboratory Manual of*  
459 *General Ecology*, (1990): 69-73.
- 460 [21] Valdes, L. J., Mislankar, S. G., & Paul, A. G. *Coleus barbatus* (C. forskohlii)(Lamiaceae) and the  
461 potential new drug forskolin (Coleonol). *Economic botany*, (1987): 41, 474-483.

- 462 [22] Gupta, D. K., Corpas, F. J., & Palma, J. M. (Eds.). *Heavy metal stress in plants* (p. 240). Berlin:  
463 Springer (2013).
- 464 [23] Ghosh, M., & Singh, S. P. A comparative study of cadmium phytoextraction by accumulator and  
465 weed species. *Environmental pollution*, (2005): 133(2), 365-371.
- 466 [24] Zhuang, P., Zhi-An, L. I., Bi, Z. O. U., Han-Ping, X. I. A., & Gang, W. A. N. G. Heavy metal  
467 contamination in soil and soybean near the Dabaoshan Mine, South China. *Pedosphere*, (2013): 23(3),  
468 298-304.
- 469 [25] Singh, R., Gautam, N., Mishra, A., & Gupta, R. Heavy metals and living systems: An overview. *Indian*  
470 *journal of pharmacology*, (2011): 43(3), 246.
- 471 [26] Carter MR, Gregorich EG. Carbon and nitrogen storage by deep-rooted tall fescue (*Lolium*  
472 *arundinaceum*) in the surface and subsurface soil of a fine sandy loam in eastern Canada. *Agriculture,*  
473 *ecosystems & environment*. 2010; 136(1-2):125-32.
- 474 [27] Aragaw, T. A., Wondimnew, A., & Asmare, A. M. Quantification, characterization and recycling  
475 potential of solid waste: case study Bahir Dar institute of technology. *Int J Sci Res*, (2016): 5, 2415-2420.
- 476 [28] Sparks, D. L. Environmental soil chemistry: An overview. *Environmental soil chemistry*, (2003): 2, 1-  
477 42.
- 478 [29] Alloway, B., & Ayres, D. C. *Chemical principles of environmental pollution*. CRC press, (1997).
- 479 [30] Uba, S., Uzairu, A., Harrison, G. F. S., Balarabe, M. L., & Okunola, O. J. Assessment of heavy metals  
480 bioavailability in dumpsites of Zaria Metropolis, Nigeria. *African Journal of Biotechnology*, (2008): 7(2).
- 481 [31] Goswami, U., & Sarma, H. P. Study of the impact of municipal solid waste dumping on soil quality in  
482 Guwahati city. *Pollution research*, (2008): 27(2), 327-330.
- 483 [32] Mathur, G. M. Effect of long-term application of fertilizers and manures on soil properties and yield  
484 under cotton-wheat rotation in north-west Rajasthan. *Journal of the Indian Society of soil Science*, (1997):  
485 45(2), 288-292.

- 486 [33] Chaudhury, J., Mandal, U. K., Sharma, K. L., Ghosh, H., & Mandal, B. Assessing soil quality under  
487 long-term rice-based cropping system. *Communications in Soil Science and Plant Analysis*, (2005): 36(9-  
488 10), 1141-1161.
- 489 [34] Munoz, V., & Serrano, L. Elucidating the folding problem of helical peptides using empirical  
490 parameters. *Nature structural biology*, (1994): 1(6), 399-409.
- 491 [35] Hassink, J., & Whitmore, A. P. A model of the physical protection of organic matter in soils. *Soil*  
492 *Science Society of America Journal*, (1997): 61(1), 131-139.
- 493 [36] Oyedele, D. J., Gasu, M. B., & Awotoye, O. O. Changes in soil properties and plant uptake of heavy  
494 metals on selected municipal solid waste dump sites in Ile-Ife, Nigeria. *African Journal of Environmental*  
495 *Science and Technology*, (2008): 2(5), 107-115.
- 496 [37] Shende, A., Juwarkar, A. S., & Dara, S. S. Phytotoxic effects of heavy metals as influenced by soil  
497 properties. *Pollution Research*, (1993): 12(2), 75-83.
- 498 [38] Udeme, A. E. Solid waste analysis and characterization and Department of Chemistry. *University of*  
499 *Uyo*, (2001).
- 500 [39] Jumbe, A. S., & Nandini, N. Heavy metals analysis and sediment quality values in urban  
501 lakes. *American Journal of Environmental Sciences*, (2009): 5(6), 678.
- 502 [40] Nwajei, G. E., Iwegbue, C. M. A., & Okafor, M. I. Heavy metals in surface soils under waste dumps  
503 from Onitsha, Nigeria. *J Biol Sci*, (2007): 7(2), 405-408.
- 504 [41] Ogunyemi, S., Bamgbose, O. O., & Awodoyin, R. O. Heavy metal contamination of some leafy  
505 vegetables growing within Ibadan metropolis, South-western Nigeria. *Tropical Agricultural Research and*  
506 *Extension*, (2003): 6, 71-76.
- 507 [42] Awokunmi, E. E., Asaolu, S. S., & Ipinmoroti, K. O. Effect of leaching on heavy metals concentration  
508 of soil in some dumpsites. *African Journal of Environmental Science and Technology*, (2010): 4(8), 495-  
509 499.

- 510 [43] Fumikazu, S., Shusuke, S., Atsunori, M., Takashi, K., Shun, I., Jun, A., & Keiko, I. Thin-rim  
511 enhancement in Gd-DTPA-enhanced magnetic resonance images of tuberculoma. *Journal of Thoracic*  
512 *Imaging*, (1992): 7(3), 64-69.
- 513 [44] Nriagu, J. O., & Pacyna, J. M. Quantitative assessment of worldwide contamination of air, water and  
514 soils by trace metals. *nature*, (1988): 333(6169), 134-139.
- 515 [45] Sharma, R. K., Agrawal, M., & Marshall, F. M. Heavy metals in vegetables collected from production  
516 and market sites of a tropical urban area of India. *Food and chemical toxicology*, (2009): 47(3), 583-591.
- 517 [46] Fayiga, A. O., Ma, L. Q., Cao, X., & Rathinasabapathi, B. Effects of heavy metals on growth and  
518 arsenic accumulation in the arsenic hyperaccumulator *Pteris vittata* L. *Environmental pollution*, (2004):  
519 132(2), 289-296.
- 520 [47] Yoon, J., Cao, X., Zhou, Q., & Ma, L. Q. Accumulation of Pb, Cu, and Zn in native plants growing on  
521 a contaminated Florida site. *Science of the total environment*, (2006): 368(2-3), 456-464.
- 522 [48] Baker, A. J. Accumulators and excluders-strategies in the response of plants to heavy  
523 metals. *Journal of plant nutrition*, (1981): 3(1-4), 643-654.
- 524 [49] Usman, A. R. A., & Mohamed, H. M. Effect of microbial inoculation and EDTA on the uptake and  
525 translocation of heavy metal by corn and sunflower. *Chemosphere*, (2009): 76(7), 893-899.
- 526 [50] Neilson, S., & Rajakaruna, N. Phytoremediation of agricultural soils: using plants to clean metal-  
527 contaminated arable land. *Phytoremediation: Management of Environmental Contaminants*, (2015): 1,  
528 159-168.