Phytoremediation of arsenic-contaminated soils by arsenic hyperaccumulating plants in selected areas of Enugu State, Southeastern, Nigeria

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**ABSTRACT**

Under the current study phytoremediation of arsenic from a tropical wetlands and lakes in selected areas of Enugu State was performed. Thirteen soil, plant root and shoot samples used in this research were collected respectively from the Adani Wetlands (six samples), Opi-Agu Lakes (four samples) and control sites (three samples). The plant and soil samples were analyzed in the laboratory using Standard Methods. In the study, As contaminated soils, with maximum As value was observed in Ada Rice Farm 2 (468.0 mg kg\textsuperscript{-1}) followed by Ohuno Wetland 2 (442.0 mg kg\textsuperscript{-1}) and Ada Rice Farm 3 (304 mg kg\textsuperscript{-1}). The highest BCF value (3.31) was recorded in Pteridium Aquilinum root and 1.76 in Ludwigia Erecta shoot, and lowest amount of 0.73 was in Cyperus Exaltatus root and 0.14 in Nymphpha Maculata shoot of As contaminated soils. The translocation factor of As from soil to shoot in the agricultural soils (Adani areas) were found to be in the order of Corrigiola Telephifolia (1.54) > Ludwigia Erecta (0.57) > Acrocras Amplectens (0.54) > Cyperus Exaltatus (0.45) > Cyperus Imbricatus (0.29) > Nymphpha Maculata (0.14) while in the lake soils (Opi-Agu areas), the translocation factor of As from soil to roots were measured in the order of Sacciolepis Cymbiandra (1.20) > Pteridium Aquilinum (0.53) > Lasimorpha Senegailesis (0.43) > Aframomum Danielli (0.36). Present research showed that indicated plant species can be used as As accumulator in As polluted soils.

**Introduction**

Soil pollution is the biggest human-faced environmental catastrophe and seen as a serious threat to humans and the environment. Before now, cases of Arsenic associated with agricultural activities have been reported in Asia. It has become a worldwide issue like other environmental pollution problems, with consequences ranging from impact on habitats, biodiversity, human health etc. Because of the heavy metals’ concentration, both inorganic and organic heavy metal pollutants and their degradation in soil ecosystems are typically linked to human activities like industrial revolution, applications of agrochemicals on farm land, energy generation and fuels processing, mining and steel making activities and waste disposal which causes hazardous to every form of life (Wei & Chen, 2001). Some of the common heavy metals that inflict soil degradation and eventually environmental contamination are As, Cd, Cr, Cu, Co, Hg, Mn, Ni, Pb and Zn. Usually, heavy metal contamination is a function of these various heavy metals (Wei & Chen, 2001). Arsenic is a naturally occurring material which is broadly disseminated in the crust of the earth. Arsenic is quite harmful in drinking water and food sources, when contained in significant amounts. In many countries such as India, China, South Africa and Bangladesh, arsenic contaminates the groundwater supply. Arsenic is prevalent in the ecosystem and occurs in sea water at a rate of 2 μ/kg (Ferguson & Gavis, 1972). Use of pesticide-containing arsenic in the past has left vast areas of farmland polluted. The preservation of timber using arsenic has also contributed to environmental degradation. Arsenic (As) is extremely lethal and poisonous metalloid widely circulated in the surface of the Earth crust and its hydrosphere (Emilie et al., 2017). It is a well notorious poison and as small as 0.1 g of arsenic trioxide could be lethal to environment. High arsenic poisoning is nowadays unique, even though chronic poisoning is extensively well-known as a result of occupational exposition (WHO, 1981). Over a century this metal at high dosage has been recognized to be a human carcinogenic and it is accepted that ingestion of inorganic arsenic can produce skin, lung and leukemia cancer, while inhalation may cause respiratory tract (Jarup, 1992; Kotoky et al., 2008). Long-term disclosure may cause skin diseases including skin blackening and swelling of palms and torso (Mahimairaja et al., 2005). Nowadays, high arsenic concentrations in the natural geochemical environment has been a major concern due to its possible adverse human effects (Thornton, 2016). The issue of arsenic contamination is seemly and more grievous with escalating...
population, industrial development and upset of natural biogeochemical revolutions (Chen et al., 1992). Natural levels of arsenic in soil generally vary from 1 to 40 mg/kg (Tchounwou et al., 2004). Human exposure to this metal may take place by a different of ways, such as exhalation of dusts from atmosphere, consumption of polluted water or soil, or via the food chain (Tchounwou & Centeno, 2008).

On the other hand, the harmfulness of arsenic has led to extensive research to examine different strategies to either reduce or remove arsenic contamination from the environment. However, these strategies have preceded to the use of green plants (phytoextraction) to cut down the concentrations or deadly influence of pollutants in the surrounding environments (Vithanage et al., 2012). Phytoremediation technology according to (Ali et al., 2013; Chaney, 1983; Greipsson, 2011) is to utilize plants as well as its related soil microorganisms to minimize the levels or lethal influence of contaminants in the surroundings. It handles soil pollutants diligently without causing harm to the soil’s utility and fertility. Alkorta et al. (2004) classified phytoremediation techniques into phytofiltration, phytoextraction, phytovolatilization, and phytostabilization. But the most widely used technique is the phytoextraction (or phytoaccumulation) which is basically refers to the ingestion of pollutants from water or soil through their roots and transfer to and gathered over ground biogas i.e., shoots (Rafati et al., 2011; Sekara et al., 2005; Yoon et al., 2006). However, plants used for phytoremediation technology is called hyperaccumulator plants (Memon et al., 2001; Memon & Schroder, 2009) because they possess hyper-tolerant capacity accumulate metals in their shoots (Table 1). From the past decades, phytoremediation technology has been generally accepted by researchers because of its uniqueness, economical, proficient, environmental and ecological cordial, in-situ suitable, heat radiation rumination approach and compatible technology for engineering-based remedy techniques (Pillon-Smits, 2005; Suresh & Ravishankar, 2004). Of the phytoremediation techniques, phytoextraction of As using As-hyperaccumulating plants are the most researched area for mitigation of As-contaminated soils.

Utilization of agricultural produce raised on polluted soils may cause human health (Chaney et al., 2005). Consequently, agricultural activity is one of the major sources of arsenic pollution of soil, surface and groundwater systems. Arsenic is a dangerous hazard to the aquatic and terrestrial environments because its perseverance along with bio-accumulation in the soils, water feeding relationships among the organisms (Linnik & Zubenko, 2000; Ogoyi et al., 2011; Taiwo et al., 2012). Arsenic levels in agricultural soil surpassing the maximum standard limits are regarded as potential danger to microorganisms, plants, humans as well as animals. Numerous mitigation criteria are ready for the restoration of As-polluted soils. Recent applications of As phytoextraction is portrayed and the importance of As pollution on agricultural activities is explained in the present work.

In the study areas, there are no existing work published on the phytoextraction of As-polluted soils

| Plant species            | Metals | Metal accumulation (mg kg\(^{-1}\)) | Reference                        |
|--------------------------|--------|------------------------------------|----------------------------------|
| Alyssum bertolonii       | Ni     | 10900                              | Li et al. (2003)                 |
| Alyssum caricum          | Ni     | 12500                              | Li et al. (2003)                 |
| Alyssum corsicum         | Ni     | 18100                              | Li et al. (2003)                 |
| Alyssum heldreichii      | Ni     | 11800                              | Bani et al. (2010)               |
| Alyssum maritigraii      | Ni     | 19100                              | Bani et al. (2010)               |
| Alyssum murale           | Ni     | 4730–20100                         | Bani et al. (2010)               |
|                          |        | 15000                              | Li et al. (2003)                 |
| Alyssum pterocarpum      | Ni     | 13500                              | Li et al. (2003)                 |
| Alyssum serpyllifolium   | Ni     | 10000                              | Prais (2003)                     |
| Azolla pinnata           | Cd     | 740                                | Rai (2008)                       |
| Berkyeya coddii          | Ni     | 18000                              | Mesjasz-Przybylowicz et al. (2004) |
| Corrigiola telephifolia  | As     | 211                                | Garcia-Salgado et al. (2012)     |
| Eleocharis acicularis    | Cu     | 20200                              | Sakakibara et al. (2011)         |
|                          | Zn     | 11200                              |                                  |
|                          | Cd     | 239                                |                                  |
|                          | As     | 147                                |                                  |
| Euphorbia cheiradenia    | Pb     | 1138                               | Chhegregani and Malayeri (2007)  |
| Isatis pinnatioloba      | Ni     | 1441                               | Altnozlu et al. (2012)           |
| Pteris biaurita          | As     | 200                                | Srivastava et al. (2006)         |
| Pteris cretica           | As     | 1800                               | Srivastava et al. (2006)         |
|                          |        | 2200–3030                          | Zhao et al. (2002)               |
| Pteris quadraurita       | As     | 2900                               | Srivastava et al. (2006)         |
| Pteris ryukyuensis       | As     | 3647                               | Srivastava et al. (2006)         |
| Pteris vittata           | As     | 8331                               | Kalve et al. (2011)              |
|                          |        | 1000                               | Baldwin and Butcher (2007)       |
| Cr                       |        | 20675                              | Kalve et al. (2011)              |
| Rorippa globosa          | Cd     | >100                                | Wei et al. (2008)                |
| Schima superba           | Mn     | 62412.3                            | Yang et al. (2008)               |
| Solanum photeinocarpum   | Cd     | 158                                | Zhang et al. (2011)              |
| Thlaspi caerulescens     | Cd     | 263                                | Lombi et al. (2001)              |
utilizing arsenic hyperaccumulating plants. The existing work published mostly centered on the comparative economic analysis of some selected crops; agricultural potentials in Adani town with a view to determine the factors responsible for the non-sustainability of agricultural production in the town; hydrochemistry of Opi-Agu; appraisal of the status and effect of preferred physiochemical parameters of fertilizer discharge on Obinna River; lake inventory and preliminary limnological investigation of lakes in Opi-Agu and investigation of heavy metal pollution of soil and Oryza Sativa grains Ada rice field, Enugu, Nigeria: evaluating the danger to human health (Agbatekwe, 2005; Agu et al., 2014; Ajaero et al., 2013; Ani, 2010; Ihedioha et al., 2016; Ozoko, 2015; Ozoko & Ifediegwu, 2015). Hence, the aim of this research is to indicate the phytoaccumulation efficiency of some selected plant species for Arsenic (As) in Ada Rice, Ohunu Wetland, Iyiuga and Ogeleube Lakes. To attain this aim, the particular objectives of this study are; (a) To examine the potentiality of Nymphaea Maculata, Ludwigia Erecta, Cyperus Imbricatus, Acroceras Amplectens, Pteridium Aquilimum, Lasimorpha Senegalessis, Saccioleps Cymbiandra, Afromomum Daniellii, Corrigiola Telephifolia Cyperus Exaltatus for phytoremediation of As from contaminated soils and (b) To analysis the As uptake, bioaccumulation, translocation and accumulation pattern within these accumulator plants. The results reveal that these selected plant species has substantial potential for neutralizing or reducing As from polluted soil.

Materials and methods

Study area

This study centered in Adani Wetlands (Ada Rice Farm and Ohunu Rice Farm) and Opi-Agu Lakes (Iyiuga and Ogeleube Lakes) both in Uzo-Uwani and Nsukka local government areas of Enugu State, Nigeria (Figure 1). These areas are located between latitudes 6°30’00”N and 7°00’00”N and longitudes 6°55’00”E and 7°35’00”E. Ada Rice farm is located in Adani which is a town in Uzo-Uwani LGA of Enugu state. The Adani Wetlands cover an area of about 100 hectares. The soil texture is clayey which is rich and fertile soils considered to be appropriate for rice and other agricultural yield considering it can be tend to be efficiently as well possess predisposition to hold valuable humidity and more vital metals. During 90’s, active irrigation farming was going on in study area with the aid of Shanghai supported irrigation plant with River Obinna providing as the main origin of irrigation water. Currently, the irrigation farming is no longer working and crops are being grown only in the rainy season. Rice processing mills are the only agricultural processing industry present in the study (Ihidehioha et al., 2016). Moreover, Opi-Agu Lakes is made up of Varavara, Iyi-Ikpa, Ojii, Adekwegbe, Isiogha, Ogeleube, Iyiuga, Orufu and Okpo. These lakes according to (Ozoko & Ifediegwu, 2015) are typically freshwater lakes and have no permanent inlet but during the rainy season when river Uhere is flooded the lakes overflow through their lower ends. Prior to this study Ogeleube and Iyiuga Lakes were considered due to their excellent biodiversity.

The topography of the Adani area is characterized by vast low-lying plains. The area falls within the area described as have elevation in the range of 25–75 m above sea level while the most prominent topography features in Opi-Agu are the north-south trending cuesta, the cone shaped hills and broad valleys (Umeji, 1980). The elevation within the Opi-Agu range from 300 to 575 m above sea level. Adani area is drained by River Obinna and its affiliated rivers including Ngene Agha, Nsu and Ishe Rivers whereas in Opi-Agu area, there are numerous surface water bodies in the study area such as Uhere and Api River which formed from the foot of the escarpment. These River are seasonal and dries up immediately after rainy season. However, in the rainy season, these rivers over-spill its bank and encourage flooding and swamp.

The study area lies within the tropical belt of Nigeria, which represents warmth and cold climate. The day temperature varies between 25°C and 37°C meanwhile night temperature fluctuates between 14 and 28°C. Two major climatic period befalls the area: dry season, which spans from early November to late March, with a cool weather period between December and early February; and the rainy season, which continues since April to October (Igbozuluoke, 1975). The rains are generally dense, with a mean yearly value of 1700 mm. Consequently, the region lies within Nigeria’s tropical rainforest zone. In the major portions of the study area the vegetation type had been replaced by Savannah grassland, combined with oil palm trees.

Figure 1. Location map showing the study areas.
Geo-hydrology

Five geological formations underlie the entire area, namely the Campanian Enugu Formations, the Maarstrichtian Mamu and Ajali, the DanianNsukka and the Paleocene Imo Formations (Figure 2) but the formations of our interest are Ajali, Nsukka and Imo Formations. The Ajali Formation, earlier named the False Bedded Sandstone by Reyment (1965), comprises of thick friable, poorly sorted sandstones, generally ranged from whitish to yellowish-brown colored with intermittently iron-stained measuring up to 300 meters thick and is regularly overlaid by substantial red earth diameters, which constitute red, earthy sands, fashioned by erosion and formation ferrugination. Tattam (1944) earlier described the Nsukka Formation as the upper Coal Measures, which lies conformingly on the sandstone of Ajali. The formation has common characteristics with Mamu Formation and the rocks are composed of regular sandstone sequence, dark shale and sandy shale, with unsubstantial coal seams at different horizons. The Imo Formation consists dominantly dense clay shale, fine textured, dark gray to bluish gray with sometimes clay and mixture ironstone and thin strips of sandstone. The formation conformably overlain Nsukka Formation and has more or less 500 m thick (Simpson, 1954).

Three aquifer units have been identified in the study area. The first one is deep aquifer systems which is formed by fine fluvial sediment of Upper Maarstrichtian origin. It is unconfined and it is the most exploited aquifer originated from fine-medium grained friable reddish-brown sandstone of Ajali Formation (Egboka, 1990). The second one is presence of shale beds at the contact between Nsukka Formation and Ajali Formation which gives rise to perched aquifer conditions; its thickness is variable (Ezeigbo & Ozoko, 1989). The existence of a low permeability clay or shale layer in a high permeability sand formation provides the requisite geologic conditions for perched aquifer formation (Ozoko, 1989).

Whereas, the third aquifer unit in the area is the shallow aquifer systems defined by Paleocene Shales of several fractures, joints and faulted rock masses have weathered zones which enhanced groundwater availability. The weathered shales are too thin to trap good water quantity in the rainy season and is very prone to water table lowering during the dry season. The Paleocene Shale is mainly clayey to be of good permeability even though the porosity may be high. This type of aquifer is exploited by hand dug wells with depth varying from 3.4 m to 10.3 m depending on the elevation of the ground surface at the point of measurement.

Sample collection

Initially, ten different plant species were collected from the study area. The collected plant species were sent to Department of Botany in the University of Nigeria, Nsukka for identification. The identified plant species include; Nymphaea Maculata, Ludwigia Erecta, Cyperus Imbricatus, Acrocras Amplectens, Pteridium Aquilimum for Adani Wetlands, Lasimorpha Senegalesis, Sacciolepis Cymbiandra, Afromomum Danielli, Corrigiola Telephifolia Cyperus Exaltatus for Opi-Agu Lakes, for Control Sites (Figures 3 and 4). However, thirteen plant root and shoot samples used in this experiment were collected from the Adani

Figure 2. Geologic map of the study area.

Figure 3. Photo-documentation of various plant species obtained from Adani Wetlands and Opi-Agu Lakes (a) Nymphaea Maculata (b) Ludwigia Erecta (c) Cyperus Imbricatus (d) Acrocras Amplectens (e) Pteridium Aquilimum (f) Lasimorpha Senegalesis.
Wetlands (six samples), Opi-Agu Lakes (five samples) and control sites (three samples) in required amounts, wrapped in brown envelop paper and transported to laboratory and preserved at +4°C for processing on the next day. Finally, thirteen soil samples at depth of between 0 and 20 cm was collected for analysis from Adani Wetlands (six samples), Opi-Agu Lakes (six samples) and control sites (three samples) respectively. The collected soil sample was transported to the Geospectra Engineering Services and Consultants LTD, Port Harcourt, Nigeria. The coordinates of the entire sample locations and sample description have been outlined in Table 2.

**Laboratory analysis**

Plants spacenem obtained from the study area was cleaned using tap water to separate attached soils, and thereafter isolated into roots and leaves. The samples were dried at 80°C within 48 hours using oven. Subsequently, agate mortar and pestle were used to grind the dried samples, then sieved to less than 2 mm afterwards move to polyethylene bags for preservation and storage prior to the analysis. The leaves and roots of the distinct plant species were analyzed individually for arsenic concentration. However, 1 g of the less than 2 mm sieved plant samples obtained were weighed in porcelain crucibles while simultaneously ignited in a muffle furnace to heat for 6 hours at a temperature range of 450–500°C until gray white ash was acquired and then 10 ml of 2 M nitric acid was added to each sample to cool. In addition, the solution had been dried on a hot plate and allowed to cool. The cooled samples were subsequently re-dissolved in 10 ml of 2 M nitric acid and filtered into 25 ml volumetric flasks. We also rinsed the crucible and the filter paper in the flasks, prepared with distilled water and then reserved for laboratory examination in polyethylene tubes. The model of Atomic Absorption Spectrophotometer (AAS-Buck Scientific 200) was used to analyze arsenic in plant digests.

The collected soil spacenem at room temperature was air-dried. The coarse-grained materials (stones) was removed manually, after which the materials were sieved with mesh of 2 mm diameter, followed by sieving through a 500 μm sieve and analyzed for arsenic concentrations. The partially digested soil spacers were heated in an oven at 50°C for 24 hours and screened to remove stones through a handheld sieve of 2.0 mm diameter polyethylene. In a mechanical agate grinder about ~20 g of the dried samples was grinding until less than 200 μm of fine particles were obtained. The soil spacenem (<200 μm) was examined for arsenic absorptions applying the strong acid digestion technique. Weighed approximately 0.250 g of soil spacers as well as placed into pre-cleaned Pyrex test tubes and then apply 8.0 ml and 2.0 ml of concentrated nitric and perchloric acid, respectively. The mixed solution was heated in an aluminum block at 50°C for 24 hours, until it was completely dry. Subsequently, the test tubes were cooled, 20 ml of 7 mol⁻¹ Nitric acid (HNO₃) and the mixture was heated at 120°C for 30 min. Upon cooling, the solution was filtered and transferred to a 100 ml flask, dilute with deionized water. The solutions were transferred into polyethylene tube prior to instrumental analysis. Arsenic concentrations of the solutions were calculated employing Atomic absorption spectrophotometer (AAS-Buck Scientific 200 model). As concentrations in soil was measured in according with the American Public Health Association (APHA, 2005). Both glass and plastic-ware are soaked overnight in a 10% nitric acid solution for quality analysis and rinsed thoroughly before use with distilled water. In the analysis to detect contamination and evaluate accuracy and errors, reagent blanks, replicates and standard reference materials representing 10%, 10% and 10% of the total sample population were used for quality control. The analytical results showed less or no signs of contamination and showed that analytical precision and errors were usually less than 10%.

**Table 2. Summary of sample locations and their coordinates.**

| Sample Area       | Location     | Latitude (N) | Longitude (E) |
|-------------------|--------------|--------------|---------------|
| Adani Wetlands    | Ohuno Wetland 1 | 6.72828°  | 9.836°       |
|                   | Ohuno Wetland 2 | 6.72821°  | 9.84°        |
|                   | Ada Rice Farm 1 | 6.71372°  | 7.03013°     |
|                   | Ada Rice Farm 2 | 6.70475°  | 7.03262°     |
|                   | Ada Rice Farm 3 | 6.69920°  | 7.03482°     |
|                   | Ada Rice Farm 4 | 6.68958°  | 7.0495°      |
|                   | Iyiuga Lake 1  | 6.74878°  | 7.4933°      |
|                   | Iyiuga Lake 2  | 6.73873°  | 7.49321°     |
|                   | Iyiuga Lake 3  | 6.74962°  | 7.48553°     |
| Opi-Agu Lakes     | Ogelebe Lake  | 6.72437°  | 7.50369°     |
|                   | Site 1        | 6.89196°  | 7.40274°     |
|                   | Site 2        | 6.89424°  | 7.41710°     |
|                   | Site 3        | 6.87601°  | 7.40406°     |

**Figure 4.** Photo-documentation of various plant species obtained from Adani Wetlands and Opi-Agu Lakes Sacciolepis Cymbiandra (b) Afromomum Daniellii (c) Corrigiola Telephifolia (d) Cyperus Exaltatus.
Quantification of phytoaccumulation efficiency

Bioconcentration factor (BCF)
Bioconcentration factor represents the efficacy of different plant species in mobilizing heavy metals from the environments in their tissues (Ladislas et al., 2012). The BCF of the plant species were calculated in accordance with Zhuang et al. (2007).

\[
BCF = \frac{C_{\text{plant/shoot}}}{C_{\text{soil}}} \tag{1}
\]

Where \(C_{\text{plant/shoot}}\) is the goal metal value for the plant shoot, and \(C_{\text{soil}}\) is the same metal value for the soil.

Translocation factor (TF)
Translocation factor reveals the plant’s capacity to translocate the mobilized metals from their roots to shoots. The TF of the plant species were calculated in accordance with Padmavathamma and Li (2007).

\[
TF = \frac{C_{\text{shoot}}}{C_{\text{root/shoot}}} \tag{2}
\]

Where \(C_{\text{shoot}}\) is the metal value in plant shoot, and where \(C_{\text{root}}\) is the metal value in plant roots.

Accumulation factor (A)
Based on the following estimate, the accumulation factor (A) can also be expressed in per cent (Wilson & Pyatt, 2007).

\[
AF = \frac{C_{\text{plant/tissue}} \times 100}{C_{\text{soil/shoot}}} \tag{3}
\]

where AF is accumulation factor %, \(C_{\text{plant/root}}\) is metal concentration in plant root and \(C_{\text{soil or shoot}}\) is metal value in soil or plant shoot.

BCF and TF are important to the analysis of arsenic hyperaccumulators in contaminated soil for phytoremediation. Assessment and selection of plants for determining phytoextraction rely entirely on rates of BCF and TF (Wu et al., 2011). Translocation factor value > 1 is a manifestation of the metal’s translocation from root to overground (Jamil et al., 2009). Yoon et al. (2006) assumed that plant species with BCF and TF values > 1 were capable of being used for phytoremediation. According to Cluis (2004), hyperaccumulators having BCF > 1, at times attaining up to 50–100. In addition, elevated metal values in soil can result in BCF < 1, e.g., in ultramafic soils with 3000 mg/kg Ni in soil and 2000 mg/kg in plants or inverse plants sprouting on soils that are insufficient in important trace metals (e.g., Zn) can be very effective in segregation and therefore have elevated BCFs that are still low in absolute metal tissue. BCF is also an appropriate and reliable means of measuring the proportionate discrepancy of metals' bioavailability to plants Naseem et al. (2009).

Results
Plant biomass and the efficiency to regrowth are critical aspects in the phytoextraction of arsenic from polluted soils utilizing persistent plants because of its necessity to lower soil arsenic to acceptable levels (Fayiga & Ma, 2005). Despite the difference concentrations of arsenic in the soil, *Pteridium Aquilinum*, Lasimorpha Senegalensis and *Cyperus Imbricatus* grew well in the arsenic treated soil.

Arsenic in plant shoots
The concentrations of arsenic in plant shoots at Adani Wetlands, Opi-Agu Lakes and the control sites indicate that there is an evidence of relative increase in the concentrations of As in plant shoots at Adani Wetlands and Opi-Agu Lakes compared to the control site (Table 3). The background range for the concentration of As in plant shoots fluctuates between 63.2 and 197.0 mg kg\(^{-1}\) (Adani Wetlands), 64.5 and 215 mg kg\(^{-1}\) (Opi-Agu Lakes) and 30.9 and 68.3 mg kg\(^{-1}\) (control sites). Such values are below the usual average As concentration of 2110 mg kg\(^{-1}\) in

Table 3. As uptake in shoots, roots and soils of different plant species in the area.

| Sample Area | Location | Plant species          | Shoot | Root | Soil |
|-------------|----------|------------------------|-------|------|------|
| Adani Wetlands | Ohunu Wetland 1 | Coriagula Telephofilia | 141   | 272  | 91.7 |
|              | Ohunu Wetland 2 | Ohunu Wetland 2       | 197   | 321  | 442  |
|              | Ada Rice Farm 1 | Ada Rice Farm 1       | 125   | 223  | 220  |
|              | Ada Rice Farm 2 | Ada Rice Farm 2       | 63.2  | 272  | 468  |
|              | Ada Rice Farm 3 | Ada Rice Farm 3       | 164   | 271  | 304  |
|              | Ada Rice Farm 4 | Ada Rice Farm 4       | 68.4  | 191  | 235  |
| Opi-Agu Lakes | Iyiuga Lake 1   | Cyperus Exaltatus      | 100   | 622  | 188  |
|              | Iyiuga Lake 2   | Lasimorpha Senegalensis | 126  | 314  | 294  |
|              | Iyiuga Lake 3   | Sacciolepis Cymbiandra | 215   | 264  | 179  |
|              | Ogeleube Lake   | Afronorumum Danielli   | 64.5  | 199  | 177  |
| Control Sites | Site 1         | Lactuca sativa        | 30.9  | 43.0 | 56.8 |
|              | Site 2         | Impersa cylindrica    | 68.3  | 70.7 | 71.3 |
|              | Site 3         | Hibiscus sabdariffa   | 39.7  | 50.1 | 45.6 |
| Background Values | WHO/FAO (2001) |                   | 107.9 | 239.4 | 213.3 |
aboriginal plant species from soils polluted by anthropogenic activity (Garcia-Salgado et al., 2012), and consistent with that of two hyperaccumulators in agricultural surroundings (100 mg kg⁻¹) for arsenic (Baldwin & Butcher, 2007). In Adani Wetlands, values above background range were recorded in shoots of *Cyperus Exaltatus*, *Acrocras Amplecents*, *Corrigiola Telephifolia* and *Ludwigia Erecta* suggesting that formation of shoot biomass was simulated by rising of As concentration in the wetland soil while in Opi-Agu Lake, *Sacciolepis Cymbiandra* and *Lasimorpha Senegalesis* plants recorded values higher than the background range in their shoots (Figure 5(a)). These could be as result of rise in malondialdehyde, a lipid layer peroxidizing reaction product alongside with electrolyte flow in As-polluted lake plants. The As concentrations in the control sites are far lower than the general background range.

**Arsenic in plant roots**

As concentrations in plant roots from Adani Wetlands, Opi-Agu Lakes and control sites showed broad variation of values. These alterations in the arsenic up take probably related with the variations within the value of plant growth and effectiveness in the direction of arsenic concentration (Kelly et al., 1999). The background range for the concentration of As in plant roots is 239.4 mg kg⁻¹. Results shown in Figure 5(b) and Table 3 revealed concentration of arsenic plant roots as 191.0 to 321.0 mg kg⁻¹ (Adani Wetlands), 199.0 to 622.0 mg kg⁻¹ and 43.0 to 70.7 mg kg⁻¹ (control sites).

The anomalous arsenic values greater than the background value in Adani Wetlands were found in the roots of *Cyperus Exaltatus*, *Nymphaea Maculata*, *Corrigiola Telephifolia* and *Acrocras Amplecents*. These suggests frequent concentration of arsenic by the plant roots. Utmost accumulation of arsenic from Adani Wetlands by *Cyperus Exaltatus* could be as a result of its rapid growth, higher biomass concentration and greater similarity towards up take. However, in Opi-Agu Lakes, the anomalous values of As above the background range were measured in roots of *Pteridium Aquilinum* (622.0 mg kg⁻¹) followed by *Lasimorpha Senegalesis* (314.0 mg kg⁻¹) and *Sacciolepis Cymbiandra* (264.0 mg kg⁻¹). These results showed that *Pteridium Aquilinum* has high As removal efficiency from water and soil could be attributed to its elevated biomass production and favorable weather conditions. The control sites showed arsenic concentration below the background value. Present work has shown that As concentrated in plant roots were higher compare to that of shoot. The works of Sultana et al. (2006) also proclaimed related results that some weeds accumulates higher value of As in root other than shoot. Sultana and Kobayashi (2011) observed that grass in the barnyard gathered more As in root than in shoot. These findings further validated the results acquired from present research.

**Arsenic in soil**

Arsenic is primarily inert in agricultural soils; hence, it concentrates in top soil layers forever. Seeping of arsenic in contaminated wetland soil hikes arsenic concentration because of modifications in iron mineralogy. In the study area, arsenic concentrations in soil varied between 91.7 and 468.0 mg kg⁻¹ in Adani Wetland, 177.0 and 294.0 mg kg⁻¹ in Opi-Agu Lakes and from 45.6 and 71.3 mg kg⁻¹ in control sites (Figure 5(c)). The background range for the concentration of As in soil is 213.5 mg kg⁻¹. This study also revealed that As accumulated more in the Adani Wetland than in Opi-Agu Lakes and control sites indicate the dispersal of As in soil contaminated by agricultural waters containing pesticides, herbicides, fertilizers that increases the accumulation of metals in plant species grown on polluted soil (Nicholson et al., 2003).

**Evaluation of phytoaccumulation efficiency**

**Cause for bioconcentration (BCF)**

BCF is an appropriate framework to estimate the possibility of plants in cumulating metals. The highest BCF rate of 3.31 was recorded in *Pteridium Aquilinum* root and 1.76 in *Ludwigia Erecta* shoot followed by *Corrigiola Telephifolia* (2.96 root and 1.54 shoot), while lowest amount of 0.73 was in *Cyperus Exaltatus* root and 0.14 in *Nymphaea Maculata* shoot of As contaminated soils from Ada
Rica Farms and Opi-Agu Lakes (Figure 5(d) and Table 4). Anawar et al. (2006) conducted experiments on the risk and bioavailability of As in contaminated soils from La Parrilla mine, Spain using *Pteridium aquilinum*, *Erica australis*, *Juncus effuses*, *Phalaris caudata*, *Spergula arvensis*, and calculated BCF values as 3.2–593.9 for one site and 2.1–20.7 for another As contaminated site. The results obtained by Anawar et al. (2006) was validated our present research. Highest BCF value in this study suggested that these plants could have the significant potential for As phytoaccumulation.

**Translocation factor (TF)**

TF ratio of metals was calculated from soil to shoot and from root to shoot (Table 4). In the study area, the translocation factor of As from soil to shoot in the agricultural soils (Adani areas) were found to be in the order of *Corrigiola Telephitofila* (1.54) > *Ludwigia Erecta* (0.57) > *Acrocras Amplectens* (0.54) > *Cyperus Exaltatus* (0.45) > *Cyperus Imbricatus* (0.29) > *Nymphae Maclulata* (0.14) while in the lake soils (Opi-Agu areas), the translocation factor of As from soil to roots were measured in the order of *Sacciolepis Cymbiandra* (1.20) > *Pteridium Aquilinum* (0.53) > *Lasimorpha Senegalesis* (0.43) > *Afromomum Daniellii* (0.36). When these values in the agricultural soils (Adani areas) are compared with lake soils (Opi-Agu areas) it was observed As contaminations are higher in agricultural contaminated soils than lake contaminated soils (Figure 5(e)). The same way root to shoot was also set in TF; however, the total measured TF values were less than 1.0 indicating that shoot accrued lower As compared to root. Slow translocation of As from root to shoot is justified because trivalent arsenite can be easily trapped in the root; moreover, under anaerobic conditions, lot of As in cells was As(V), and As(V) could be partially reduced to arsenite due to endogenous arsenate reductase enzyme activity with thiol conjugation, resulting in As being isolated in the root vacuole (Zhu & Rosen, 2009).

**Accumulation factor (AF)**

The percentage of AF in arrangement is root > shoot. The percentage increase of AF in different parts of the plant with rising As concentration in soil. For the whole plant species (Table 4), the AF values in this study revealed elevated accumulation of As by roots than shoot.

| Sample Area | Location | Plant species         | Plant Tissue | BCF | TF | AF % |
|-------------|----------|-----------------------|--------------|-----|----|------|
| Adani Wetlands | Ohuno Wetland 1 | *Corrigiola Telephitofila* | Shoot        | 1.54 | -  | 150  |
|              |          |                       | Root         | 2.96 | 0.52 | 296  |
|              |          |                       | Soil         | -    | 1.54 | -    |
|              | Ohuno Wetland 2 | *Cyperus Exaltatus*    | Shoot        | 0.45 | -  | 45   |
|              |          |                       | Root         | 0.73 | 0.61 | 73   |
|              |          |                       | Soil         | -    | 0.45 | -    |
|              | Ada Rice Farm 1 | *Ludwigia Erecta*      | Shoot        | 1.76 | -  | 176  |
|              |          |                       | Root         | 1.01 | 0.56 | 101  |
|              |          |                       | Soil         | -    | 0.57 | -    |
|              | Ada Rice Farm 2 | *Nymphae Maclulata*    | Shoot        | 0.14 | -  | 14   |
|              |          |                       | Root         | 0.58 | 0.23 | 58   |
|              |          |                       | Soil         | -    | 0.14 | -    |
|              | Ada Rice Farm 3 | *Acrocras Amplectens*  | Shoot        | 0.54 | -  | 54   |
|              |          |                       | Root         | 0.89 | 0.61 | 89   |
|              |          |                       | Soil         | -    | 0.54 | -    |
|              | Ada Rice Farm 4 | *Cyperus Imbricatus*   | Shoot        | 0.29 | -  | 29   |
|              |          |                       | Root         | 0.81 | 0.36 | 81   |
|              |          |                       | Soil         | -    | 0.29 | -    |
| Opi-Agu Lakes | Iyiuga Lake 1 | *Pteridium Aquilinum*  | Shoot        | 0.53 | -  | 53   |
|              |          |                       | Root         | 3.31 | 0.16 | 331  |
|              |          |                       | Soil         | -    | 0.53 | -    |
|              | Iyiuga Lake 2 | *Lasimorpha Senegalesis* | Shoot      | 0.43 | -  | 43   |
|              |          |                       | Root         | 1.07 | 0.40 | 107  |
|              |          |                       | Soil         | -    | 0.43 | -    |
|              | Iyiuga Lake 3 | *Sacciolepis Cymbiandra* | Shoot      | 1.20 | -  | 120  |
|              |          |                       | Root         | 1.47 | 0.81 | 147  |
|              |          |                       | Soil         | -    | 1.20 | -    |
|              | Ogeleube Lake | *Afromomum Daniellii*  | Shoot        | 0.36 | -  | 36   |
|              |          |                       | Root         | 1.12 | 0.32 | 112  |
|              |          |                       | Soil         | -    | 0.36 | -    |
| Control Sites | Site 1 | *Lactuca Sativa*       | Shoot        | 0.54 | -  | 75.7 |
|              |          |                       | Root         | 0.75 | 0.72 | 54.4 |
|              |          |                       | Soil         | -    | 0.54 | -    |
|              | Site 2 | *Imperata Cylindrica*  | Shoot        | 0.96 | -  | 99.2 |
|              |          |                       | Root         | 0.99 | 0.97 | 103.5|
|              |          |                       | Soil         | -    | 0.95 | -    |
|              | Site 3 | *Hibiscus Sabdariffa*  | Shoot        | 0.87 | -  | 109.9|
|              |          |                       | Root         | 1.09 | 0.79 | 126.2|
|              |          |                       | Soil         | -    | 0.90 | -    |
As the results, the highest AF was found among the ten plant species for *Pteridium Aquilinum* followed by *Corrigiola Telephifolia* for root and shoot part, but overall, the order did not follow any specific pattern—some are more than hundred per cent and in some cases less than hundred per cent (Figure 5f).

### Discussion

This is the very first research about the *Corrigiola Telephifolia*, *Ludwiga Erecta*, *Acrocras Amplectens*, *Cyperus Exaltatus*, *Cyperus Imbricatus*, *Nymphaea Maculata*, *Sacciolepis Cymbiandra*, *Pteridium Aquilinum*, *Lasimorpha Senegalesis*, *Afromomum Daniellii*, *Lactuca sativa*, *Imperata cylindrica* and *Hibiscus sabdariffa* as primary hyperaccumulators of As on arsenic-contaminated soils in selected areas of Enugu State, Nigeria. The discussion will be focused on uptake and accumulation of As in soils and plants.

Comparing to present results concerning soil heavy metal background value in these areas (As in Adani Wetland varies from 91.7 to 468.0 mg/kg and in Opi Agu Lakes 56.8 to 294.0 mg/kg respectively), revealed As concentrations in soils were significantly increased. The value of As in Adani Wetland and Opi Agu Lake soils were approximately 5 times above the background value. This may be due to As exist accompanying in agricultural practice. However, in soil sample of Ada rice farm, Opi Agu Lakes and control sites, As concentrations were greatly higher than WHO/FAO (2001) (Table 3).

The order of levels of As in soils were comparable as in plant shoots and roots, which implies that result of As concentrations in soils should have impact on the concentrations in plants. However, only As concentration in *Sacciolepis Cymbiandra* within the Adani Wetland and *Imperata cylindrica* within control site had significant associate between plant shoots and roots (Table 3), this showed the As concentrations in shoots were positively related to the As concentrations in roots, maybe due to the passive As translocation from roots to the shoots. Due to the total concentrations of As in both Adani Wetland and Opi Agu Lake soils were impacted by several factors, and motivated the concentrations in plant indirectly. Thus, there are three main types of tolerance tactic for heavy metals (accumulation, exclusion and indication), which define the interconnectivity between the overall concentration of soil and plant metals uptake and excluder as well as accumulator plants might develop together in the same environment. The interactions between both the concentration of soil and plant metal should be but again, evaluated differently by each plant species; perhaps we can comprehend biochemical functions. Accumulation and exclusion were two primary approaches by which plants react to high heavy metals concentration. Translocation factor higher than 1 was normal in metal accumulator species, while translocation factor in metal excluder species was usually less than 1 (Baker, 1981). In accordance with translocation factor (Table 4), accumulation of As in all the 13 plant species were recommended as a tolerance approach. Translocation factor above 1 showed a very proficient competence to transport metal from roots to shoots, mostly as a result of effective metal transporter process and segregation of metals in leaf vacuoles (Lasta et al., 2000). Similarly, strategy of other species to As may probably regarded as exclusion (Table 4). Bioconcentration factors are essential factor when studying the ability of phytoremediation of a particular plant species. In the study areas, the bioconcentration factors of both root and shoot of *Corrigiola Telephifolia*, *Ludwiga Erecta* and *Sacciolepis Cymbiandra* to As were higher than 1 (Table 4), respectively.

### Conclusion

In as much as water and soil contaminations by hazardous metals is a grievous environmental degradation, hence efficient remediation techniques are important. Since, cleanup and restoration of metal contaminated soils by physical and chemical techniques have severe limitations such as irreparable changes in soil properties and cost effective. However, phytoremediation is a best answer to the problem. Phytoremediation is generally acceptable environment-friendly and ecologically responsible solar-driven that is comparatively recent technology and is mostly in research stage.

This research demonstrated the intense accumulative capacity for As by *Pteridium Aquilinum*, *Corrigiola Telephifolia* and *Cyperus Exaltatus* for cleanup and restoration of As-contaminated soils in the study area. The investigation also showed that these plants commonly had the maximum concentrations of As in their shoots and roots which indicated their potentials in cleaning up the contaminated soils.

This is an important work for phytoremediation of As-contaminated soil form Adani Wetland and Opi Agu Lakes. Since phytoremediation study is truly interdisciplinary in nature, hence researchers from various environment should be welcomed and support to apply their ability and skill in this field. Further studies are also recommended to check the phytoremediation capacity of these plants for other heavy metals removal from the contaminated soil.

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**Disclosure statement**

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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